EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

Guidance Material for the Design of Terminal Procedures for Area Navigation (DME/DME, B-GNSS, Baro-VNAV & RNP-RNAV)

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Guidance Material for the Design of Terminal Procedures for Area Navigation (DME/DME, B-GNSS, Baro-VNAV & RNP-RNAV)

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Abstract

This document provides information about RNAV requirements and capabilities and details a method for designing and publishing instrument flight procedures for RNP-RNAV, B-RNAV and P-RNAV operations using DME/DME or GNSS inputs.

Keywords

AIP	Chart	Obstacle	RNP-RNAV
Approach	Design	Procedure	SID
P-RNAV	FMS	PANS-OPS	STAR
B-RNAV	Hold	RNAV	Terminal

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The following table identifies all management authorities who have successively approved the present issue of this document.

AUTHORITY	NAME AND SIGNATURE	DATE
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The following table records the complete history of the successive editions of the present document.

EDITION	DATE	REASON FOR CHANGE	SECTIONS PAGES AFFECTED
1	31 October 1997	Released for review by ANT	All
2	23 March 1999	New material addressing GNSS procedures and reflecting deliberations of OCP working group prior to OCP12. Comments received from DIRCAM Taverny, Standards Development Branch FAA and Flight Procedures Inspectorate CAA Czech Republic have also been incorporated.	All
2.1	24 September 1999	Correction to rate of turn formula	42
2.2	December 1999	Correction of PDG formula and clarification of use of CF and TF path terminators after a fly-over turn.	51 & 81
3.0	March 2003	Introduction of SBAS, B-RNAV criteria, RNP-RNAV criteria, Baro VNAV criteria and charting guidelines. Clarification of path terminators, TGL 10, KK'K" lines, high altitude turns, Terminal Arrival Altitudes, open and closed STARs. Corrections to departure criteria.	All

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REFERENCE DOCUMENTS

ICAO International Standards and Recommended Practices (SARPs)

Annex 4 Aeronautical Charts

Annex 11 Air Traffic Services

Annex 14 Aerodromes

Annex 15 Aeronautical Information Services

ICAO Procedures for Air Navigation Services (PANS) and related documents

Doc 4444-RAC/501/12() Rules of the Air and Air Traffic Services

Doc 8126-AN/872() Aeronautical Information Services Manual

Doc 8168-OPS/611() Aircraft Operations

Doc 8400() ICAO Abbreviations and Codes

Doc 8697-AN/889() Aeronautical Chart Manual

Doc 9274-AN/904() Manual on the Use of the Collision Risk Model (CRM) for ILS Operations

Doc 9368-AN/911() Instrument Flight Procedure Construction Manual

Doc 9426-AN/924() Air Traffic Services Planning Manual

Doc 9613-AN/937() Manual on Required Navigation Performance

Doc 9674-AN/946() World Geodetic System 1984 (WGS-84) Manual

European Organisation for the Safety of Air Navigation EUROCONTROL

Doc 003-93() Area Navigation Equipment Operational Requirements and Functional Requirements

Joint Aviation Authorities

JAR-OPS

JAR/FAR 25

GAI 20 - General Acceptable Means of Compliance/Interpretative and Explanatory Material

ACJ20X4 - Guidance Material on Airworthiness Approval and Operational Criteria for the use of Navigation Systems in European Airspace Designated for Basic RNAV Operations

ACJ20X5 - Guidance Material on Airworthiness Approval and Operational Criteria for the use of the Navstar Global Positioning System (GPS)

Temporary Guidance Leaflet 9() - Recognition of EUROCAE Document ED-76 (RTCA DO-200A): Standards for Processing Aeronautical Data

Temporary Guidance Leaflet 10() - Airworthiness and Operational Approval for Precision RNAV Operations in Designated European Airspace

Radio Technical Commission for Aeronautics (RTCA)

DO-236() Minimum Aviation System Performance Standards:
Required Navigation Performance for Area Navigation (EUROCAE ED 75)

DO-229() Minimum Operational Performance Standards for GPS/SBAS Airborne Equipment

DO-200() Requirements for the Aeronautical Data Process (EUROCAE ED 76)

DO-201() Industry Requirements for Aeronautical Information (EUROCAE ED 77)

Aeronautical Radio Incorporated (ARINC)

424-() Navigation System Data Base

United States Federal Aviation Administration

Order 7100.11() Flight Management System Procedures Program

Order 8260.3()Terminal Instrument Procedures (TERPS)

Order 8260.38() Civil Utilization of Global Positioning System (GPS)

Order 8260.40() Flight Management System Instrument Procedure Development

Order 8260.44() Civil Utilization of Area Navigation Departure Procedures

Order 8260.48() Area Navigation Approach Construction Criteria

AC 20-RNP() Airworthiness Approval of Required Navigation Performance

AC 90-RNP() Required Navigation Performance Implementation in the United States National Airspace System.

FOREWORD

This Guidance Material has been developed for the European Organisation for the Safety of Air Navigation (EUROCONTROL) in response to a requirement identified at the fourth meeting of the Terminal Airspace RNAV Application Task Force (TARA 4).

The purpose of this document is to inform the reader of RNAV requirements and capabilities, in general, and to provide a method for defining and publishing terminal procedures for RNP-RNAV, and RNAV using DME/DME and/or GNSS inputs.

It is hoped that this guidance material will help procedure designers to produce flyable RNAV procedures. It is NOT intended to resolve any of the institutional, certification or operational issues that affect RNAV.

The document has been reviewed regularly by members of the TARA Task Force and their comments have been incorporated. In particular, the author wishes to acknowledge the support provided by the following: Mr F Argueso, Ms E Belin, Mr T Buchanan, Mr Y Coutier, Mr M Davidson, Mr T Domroes, Mr L Finken, Mr J Gjerlev, Mr A McKinnon, Mr B Rockel, Mr D Sajn, Mr M Saalasti, Ms S Schautteet, Mr N Smith, Mr R Thaemer, Ms M Ulvetter, Mr T van der Ven and Mr M Zillig.

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1 INTRODUCTION

1.1 OVERVIEW

1.1.1 The introduction of Area Navigation (RNAV) brings greater flexibility for procedure designers as well as significant environmental, economic and operational advantages for aircraft operators and Air Traffic Service (ATS) providers. This are expected to be achieved mainly through the use of:

a) Improved track-keeping.

b) More direct routing.

c) Optimised vertical profiles.

d) Parallel offsets.

e) Reduced route spacing.

all of which will lead to a more efficient use of available airspace.

1.1.2 The RNAV concept represents a fundamental change in philosophy. Where aircraft used to fly to and from specific navaids, using each navaid as a source of data, many may now obtain data from a number of different navaids in order to fix their positions along a route. Originally introduced with respect to specific navaids such as VOR/DME and, more recently, DME/DME and GNSS, the RNAV concept is widening to include airborne navigation systems that are capable of using multiple sources of navigation data and operating within very closely defined limits of accuracy, availability, integrity and repeatability.

1.1.3 Many of the traditional procedure design processes are not suitable for RNAV applications. Moreover, the different RNAV-capabilities that are currently available through the many combinations of aircraft type and RNAV system and the various problems posed by the airspace around different aerodromes, mean that there is no simple ideal solution for all RNAV procedure designs. Indeed, many of the early attempts at designing RNAV procedures for the Terminal Area met with little success. This was mainly because the designers lacked a proper understanding of the RNAV process itself, the way that data is processed in the RNAV systems and the capabilities of different RNAV systems. As a result, some procedures were incompatible with the some RNAV systems and could not be coded; some procedures resulted in inconsistent routing by different RNAV systems and some procedures required complex coding that failed to take full advantage of the RNAV system capabilities.

1.1.4 The purpose of this document is to explain RNAV requirements and capabilities and to provide a formal method for defining RNAV terminal procedures using DME/DME or GNSS inputs. It is hoped that this will help procedure designers to produce RNAV procedures which are safe in terms of terrain clearance, codable, flyable, repeatable, simple and unambiguous. This formal method is based upon a set of minimum standards and criteria and may be modified to address particular technical problem areas as, and when, they are identified. It is NOT intended to resolve any of the institutional, certification or operational issues that affect RNAV.

1.1.5 This guidance document is based primarily upon Doc 8168 and recent deliberations of the ICAO Obstacle Clearance Panel (OCP)[1]. Where reference is made to VOR/DME RNAV, it is for the purpose of comparison only.

1.2 RNAV

1.2.1 RNAV is a method of navigation which permits aircraft operation on any desired flight path within the coverage of referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.[2] 2D RNAV relates to RNAV capabilities in the horizontal plane only; 3D RNAV includes a guidance capability in the vertical plane and 4D RNAV provides an additional timing function.

1.2.2 An RNAV-capable aircraft can automatically determine its position, from one or more of a variety of inputs, from such navaids as VHF Omni-directional Range (VOR), Distance Measuring Equipment (DME), LORAN-C, Global Navigation Satellite System (GNSS) and Inertial Navigation Systems (INS) and Inertial Reference Systems (IRS). Single-sensor RNAV systems only use one source of navigation data, such as DME stations, while multi-sensor RNAV systems monitor a number of navaid systems to determine the best source of navigation data[3].

1.2.3 The RNAV system has access to a sophisticated on-board navigation data base containing details of the pre-programmed routes, the airspace through which the routes pass, the navaids servicing this airspace and the departure, destination and planned diversion aerodromes. The system identifies the next waypoint on the planned route, selects the most appropriate navaids to determine the aircraft position and usually provides steering inputs to the autopilot.[4]

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1 OCP 12 and OCP 13.

2 ICAO Doc 9573 Manual of Area Navigation (RNAV) Operations First Edition

3 Multi-sensor systems may use a process known as Kalman filtering to integrate inputs from different sensors and determine the best position estimate based upon a number of factors. In the event of GNSS unavailability or where insufficient DME stations are available for update, or where the signal quality is unacceptable, for example, some systems apply a fixed downgrading schedule from DME/DME to VOR/DME to IRS or from DME/DME to IRS to VOR/DME. Other systems apply the Kalman filter process to the remaining sensor inputs before downgrading to DME/DME, VOR/DME or IRS only.

4 For the sake of simplicity, this document will always refer to RNAV systems rather than Flight Management Systems (FMS). The term FMS is often used to describe any system which provides a degree of control

1.2.4 It is generally possible for an RNAV route to be flown without the RNAV system being coupled to the autopilot. RNAV system outputs displayed on the flight director or the course deviation indicator (CDI) can, in most cases, provide adequate indication of imminent changes in track, altitude and speed to allow the pilot time to respond. As an RNAV procedure can be flown coupled or uncoupled, the procedure should be designed to accommodate both methods. Where a procedure requires the RNAV system to provide vertical guidance, or where a high degree of accuracy is required, autopilot coupling may be mandatory - in such a case there has to be a clear statement on the chart - "Autopilot coupling required".

1.2.5 It is the responsibility of the airspace provider to ensure that sufficient navaids are provided and are available to achieve the approved operation. This should be established during the procedure design phase and validation phases. Any particular navaid which is critical to the operation of a specific procedure must be identified in the AIP. The airspace provider must ensure that, where ground-based navaids are published as being available for use within a designated RNAV airspace, there are sufficient serviceable aids to provide ‘continuous determination to the required accuracy’ of an aircraft’s position within that airspace. Similarly, the airspace provider should monitor the serviceability of the navaids upon which the procedure is predicated and advise pilots and controllers in the event that coverage from a particular navaid type is compromised. In such a case the procedure may be withdrawn or may be restricted to aircraft capable of using the remaining navaid type.

1.2.6 It is the responsibility of the aircraft operator to ensure that the related certification, airworthiness approval and operation approval criteria are met. In particular:

a) The RNAV equipment on the aircraft should maintain the required level of accuracy, integrity, availability and continuity.

b) The flight crew must be suitably trained for a flight in designated RNAV airspace.

1.2.7 It is the responsibility of the pilot-in-command to ensure that the aircraft is navigated to the prescribed accuracy. In particular, where a GNSS procedure is to be flown, it is the responsibility of the pilot-in-command to determine the operational integrity of the GNSS at the time and the anticipated availability of RAIM for the planned procedure.

over navigation, in lateral, longitudinal and vertical directions, together with fuel management; route planning etc. These individual functional areas may also be referred to as separate entities such as performance management systems, fuel management systems, flight management control systems, navigation management systems etc. In most cases, the RNAV system can be expected to be embedded in the navigation management element of the FMS.

1.2.8 When RNAV systems were first brought into service, a number of States introduced RNAV routes which were overlaid on existing conventional routes, particularly in Terminal Areas. This was intended to allow aircraft operators to draw some benefit from their investment in RNAV equipment without disrupting the existing traffic flow. Where such RNAV overlays are based upon published conventional instrument procedures, they are, at best, a temporary measure and do not provide the increased flexibility, environmental benefits and cost savings that can be expected from normal, non-overlay, RNAV procedures. Where the existing traffic flow is based upon radar vectoring, the use of RNAV overlay procedures can simplify matters considerably and can lead to reduced R/T and reduced controller and pilot workloads.

1.3 RNP

1.3.1 The RNAV concept was originally introduced with respect to specific navaids such as VOR/DME. In such circumstances, it was possible to determine an across track tolerance (XTT) and an along track tolerance (ATT) associated with each waypoint, based upon the navaid used to define the fix at the waypoint. With the introduction of multiple DME sources, the XTT/ATT philosophy was continued in the form of a set of values that vary according to the aircraft height, the number of DMEs available and the phase of flight. As far as GNSS is concerned, the XTT/ATT are determined by the horizontal alert limits that are applied in the different phases of flight.

1.3.2 Required Navigation Performance (RNP) is a statement of the navigation performance accuracy necessary for operation within a defined airspace.[5] RTCA DO 236A (Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation), also known as EUROCAE ED75A, develops the ICAO definition of RNP into a single concept by elaborating the definition of RNP taken from the ICAO RNP Manual.

1.3.3 The term RNP was retained as a generic term for any set of requirements applicable to an airspace and a new term, RNP-RNAV was introduced. This term merged the accuracy standard in the ICAO Manual, with the containment requirements and the area navigation functional and performance standards in DO 236A/ED75A. The functional requirements currently include VNAV and Time of Arrival Control aspects as well.

[5] ICAO Doc 9613 Manual on Required Navigation Performance

ICAO Doc 9650 (Report of the Special Communications /Operations Divisional Meeting - 1995) defines RNP as the statement of the navigation performance accuracy, integrity, continuity and availability necessary for operations within a defined airspace.

ICAO Manual: While the navigation accuracy is the basis for defining the RNP type, the other navigation performance parameters of availability, coverage, reliability, fix rate, fix dimension, capacity, time to recover and integrity determine the utilisation and limitations of the individual navigation systems, both ground and airborne, and characterise the means by which a user derives navigation information within an RNP type airspace.

1.3.4 There are additional related requirements for availability, integrity and continuity. The RNP type defines the total navigation system error (TSE) that is allowed in lateral, longitudinal, and, in some cases, vertical dimensions within a particular airspace. It includes navigation system errors, RNAV computation errors, display errors and flight technical errors. The TSE must not exceed the specified RNP value for 95% of the flight time on any part of any single flight.[6] RNP-RNAV places the onus on the operator to ensure that the aircraft meets the required standard.

1.3.5 The fundamental criteria for RNP-RNAV are that the flight paths of participating aircraft are both predictable and repeatable to declared levels of accuracy. To achieve this, it is necessary to be more specific about the functional requirements of the RNAV system and aircraft systems that meet RNP-RNAV criteria within terminal airspace will have to comply with RTCA DO 236A/EUROCAE ED 75. In theory, in RNP-RNAV airspace there are no minimum carriage requirements and no specific navaid is mandated for use at any specific point. In practice, the airspace provider must ensure that an appropriate navaid infrastructure exists to support the published RNP. Moreover, if the RNP cannot be supported by both DME and GNSS infrastructures, this must be clearly stated in the AIP. The procedure designer uses XTT and ATT error values that are based upon the declared RNP for that airspace. The RNP value for a specific route is stored in the onboard navigation database although the pilot is usually able to modify it manually.

1.3.6 When the RNAV concept for Europe was being developed, two RNP types were proposed: Basic RNAV (B-RNAV) and Precision RNAV (P-RNAV). These criteria do not meet all the requirements of DO 236A/ED75, but allow a large proportion of the existing aircraft fleet to be certified for RNAV operations. The global RNP concept equates B-RNAV to RNP 5 and P-RNAV to RNP 1[7].

1.3.7 The RNP types that are currently in use or are being considered for use are detailed in Table 1 below:[8]

[6] Proposed amendment to ICAO Doc 9613 Paragraph 1.3.1

[7] Globally, the standard for continental en-route airspace where navigation facilities are not far apart is RNP 4. However, VOR/DME navaids can only support RNP 5 and hence this has been included as an interim type, particularly for use within European airspace.

[8] Oct 2002

RNP Type	Required Accuracy (95% Containment)	Description
0.3	± 0.3 NM	Supports Initial/Intermediate Approach, 2D RNAV Approach, and Departure. Expected to be the most common application.
0.5	± 0.5 NM	Supports Initial/Intermediate Approach and Departure. Only expected to be used where RNP 0.3 cannot be achieved (poor navaid infrastructure) and RNP 1 is unacceptable (obstacle rich environment)
1	± 1.0 NM	Supports Arrival, Initial/Intermediate Approach and Departure; also envisaged as supporting the most efficient ATS route operations. Equates to P-RNAV.
4	± 4.0 NM	Supports ATS routes and airspace based upon limited distances between navaids. Normally associated with continental airspace but may be used as part of some terminal procedures. There are no plans at present to use RNP 4 in ECAC.
5	± 5.0 NM	An interim type implemented in ECAC airspace to permit the continued operation of existing navigation equipment. Equates to B-RNAV.
10	± 10 NM	Supports reduced lateral and longitudinal separation minima and enhanced operational efficiency in oceanic and remote areas where the availability of navigation aids is limited.[9]
12.6	± 12.6 NM	Supports limited optimised routing in areas with a reduced level of navigation facilities
20	± 20.0 NM	The minimum capability considered acceptable to support ATS route operations.

Table 1 - RNP Types

1.3.8 When the application of RNP concepts to approach procedures, and in particular to precision approaches, was being considered by AWOP, it was determined that vertical navigational accuracy had to be addressed as well as horizontal accuracy. As a result, a range of RNP types were defined from RNP 0.3 to RNP 0.003/z, where z reflects the requirement for vertical guidance. This is illustrated in Table 2. The GNSSP took over the task from AWOP and proposed a set of values which could be supported by Space Based Augmentation Systems (SBAS) and Ground Based Augmentation Systems (GBAS)[10]. To date however, there are no MASPS or certification standards for vertical RNP containment with 10^{-5} integrity and no procedure design criteria for a lateral RNP<0.3, or any vertical RNP.

9 RGCSP/9-WP25 Appendix A to Report on Agenda Item 2, Proposed amendment to Annex 11 Paragraph 3.3.5

10 These values are still under discussion at GNSSP and other ICAO and RTCA fora and it may be some time before definitive criteria are developed for RNP<0.3.

RNP Type	Required Accuracy (95% Containment)	Description
0.003/z	± 0.003 NM [± z ft]	Planned for CAT III Precision Approach and Landing including touchdown, landing roll and take-off roll requirements. (ILS, MLS and GBAS)
0.01/15	± 0.01 NM [± 15 ft]	Proposed for CAT II Precision Approach to 100 ft DH (ILS, MLS and GBAS)
0.02/40	± 0.02 NM [± 40 ft]	Proposed for CAT I Precision Approach to 200 ft DH (ILS, MLS, GBAS and SBAS)
0.03/50	± 0.03 NM [± 50 ft]	Proposed for RNAV/VNAV Approaches using SBAS or GBAS
0.3/125	± 0.3 NM [± 125 ft]	Proposed for RNAV/VNAV Approaches using Barometric inputs or SBAS inputs.

Table 2 - Proposed Vertical RNP Types

1.3.9 B-RNAV was originally only intended to be used during the en-route phase of flight and this is evident from the very limited RNAV system requirement defined in the JAA GAI 20 ACJ20X4[11], which covers Airworthiness Criteria and Operational Approval for B-RNAV. However, B-RNAV documentation referred to 'designated feeder routes into and out of TMAs' and the route network in Europe was developed on the assumption that these connections could be made using RNAV systems.

1.3.10 B-RNAV was the only certified RNAV solution available when the first network design requiring RNAV connections was published. Unfortunately, with no common understanding of a feeder route, the existing ATM systems could only process air routes (en-route), SIDs and STARs. As a result, it was agreed that, until P-RNAV became widely available, portions of SIDs and STARs could be designated as B-RNAV provided that:

a) The B-RNAV portion of the route is above Minimum Sector Altitude/Minimum Flight Altitude/Minimum Radar Vectoring Altitude (as appropriate), is developed in accordance with established PANS-OPS criteria for en-route operations and conforms to B-RNAV en-route design principles.[12]

b) The initial portion of departure procedures is non-RNAV up to a conventional fix or minumum altitude beyond which the B-RNAV procedure can be provided in accordance with the criteria given above.

11 Previously known as Temporary Guidance Leaflet (TGL) 2.

12 PANS-OPS does not address minimum turn distances between waypoints in the en-route phase. This is covered in paragraph 2.9.3 of this document.

c) The B-RNAV portion of an arrival route terminates at a conventional fix in accordance with the criteria given above and the arrival is completed by an alternative final approach procedure, also appropriately approved.

d) Due regard is taken of the operating procedures of the users.

1.3.11 In June 2001, the Airspace and Navigation Team agreed to fix a date of 22 Mar 2003, from when all RNAV Terminal Procedures (SIDs and STARs) in ECAC States would require a P-RNAV capability. As B-RNAV was mandated for en-route operations in ECAC, it was anticipated that B-RNAV would continue to be used in terminal airspace above the MSA to connect conventional SIDs and STARs to the en-route structure. Since June 2001, the rate at which operators are achieving P-RNAV approval is causing concern in many quarters and EUROCONTROL is now playing an active role managing the implementation. As a result, P-RNAV implementation may be delayed. Furthermore, a decision on what to mandate in the future is expected to be made in 2003/2004 and it is not clear at this time whether the mandate will include all aspects of RNP-RNAV or when the mandate will take effect.

1.4 EARLY LESSONS

1.4.1 An important aspect of RNAV procedure design methodology is the need to keep things simple. Complex solutions are difficult to validate, are open to misinterpretation and are prone to error. The designer should always strive to develop the simplest procedure and, in so doing, focus on waypoint to waypoint flying.

1.4.2 Secondly, and just as important, is the need to test and validate the procedure at every step of the design process. The validation process should address the worst case conditions that could prevail such as maximum crosswind, maximum and minimum temperatures and aircraft weights. There are further benefits that can accrue from the lead carrier/operator concept where a particular user co-operates closely with the designer throughout the design process and provides the resources for the simulation and live flying aspects of the test and validation programme. In every case, new RNAV procedures must be flight checked before they are published for public use.

1.4.3 Finally, the design of an RNAV procedure must take account of the aircraft that are expected to use it. Different aircraft types may not have the same performance characteristics and, hence, the climb/descent gradients and the speed and turn criteria selected for one type may not be suitable for all aircraft in the same category. Procedure designers must also be aware that different RNAV systems fitted on the same aircraft type can produce very different performance characteristics and, if the procedure is not designed correctly, this can result in significant differences in the tracks that the aircraft fly. (For this reason, more than any other, designers cannot simply overlay RNAV routes on existing procedures and expect instant success.)

2 CONTAINMENT AND OBSTACLE CLEARANCE

2.1 INTRODUCTION

2.1.1 When designing a procedure, the size and nature of the containment area and, hence, the obstacle clearance area for each leg is predicated on two main factors:

a) The accuracy of the navigation system in use.

e) Whether the aircraft has track guidance.

2.2 ACCURACY AND TRACK GUIDANCE

2.2.1 The accuracy of an RNAV system is defined in terms of the total system tolerance, which represents the difference between an aircraft's true position and the desired position. The total system tolerance takes account of the flight technical tolerances as well as the cross track and along track tolerances. This is illustrated in Figure 1. Track guidance is usually provided by the RNAV system directly to the autopilot or via the flight director/course deviation indicator. If the aircraft is being flown uncoupled to the RNAV system, the display of imminent changes in speed, heading or height, are expected to be provided, in sufficient time, for the pilot to respond in a manner which will keep the aircraft within similar flight technical tolerances to that achieved with the autopilot coupled. Flight Technical Error (FTE) is defined as the ability of the pilot or the avionics to fly the aeroplane along a selected path.

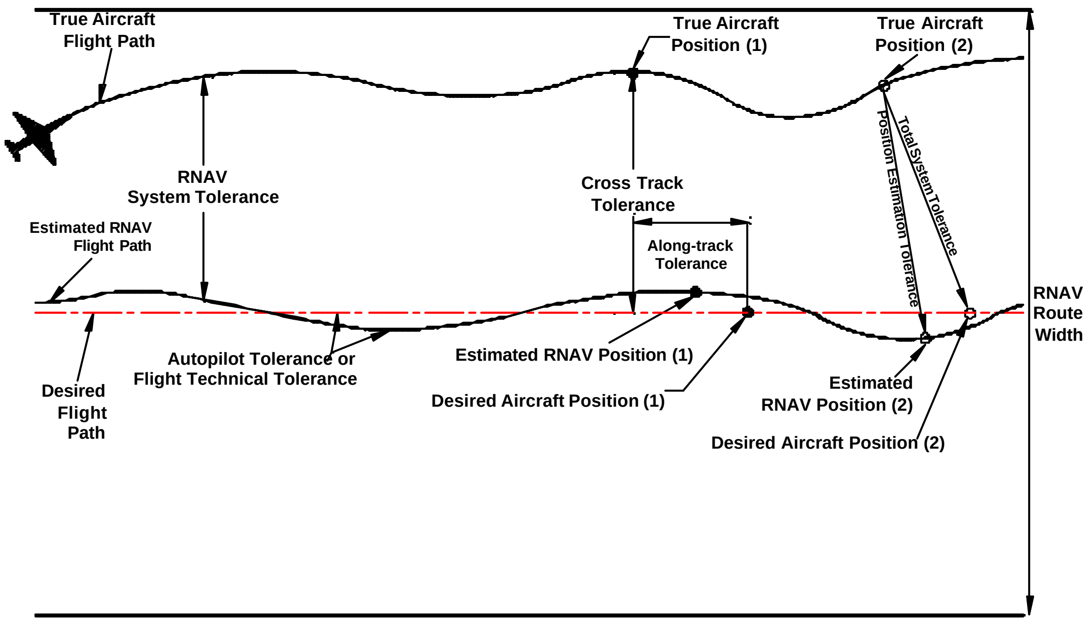

Figure 1 - RNAV Tolerances

2.2.2 The lateral accuracy of a navigation system that is used to provide track guidance is traditionally described in terms of the tolerance of the intersection fixes, based upon the 2σ (95.4%) confidence limits or, where the area is splayed for instrument/missed approaches, the 3σ (99.7%) confidence limits.[13] This may also be described as the containment value and is defined as the distance from the intended position within which a flight would be found for, at least, 95% or 99.7% of total flying time. Obstacle clearance containment requirements are generally based upon a 3σ value to which an additional buffer value is added[14].

2.2.3 The risk of collision with fixed obstacles or other aircraft depends upon a number of factors, including traffic density, lateral and vertical overlap of routes, size and performance of participating aircraft and the proximity of obstacles. The containment requirements should meet a specified target level of safety and hence can be expected to increase in size as the risk of collision increases. Doc 4444 provides guidance concerning the criteria necessary to ensure adequate separation between aircraft while Doc 8168 addresses obstacle clearance. Although the latter only addresses obstacle clearance, the procedure designer must also take account of the requirements of the ATS provider, particularly with respect to traffic/route separation.[15] At present there are no internationally recognised route spacing criteria for RNP values less than 4NM although the ICAO Safety and Separation Panel (SASP) is addressing the issue.

[13] Doc 8168 Vol. II Part III Chapter 1 Paragraph 1.12

[14] Different buffer values are applied for phase of flight and for RNAV and RNP-RNAV applications.

[15] Annex 11, Attachment B, Paragraph 2.4 states that non-parallel RNAV routes should be separated by a distance that provides at least 99.5% containment without overlap. Doc 4444 Part III Chapter 7 Paragraph 7.1.1 requires that the lateral separation is never less than an established distance which accounts for navigational inaccuracies plus a specified buffer. Note that the primary area for obstacle clearance can be smaller than the associated 95% containment limits, in certain circumstances.

2.3 DME/DME CONTAINMENT

2.3.1 In VOR/DME based RNAV procedures, the navigational accuracy is defined in terms of an across track tolerance (XTT) and an along track tolerance (ATT) associated with each waypoint, based upon the position of the reference navaid used for the procedure. This is described in Doc 8168 Vol. II Part III Chapter 31. However, for DME/DME systems, it is not always possible to know which stations an airborne system is using at any instant. Moreover, the number and relative location of the DME stations that an RNAV system can use, together with the aircraft track orientation, will affect the accuracy of the navigation process. The required total system tolerance may be reduced if inputs from more than two DME stations are available and can be used by all participating airborne RNAV sensors[16]. To take account of this, where inputs from more than two DME stations cannot be guaranteed, the DME tolerance, which is used to calculate the XTT and ATT values, must be multiplied by a factor of 1.29. States may choose to apply the 1.29 factor across the board regardless of navaid availability or RNAV system performance[17].

2.3.2 Table 3 summarises the XTT, ATT and area width (AW) attributes of DME/DME procedures. The XTT value represents a 2σ containment and the required 3σ containment is, therefore, calculated by multiplying the XTT value by 1.5. A buffer value, appropriate to the phase of flight, is added to this containment value in order to define the width of the protected airspace, on either side of the track, that would provide an acceptable level of operational risk. This is known as the Semi-Area Width (½AW). The inner 50% of the whole area is annotated as the primary area with the remainder treated as a secondary area, unless otherwise stated.

[16] Scanning DME systems identify all available DMEs for the RNAV system to select the optimum inputs to determine the aircraft's position. Non-scanning DME systems use inputs from 2 DME stations selected from the navigation database as the optimum pair - if this pair proves to be unsuitable, a different pair is selected.

[17] The ICAO Annex 10 criteria for DME accuracy was changed in 1989 and any DMEs installed since then should provide considerably improved accuracy. The OCP 13 has introduced a new set of values for navigation infrastructures where all the DME stations meet the post 1989 requirements. See paragraph 2.3.5. The main problem associated with this is providing assurance that all the stations that can be received meet the new criteria. This includes any military TACANs that have been promulgated for civil aviation use.

	DME/DME
System Accuracy	$XTT = \sqrt{d^2 + FTT^2 + ST^2}$ [18] $ATT = \sqrt{d^2 + ST^2}$
Semi-Area Width	(KV(XTT)+BV) Where KV=1.5,(KV(XTT) corresponds to 3σ (99.7%), and BV is a nominal buffer value of 2 NM for arrival segments that are more than 25 NM from the IAF, 1 NM for initial and intermediate approach segments, and 0.5 NM for departure, final approach and missed approach segments
Secondary Areas	25% of the total width on each side, unless stated otherwise

Table 3 - Calculation of XTT, ATT, Primary & Secondary Area Widths for DME/DME RNAV

2.3.3 The XTT, ATT and AW values for VOR/DME are detailed in Tables III-31-1 to III-31-4, in Doc 8168. As far as DME/DME systems are concerned, two generic sets of worst case values for XTT, ATT and ½AW have been derived for the different phases of flight:

a) When there are only two DME stations available.

b) When there are more than two DME stations available.

These values are detailed in Table 4 and Table 5. The tables must only be used for DME/DME RNAV procedures and must NOT be used for any RNP-RNAV procedures.

2.3.4 The procedure designer should choose the table based upon the worst case navaid availability for the waypoint in question. In other words, how many DME stations are within range and available for use at the lowest usable level at the waypoint. The XTT, ATT and ½AW values at that level, for the appropriate phase of flight, should then be used for all containment area calculations associated with that waypoint. The en-route values are provided for use on arrival legs that are more than 25 NM from the IAF.

18 $d = 123 \times \sqrt{Aircraft\_Altitude} \times 0.0125 + 0.25NM$ (Altitude in ft) = DME tolerance - Doc 8168 Vol. II Pt III Paragraph 2.6.4.2

{1.25% maximum radio range plus 0.25 NM. Theoretical radio horizon is 1.23√h NM (2.22√h km).}

Procedures using more than two DME stations are assumed to have 90° intersect angles at all times. Procedures using only two DME stations must factor the maximum DME tolerance by multiplying ‘d’ by 1.29.

ST = System Computational Tolerance = 0.25 NM

FTT = Flight Technical Tolerance = 2 NM (En-route), 1 NM (Initial and intermediate approach), 0.5 NM (Departure, final and missed approach) and 0.1 NM (Departure at the DER)

Altitude	En-route			IAF/IF			FAF/MAPt/DWP		
(ft)	XTT (NM)	ATT (NM)	½AW (NM)	XTT (NM)	ATT (NM)	½AW (NM)	XTT (NM)	ATT (NM)	½AW (NM)
15,000	For all altitudes			2.94	2.76	5.41			
14,000	4.08	3.56	8.10	2.86	2.68	5.29			
13,000				2.78	2.60	5.17			
12,000				2.70	2.51	5.05			
11,000				2.61	2.42	4.92			
10,000				2.53	2.32	4.79	2.37	2.32	4.06
9,000				2.43	2.22	4.65	2.27	2.22	3.91
8,000				2.34	2.11	4.50	2.17	2.11	3.75
7,000				2.23	2.00	4.35	2.06	2.00	3.59
6,000				2.13	1.88	4.19	1.94	1.88	3.41
5,000				2.01	1.74	4.01	1.81	1.74	3.22
4,000				1.88	1.60	3.83	1.67	1.60	3.01
3,000				1.75	1.43	3.62	1.52	1.43	2.77
2,000				1.59	1.24	3.38	1.33	1.24	2.50
1,000				1.40	0.98	3.10	1.10	0.98	2.15
500							0.95	0.81	1.92

Table 4 - XTT, ATT and Semi-width Values (in NM) for Pre-1989 DME/DME RNAV (Only 2 DMEs available)

Altitude	En-route			IAF/IF			FAF/MAPt/DWP		
(ft)	XTT (NM)	ATT (NM)	½AW (NM)	XTT (NM)	ATT (NM)	½AW (NM)	XTT (NM)	ATT (NM)	½AW (NM)
15,000	For all altitudes			2.37	2.15	4.55			
14,000	3.40	2.67	7.10	2.31	2.08	4.47			
13,000				2.25	2.02	4.38			
12,000				2.19	1.95	4.29			
11,000				2.13	1.88	4.19			
10,000				2.06	1.80	4.10	1.87	1.80	3.31
9,000				2.00	1.73	3.99	1.80	1.73	3.20
8,000				1.92	1.64	3.89	1.72	1.64	3.08
7,000				1.85	1.56	3.78	1.63	1.56	2.95
6,000				1.77	1.46	3.66	1.55	1.46	2.82
5,000				1.69	1.36	3.53	1.45	1.36	2.67
4,000				1.60	1.25	3.40	1.34	1.25	2.52
3,000				1.50	1.12	3.25	1.23	1.12	2.34
2,000				1.39	0.97	3.09	1.09	0.97	2.14
1,000				1.27	0.78	2.90	0.92	0.78	1.89
500							0.82	0.64	1.72

Table 5 - XTT, ATT and Semi-width Values (in NM) for Pre-1989 DME/DME RNAV (More than 2 DMEs available)

2.3.5 Subsequent to 1 January 1989, every new DME station is required by Annex 10 to meet an accuracy of 0.2 NM throughout its area of operational coverage. The XTT, ATT and ½AW values for a post 1989 DME environment are detailed in Table 6 below. However, unless a designer can be assured that every DME station that may be used on a proposed procedure meets the post-1989 criteria and that adequate coverage by at least 3 DMEs can be assured at all times, the ATT, XTT and area width values associated with pre-1989 standards must be used.

Altitude	En-route			IAF/IF			FAF/MAPt/DWP		
(ft)	XTT (NM)	ATT (NM)	½AW (NM)	XTT (NM)	ATT (NM)	½AW (NM)	XTT (NM)	ATT (NM)	½AW (NM)
For all altitudes	2.03	0.32	5.05	1.05	0.32	2.58	0.59	0.32	1.39

Table 6 - XTT, ATT and Semi-width Values (in NM) for Post-1989 DME/DME RNAV (More than 2 DMEs available)

2.4 BASIC GNSS CONTAINMENT

2.4.1 The total system tolerance for a Basic GNSS[19] procedure is based upon the following:

a) Inherent Space System Accuracy

b) Airborne Receiving System Accuracy

c) System Computational Tolerance

c) Flight Technical Tolerance

2.4.2 Although the 2σ value for the inherent space system accuracy can be assumed to be $\pm$ 100 m[20], the accuracy of a Basic GNSS fix depends upon the system integrity at the time of use. System integrity is determined by the number of satellites available and their orientation with respect to the receiver. As this can vary, Basic GNSS receivers used for terminal procedures must include an integrity monitoring facility which will alert the pilot, within a specified time, when the horizontal accuracy of the fix cannot be assured within specified limits. These integrity monitoring alarm limits (IMAL) are considerably larger than the 3σ RSS value associated with the space system accuracy, airborne receiving system accuracy and system computational tolerance, which is considered to be less than 0.2NM. As a result, the OCP decided that the IMAL represents a worst case value for the navigation system for each phase of flight. The IMAL values are detailed in Table 7.

19 The term Basic GNSS is often specifically applied to Class A GNSS receivers while Class B and C equipment are sometimes referred to as Aircraft Based Augmentation Systems (ABAS). In this document, the term Basic GNSS is used to describe both types of system and specific criteria applicable to Class A receivers are highlighted.

20 With Selective Availability (SA) switched off, horizontal accuracies in the region of 10m are common and the US Government is committed to providing a worst case accuracy of $\leq$36m.

Phase of Flight	IMAL (NM)	Time to Alarm (Sec)
En-route	2.0	30
Terminal (Within 30 NM of ARP)	1.0	10
Approach	0.3	10
Missed Approach	1.0	10

Table 7 - Integrity Monitoring Alarm Limits

2.4.3 The IMAL and the CDI sensitivity values depend upon the phase of flight. Basic GNSS procedure design for arrivals is based upon the assumption that the transition between en-route and terminal phases of flight occurs at 30NM from the arrival ARP[21]. Transition from terminal phase to approach phase, known as 'arming the approach', takes place automatically 2 NM before the FAF subject to a number of additional criteria[22]; and transition to the missed approach phase takes place at the missed approach waypoint as the result of pilot switch action. Basic GNSS procedure design for departures is based upon the assumption that the transition between terminal and en-route phases of flight occurs at 30NM from the departure ARP.

2.4.4 The PANS-OPS Basic GNSS criteria have been designed to cater for Class A airborne GNSS RNAV systems with very limited functionality. Worst case FTT using a Class A GNSS receiver occurs where the airborne system is coupled to a CDI and the FTT depends upon the sensitivity of the CDI display. Values for CDI deflection and FTT for the various phases of flight with Basic GNSS receivers are given in Table 8.

[21] An appropriate flight plan must be loaded.

[22] FAF is active waypoint, aircraft track within 70° of final approach track, QNH data has been input and no RAIM alarm active.

Phase of Flight	CDI Full Scale Deflection (NM either side of centre-line)	FTT (NM)
En-route	5.0	2.0[23]
Terminal (when Terminal Mode is activated[24])	1.0	0.5[21]
Approach (2 NM before FAF)	1.0 reducing to 0.3	0.3[25]
Approach (at FAF)	0.3	0.2[26]
Departure/Missed Approach (TOGA initiated)	1.0	0.5

Table 8 - CDI Deflection and FTT with Basic GNSS Receivers

2.4.5 Table 9 summarises the XTT, ATT and AW attributes of Basic GNSS procedures and Table 10 provides details of the XTT, ATT and AW values for the different phases of flight. These tables must only be used for Basic GNSS RNAV procedures and must NOT be used for any RNP-RNAV procedures.

	GNSS
System Accuracy	ATT=IMAL XTT=IMAL+FTT
Semi-Area Width	2*XTT[27]
Secondary Area	25% of the total width on each side, unless stated otherwise

Table 9 - Calculation of XTT, ATT, Primary & Secondary Area Widths for Basic GNSS RNAV

23 Considered comparable to conventional VOR navigation with a 5NM/1NM full scale CDI deflection.

24 In some quarters, this is known as 'Approach Mode'. However, this is easily confused with the action known as 'Arming the Approach' which takes place 2NM before the FAF. For this reason, this document uses the term 'Terminal Mode'.

25 The CDI FSD starts to decrease 2NM from the FAF in order to achieve 0.3 at the FAF and the FTT is considered to benefit immediately the reduction starts.

26 Considered comparable to ILS - the same FTT is used in the ILS CRM.

27 The 2x(IMAL+FTT) value is greater than the (3σ+BV) value but the primary area has to be at least as wide as (IMAL+FTT) either side of the nominal track. Hence the requirement for 2*XTT.

Phase of Flight	ATT (NM)	FTT (NM)	XTT (NM)	½AW (NM)
En-route (Arrival>30NM from ARP)	2.0	2.0	4.0	8.0
IAF/IF (Including Arrival<30NM from ARP)[28]	1.0	0.5	1.5	3.0 (5.0 for Class A Receiver)[29]
FAF	0.3	0.3	0.6	2.0[30]
MAPt	0.3	0.2	0.5	1.0
Turning points in missed approach procedures and DWP <30NM from ARP	1.0	0.5	1.5	3.0 (5.0 for Class A Receiver)
DWP >30 NM from ARP	2.0	2.0	4.0	8.0

Table 10 - XTT, ATT and Semi-width Values (in NM) for Basic GNSS RNAV

2.5 SBAS CONTAINMENT

2.5.1 An SBAS RNAV system, built to the standards of RTCA DO 229(), has improved functionality, integrity and accuracy compared to a Basic GNSS RNAV system. The performance in the enroute is equivalent to Basic GNSS but benefits can be gained in terminal airspace:

a) The receiver switches between en-route and terminal mode when sequencing the first STAR waypoint/last SID waypoint.

b) The accuracy, integrity and continuity of service provided by the SBAS justifies the use of Class B/C criteria for stand alone SBAS receivers in the initial approach phase.

c) The receiver provides a level of performance sufficient to meet one of the following criteria: Cat I, APV II, APV I or NPA. The performance that is achieved depends upon the location of the aerodrome - most aerodromes in the US will be provided with APV I performance while many in Europe should be provided with APV II performance. Cat I performance is not expected to be achieved before 2010.

d) The equipment automatically switches at the MAPt and continues on the same course if no missed approach has been initiated by the pilot. If a missed approach has been initiated, the equipment stays in NPA mode up until the turn initiation point of the first waypoint in the missed approach procedure.

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[28] The Terminal Mode is armed automatically, if an appropriate flight plan is loaded, when the aircraft is flying the leg to the IAF. (See paragraph 10.3.1) Omni-directional arrivals require the pilot to fly direct to an IAF and hence the Terminal Mode has to be activated as the aircraft reaches 30 NM from the ARP.

[29] See paragraph 3.4.

[30] This deviation from the 2*XTT formula was based upon FAA flight tests that included a turn at the FAF and is also intended to accommodate the change in CDI sensitivity which occurs 2 NM before the FAF.

2.5.2 The total system tolerances and associated semi-area widths for the different phases of flight for SBAS receivers providing a level of performance equivalent to NPA are provided in Table 11.

Phase of Flight	Accuracy (NM)	Horizontal Alarm Limit (NM)	Time to Alarm (sec)	ATT (NM)	FTT (NM)	XTT (NM)	½AW (NM)
Arrival	0.12	1.0	10	1.0	0.5	1.5	5.0[31]
Initial Approach	0.12	1.0	10	1.0	0.5	1.5	3.0
IF	0.12	1.0	10	1.0	0.5	1.5	3.0
FAF	0.12	0.3	10	0.3	0.3	0.6	2.0
MAPt	0.12	0.3	10	0.3	0.2	0.5	1.0
First Waypoint in Straight Missed Approach or Departure	0.12	0.3	10	0.3	0.2	0.5	1.0
Other Missed Approach and Departure Waypoints	0.12	1.0	10	1.0	0.5	1.5	3.0

Table 11 - SBAS System Tolerances and Semi-Area Widths

2.5.3 At present, the OCP has only approved the publication of departure criteria for SBAS. Criteria for initial approach and missed approach have been drafted but will only be published once the APVI and APV II criteria have been developed.

2.6 CONTAINMENT FOR MULTIPLE NAVIGATION INFRASTRUCTURES

2.6.1 In general, procedures should be designed to provide the optimum flexibility to the users and to enable inputs from as wide a variety of infrastructures as possible to be used. This allows aircraft with suitable multi-sensor RNAV systems to continue with a procedure in the event of a failure of the primary navigation sensor/infrastructure. Where a procedure allows the use of a number of infrastructures, the containment surfaces must be calculated for the worst case infrastructure. However, prudence is required as procedures designed for DME/DME and Class B and C GNSS receivers may not be appropriate for Class A GNSS receivers.

[31] Current view is that arrival segment should stay at 5NM rather than 3NM.

2.6.2 In certain circumstances, where it is not possible to provide continuous DME/DME cover, a State may wish to allow reversion to VOR/DME. Such instances must be studied very carefully as not all systems automatically revert from DME/DME to VOR/DME [32] and it is difficult to ensure that systems revert to the same VOR/DME. Such reversion should only be considered if the leg in question is above MSA/MRVA/TAA, radar monitoring is provided and traffic levels are such that any excursions from the required track can be safely handled. If the State determines that VOR/DME reversion is acceptable, the charts should be clearly marked to show where reversion can be expected to occur and which VOR/DME is required to be used.

2.7 AIRWORTHINESS CERTIFICATION AND OPERATIONAL APPROVAL

2.7.1 The JAA Temporary Guidance Leaflet (TGL) 10, Airworthiness And Operational Approval for Precision RNAV Operations in Designated European Airspace, is applicable to all aircraft flying RNAV SIDs, STARs and Approaches up to the FAF. It requires a lateral track-keeping accuracy of at least ±1NM for 95% of flight time. This should not be confused with RNP1 (as defined in ED75 - the RNP MASPS), which has specific requirements for integrity, availability and continuity, including annunciation of the estimated navigation performance to the pilot, and may also be predicated on aircraft being capable of flying fixed radius turns. The protection provided by the criteria applicable to the worst case infrastructure available in a terminal area, be it DME/DME or Basic GNSS, is considered to be adequate for P-RNAV systems[33].

2.7.2 The TGL also makes the following assumptions:

a) All terminal P-RNAV procedures:

i) are consistent with the relevant parts of ICAO Doc 8168 PANS OPS;

ii) are designed following the guidelines of EUROCONTROL document NAV.ET1.ST10 ‘Guidance Material for the Design of Procedures for DME/DME and GNSS Area Navigation’, as amended, or equivalent material; and

[32] Airbus systems usually revert from GNSS to DME/DME to IRS to VOR/DME.

[33] This applies to all phases of flight except the final approach and missed approach. As far as the final approach is concerned, the changeover from P-RNAV to the navigation performance required for the final approach should occur during the intermediate segment, prior to the FAF. Some of the DME/DME ½AW values below 2000ft are based upon NSE values which are less than ±1NM, however, it is considered that the protection currently provided by DME/DME and Basic GNSS criteria in the initial climb-out phase will be satisfactory.

iii) take account of the functional and performance capabilities of RNAV systems and their safety levels as detailed in the leaflet.

iv) take account of the lack of a mandate for vertical navigation by ensuring that traditional means of vertical navigation can continue to be used;

v) support integrity checking by the flight crew by including, on the charts, fix data (e.g. range and bearing to navigational aids) from selected waypoints.

b) All routes/procedures are based upon WGS 84 co-ordinates.

c) The design of a procedure and the supporting navigation infrastructure (including consideration for the need of redundant aids) have been assessed and validated to the satisfaction of the responsible airspace authority demonstrating aircraft compatibility and adequate performance for the entire procedure. This assessment includes flight checking where appropriate.

d) If the procedure allows a choice of navigation infrastructure, e.g. DME/DME or GNSS, the obstacle clearance assessment has been based upon the infrastructure giving the poorest precision.

e) The required navigation aids critical to the operation of a specific procedure, if any, i.e. those which must be available for the required performance, are identified in the AIP and on the relevant charts. Navigation aids that must be excluded from the operation of a specific procedure, if any, are identified in the AIP and on the relevant charts. *Note: This may include required VOR/DME beacons.*

f) Barometric altitude compensation for temperature effects is accounted for in accordance with current approved operating practices. (Temperature compensation is not addressed as a special P-RNAV consideration).

g) The supporting navigation infrastructure, including the GNSS space segment, is monitored and maintained and timely warnings (NOTAM) are issued for non-availability of a P-RNAV procedure if navigational aids, identified in the AIP as critical for a specific P-RNAV procedure, are not available.

h) For procedures which rely on GNSS, the acceptability of the risk of loss of P-RNAV capability for multiple aircraft due to satellite failure or RAIM holes, has been considered by the responsible airspace authority. Similarly, the risk has been considered where a single DME supports multiple P-RNAV procedures.

i) The particular hazards of a terminal area and the feasibility of contingency procedures following loss of P-RNAV capability have been assessed and, where considered necessary, a requirement for the carriage of dual P-RNAV systems has been identified in the AIP for specific terminal P-RNAV procedures, e.g. procedures where radar performance is inadequate for the purposes of supporting P-RNAV. *Note: Airspace authorities may need to amend their national legal code to establish the power to require that P-RNAV or dual P-RNAV systems be carried in airspace notified for the purposes of these requirements.*

j) Where reliance is placed on the use of radar to assist contingency procedures, its performance has been shown to be adequate for that purpose, and the requirement for a radar service is identified in the AIP.

k) RT phraseology appropriate to P-RNAV operations has been promulgated.

l) Navigation aids, including TACAN, not compliant with ICAO Annex 10 are excluded from the AIP.[34]

2.7.3 It is the responsibility of the pilot to ensure that the RNAV system uses inputs from at least one of the nominated infrastructures and maintains the required navigation accuracy.

2.8 RNP CONTAINMENT

2.8.1 The accuracy value ascribed to an RNP type approximates to a circle, with a radius equal to the RNP value, centred on the intended position of the aircraft. The actual position of an aircraft, which meets the RNP requirements, would be expected to be within such a circle, for 95.4% of the total flying time of that aircraft. This represents a 2σ containment.

2.8.2 DO236A/ED75 states that ‘a lateral containment limit of two times the RNP was chosen following consideration of the typical performance of existing navigation systems and evaluation of what was necessary to obtain the operational benefit’. A containment of two times RNP is considered to equate to 3σ in all except precision approach segments.

2.8.3 In order to maintain consistency with the DME/DME and B-GNSS criteria, the OCP has adopted the following formulae to determine area semi-width for all non-precision RNP-RNAV applications:

ATT=RNP

XTT=RNP

½AW=2xRNP+BV

[34] Designers should only take account of navaids that are published in AIPs.

BV is a nominal buffer value of 0.3 NM for departure and missed approach segments, 1 NM for arrival segments that are more than 25 NM from the IAF, 0.5 NM for initial and intermediate approach segments, and 0.2 NM for final approach segments.

2.8.4 Table 12 below shows the proposed containment values for the various RNP types. It also provides details of some of the additional RNP requirements which have already been defined in ICAO documents.

RNP Type	Semi Area Width (½AW)[35]	Continuity[36]	Integrity
0.3	0.8 - 1.1 NM	[10-5/hour]	[10-5/hour]
0.5	1.2 - 2 NM	[10-5/hour]	[10-5/hour]
1	2.3 - 3 NM	[10-5/hour]	[10-5/hour]
4	10 NM		
5	12 NM	[10-5/hour][37]	[10-5/hour][37]
10	22 NM		
12.6	None required[38]		
20	None required		

Table 12 - RNP Containment Values

2.8.5 B-RNAV segments in SIDs and STARs should be clearly marked as such and should be designed in accordance with the B-RNAV criteria and the restrictions detailed in paragraph 1.3.10. Sensor specific RNAV procedures such as DME/DME and GNSS procedures may only be flown by appropriately certified aircraft. In the case of SIDs, STARs and initial approaches, a P-RNAV ceritification and operational approval is necessary. In the case of final approaches a new JAA TGL on RNAV approaches, which is currently being drafted, will apply[39]. P-RNAV certification does NOT allow an operator to fly in RNP 1 airspace.

[35] The range of values takes account of the different buffer values used for different phases of flight. It is not expected that RNP 0.3 will be used more than 25 NM from the ARP or that RNP 1 will be used for final approach.

[36] EUROCONTROL Area Navigation Equipment Operational Requirements and Functional Requirements Paragraph 5.3.2. sets values for RNP 1 and RNP 5 (10^{-5}) which exceed those set by the ICAO AWOP RNP Sub-group proposals for changes to ICAO Doc 9613 RNP Manual for RNP 1 to RNP 0.3 (10^{-4}).

[37] EUROCONTROL Area Navigation Equipment Operational Requirements and Functional Requirements Paragraph 5.3.2.

[38] EUROCAE 75 (RNP MASPS) Draft 9 Paragraph 2.2

[39] In the interim, some States have chosen to use the JAA TGL 3 to certify GPS approaches.

2.8.6 Precision approach criteria for Cat I are currently based upon the ICAO Annex 10 characteristics for ILS and the nominal performance obtained with ILS. Cat I systems using GBAS or SBAS will be linked directly to the autopilot and the Flight Director and in many cases the RNAV system will not be involved at all. RNP 0.02/40 is based upon an assumed pseudo localiser to threshold distance of 3000m. If the actual localiser to threshold distance is different, the lateral RNP requirement will have to be adjusted to reflect this.

2.9 B-RNAV DESIGN CRITERIA

2.9.1 Obstacle Clearance Areas

As the B-RNAV route is required to be above Minimum Sector Altitude/Minimum Flight Altitude/Minimum Radar Vectoring Altitude (as appropriate), obstacle clearance should not be an issue where a radar service is provided. Where no radar service is provided the following en-route obstacle clearance criteria for B-RNAV apply:

ATT – 5 NM

XTT – 5 NM

½AW – 12 NM

The principles of secondary areas apply to all B-RNAV routes except in the case of turns at an altitude.

2.9.2 Waypoint Types

TGL 2 does not require turn anticipation as a minimum standard and as a result, the designer must exercise caution when designing and promulgating B-RNAV procedures. The designer has two main options:

a) Design procedures that can be flown by all B-RNAV certified aircraft (including those that just meet the minimum requirements) when the designer has two further choices

  i) All the waypoints must be designated as fly-over and must be protected accordingly, or,

  ii) The waypoints may be designated as fly-by but protected to accommodate both fly-over and fly-by transitions. In this case, it must be made clear to the ATC organisations employing the procedure that certain aircraft will not execute fly-by turns and, hence, may exhibit significantly different track behaviour.

or

b) Design procedures just for those systems that are capable of flying fly-by transitions[40] and publish this limitation clearly on the charts and in the AIP. In this case only fly-by protection is required for the transitions.

2.9.3 Minimum Distances Between Waypoints

Although there are no existing ICAO criteria for minimum distances between waypoints on a B-RNAV route, the algorithms detailed in paragraph 6.5 should be applied with an additional 5 NM added to the minimum distance value in order to take account of the large ATT value associated with B-RNAV applications. (This applies to both fly-by and fly-over transitions.):

2.9.4 Limiting the Number of Waypoints

As TGL 2 only requires a B-RNAV system to be capable of storing 4 waypoints, a procedure should not have more than 4 waypoints per 100 NM track distance.

2.9.5 B-RNAV SIDs

A B-RNAV SID may start from a conventional fix or from a minimum altitude. In the latter case, the turn at altitude criteria should be applied.

2.9.6 B-RNAV STARs

The end of a B-RNAV STAR segment must be clearly linked to a non-RNAV STAR segment. The provision of radar vectors may be an adequate linkage – this should be anotated as ‘Radar vectors to …’.

2.9.7 Charting Requirements

The start and end points of all B-RNAV procedures should be clearly marked on the appropriate charts. The requirement for B-RNAV should also be clearly identified.

2.10 SYSTEM FAILURES

2.10.1 In the event of an RNAV system failure or the failure of a sole navigation infrastructure, the pilot should revert to conventional navigation and may be provided with radar vectoring, where this is available. While the pilot will determine the appropriate 'break-out' procedure in the event of a loss of track guidance, the designer should ensure that appropriate obstacle information is published to assist this decision.

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[40] A national regulator may authorise the use of systems without the fly-by capability provided that adequate crew procedures are in place which ensure that the aircraft still follows the nominal track.

2.10.2 In the event of a failure of the navigation infrastructure where alternate infrastructures are available, the participating aircraft should automatically revert to the alternate RNAV sensor and continue with the procedure.

2.10.3 In the event of a communications failure, the published procedure should require the aircraft to continue with the RNAV procedure.

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3 RNAV METHODS

3.1 OVERVIEW

3.1.1 Any RNAV system must obtain navigation data, of a suitable accuracy and integrity, from a source which can guarantee an acceptable level of availability and continuity of service. In civil aviation terms, this source may be ground-based, space-based and, in certain circumstances, IRS.

3.1.2 RNAV systems may use inputs from one or more navigation systems, including:

a) VOR/DME

b) DME/DME

c) GNSS

d) Instrument Landing System (ILS)

e) Inertial Reference System (IRS)

3.2 VOR/DME

3.2.1 The simplest RNAV systems are based upon VOR/DME.

3.2.2 In general, the aircraft must be within the designated operational coverage of the reference VOR/DME site and input from a second facility may be used to provide a check.

3.2.3 The accuracy of the navigation will be dependent upon the distance from the reference facility and any limitations associated with the facility. RNAV systems using only VOR/DME inputs cannot use procedures designed according to this document.

3.2.4 There may be occasions when it is not possible to provide comprehensive DME/DME coverage at all the required altitudes and where adequate coverage is available from a VOR/DME. In general, a VOR/DME input within 10-15NM of the navaid will provide a position fix that is suitable for P-RNAV operations. The problem is ensuring that every RNAV system uses the same navaid. For this reason, any decision to rely on a reversion to VOR/DME as part of the terminal procedure must be supported by a comprehensive safety analysis.

3.3 DME/DME

3.3.1 DME/DME systems are now in widespread use and there is sufficient coverage for all en-route operations, within the European Civil Aviation Conference (ECAC) area (above FL95). DME/DME systems are capable of meeting most RNAV requirements in terms of accuracy although additional DME facilities may have to be provided, in many cases, to support navigation below FL 95[41].

3.3.2 Generally, the aircraft must be within the designated operational coverage of, and must be able to receive simultaneous inputs from, at least two DME sites. The bearings from the aircraft to the sites must subtend an angle of between 30° and 150°. The effective area covered by two DME stations is defined by the intersection of the following circles:

a) A circle centred on each DME station, of radius equal to the Designated Operational Coverage (DOC) of the station.

b) Two circles passing through both DME stations, of radius equal to the distance (d) between the two DME stations.

This is illustrated by the shaded areas in Figure 2. The coverage will vary with altitude, depending upon the influence of the local topography. Note that there is also a 1 NM 'no-update zone' centred on each DME station.

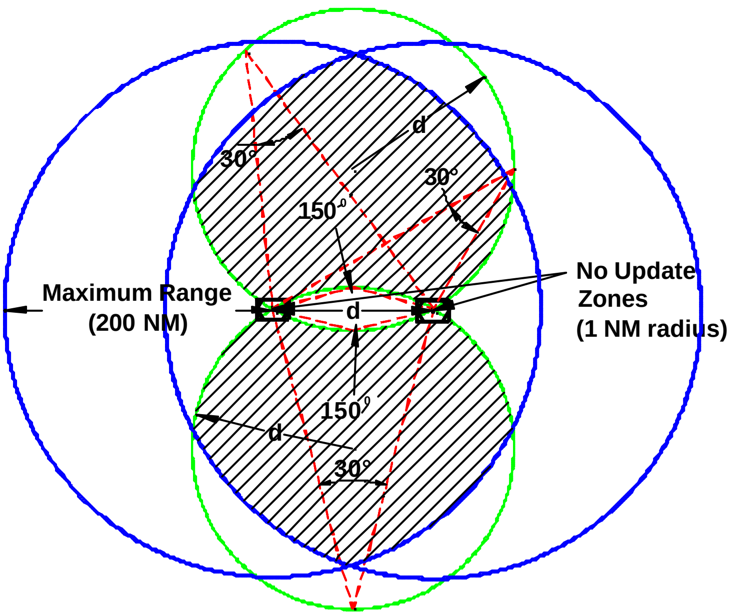

Figure 2 - DME Coverage

[41] No complete evaluation of DME coverage down to 1000ft has been carried out for ECAC airspace and hence it is not clear how many additional DMEs would be necessary to support full RNAV operations in all terminal areas.

3.3.3 There are software tools available which can be used to determine the coverage provided by a DME infrastructure in a specific terminal area at different altitudes.[42]

3.3.4 The accuracy of the navigation will be dependent upon the published tolerances and limitations associated with each facility. Input from a third facility will provide a check and a back-up should either of the others fail.

3.4 GNSS

3.4.1 The Global Navigation Satellite System currently comprises: the United States' Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS). By 2010 it is anticipated that a third European system, Galileo, will also be operational. Three satellites are required, with adequate elevation and suitable geometry relative to the receiver, to determine a position in two dimensions. Four satellites are required for three dimensional positioning.

3.4.2 A global satellite navigation system (GNSS), such as the NAVSTAR Global Positioning System (GPS), the Global Orbiting Navigation Satellite System (GLONASS) or Galileo, requires a constellation of at least twenty-four satellites, in orbits approximately 11,000 NM above the earth, in order to provide global coverage[43]. It functions as follows:

a) Each satellite broadcasts a time stamped signal with a data message. The receiver computes a position and velocity based upon the time taken for the signals to arrive from the satellites in view. The data message includes details of the satellite orbits, serviceability and accuracy, as well as the difference between UTC and the time used by the satellite positioning system.

b) The satellite positioning system is referenced to the International Terrestrial Reference Frame (ITRF). This is more accurate than, but compatible with, the World Geodetic System 1984 (WGS-84) Datum. WGS-84 has been in use as a global ICAO standard since 1998.

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[42] The FAA has developed a software tool to assist procedure designers in this regard and has released copies to ICAO, EUROCONTROL and other member States for evaluation. EUROCONTROL has developed a tool, known as DEMETER, which can be used to evaluate coverage, accuracy and redundancy, taking account of terrain. (See www.ecacnav.com for more details).

[43] The GPS constellation is currently optimised for 24 satellites although it has operated with 27 satellites for the past 5 years. The US government has indicated in the GPS SPS Performance Standard that the intent is to manage the constellation such that it never drops below 22 healthy satellites in nominal slots. The Galileo system is planned to have up to 30 satellites.

c) Three satellites are needed to fix a position in two dimensions (latitude/longitude) and four are required for three dimensions (latitude/longitude/altitude). The additional satellite is required to determine the GPS time. The accuracy of the fix depends upon the geometry of the satellites in view, relative to the receiver. According to the US Department of Defense (DoD) GPS Standard Positioning Service (SPS) Performance Standard, dated October 2001, the US Government is committed to providing a worst case positioning accuracy of ≤36m horizontally and ≤77m vertically for 95% of the time anywhere within the service volume[44]. In general, a GPS performance of ≤10m horizontally and ≤20m vertically may be expected.

d) The constellation is monitored from the ground and satellite outages are reported in the data message. However, because of the limited sampling rate and the fact that the DoD only monitors PPS, and not SPS, in real time, it may be some time before users become aware of a malfunction within the system. Such delays could be in excess of one hour. Two methods exist within the airborne equipment to address this problem and improve the integrity of the navigation solution: RAIM and Aircraft-based Autonomous Integrity Monitoring (AAIM). Both these methods are classified as Aircraft-based Augmentation Systems (ABAS)[45].

   i) Five satellites are needed to perform the RAIM function in addition to a 3D solution. A sixth satellite is required to isolate a faulty satellite and to remove it from the navigation solution (Fault Detection and Exclusion (FDE) function). Where a receiver uses barometric altitude to augment the RAIM function, the number of satellites needed may be reduced by one, given appropriate geometry. As the availability of six satellites is less than 100%, the RAIM function (including FDE) may be interrupted. These interruptions may be predicted using existing ephemeris information provided in the data message together with NANUs and NOTAMs of planned outages.

   ii) Where a satellite receiver provides data to an integrated navigation system, the RAIM function can be performed by the receiver system or the multi-sensor navigation system can include the AAIM functionality to ensure a level of integrity equivalent to that provided by RAIM. This usually involves the use of an Inertial Reference System.

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44 The worst site performance for the month June 2000 was <6m horizontal and <12m vertical.

45 The use of the word augmentation in this context can be confusing as it is only the integrity of the solution which is augmented, whereas, in SBAS and GBAS the accuracy of the solution is augmented as well.

iii) Navigation solutions from ABAS are used for lateral navigation (LNAV) only. Input from an IRS could be used to enhance the vertical solution but no credit is currently given for this in the operational approval. GPS receivers used in ABAS must meet the requirements of TSO C 129a.

Note: The probability of excessive position error due to failure is a function of the failure rate of all signals (satellites) in view (10^{-4}) and the probability of undetected failures. Generally RAIM can be expected to detect 99.9% of the failures and, hence the overall integrity is considered to be 10^{-7}.[46] No performance standard has been identified for AAIM.

3.4.3 A RAIM prediction service for route planning purposes is provided on the internet at www.augur.ecacnav.com/reports. This site automatically monitors the NANU messages issued by the US Coastguard and calculates the coverage provided by the GPS constellation[47]. A user can specify a route, area or destination aerodrome and a time period and the tool provides estimates of where RAIM outages are expected to occur. A similar service is provided by the DFS.

3.4.4 There are 3 classes of Basic GNSS equipment and each class is further subdivided into sub-classes. This is detailed in Table 13.

	Class	**A**	**B**	**C**
Sub-class	**Definition**	Stand-alone equipment incorporating GNSS sensor, RAIM and navigation	A GNSS sensor that provides data to an integrated navigation system capability	A GNSS sensor that provides data to an integrated navigation system that provides enhanced guidance to an autopilot/flight director to reduce the FTT
1	Non precision approach capability with RAIM	Traditional means of navigation approved for IFR must be available when the RAIM capability is lost		
2	NO approach capability with RAIM	Traditional means of navigation approved for IFR must be available when the RAIM capability is lost		
3	Non precision approach capability WITHOUT RAIM	Not applicable	Traditional means of navigation approved for IFR must be available; integrity monitoring equivalent to RAIM must be performed by the navigation system	
4	NO approach capability WITHOUT RAIM			

Table 13 - Basic GNSS Equipment Classes

46 The EUROCONTROL B-RNAV Safety Case established that, for a positioning accuracy of ±100m, the probability of RAIM failing to alert within 5NM was 10^{-8}.

47 The FAA also issues NOTAMs concerning GPS satellite serviceability which are based upon the US Coastguard NANU messages. These NOTAMs are issued later than the NANUs and have, on occasion, been found to be susceptible to error.

3.4.5 The satellite navigation system can be further augmented using an SBAS such as the US Wide Area Augmentation System (WAAS), the Japanese Multi-functional Transport Satellite Space-based Augmentation System (MSAS) and the European Geostationary Navigation Overlay Service (EGNOS)[48].

3.4.6 An SBAS consists of a number of geostationary satellites (GEO) and a network of ground stations. An SBAS provides:

a) Additional ranging information based upon the GEOs that carry the SBAS transponders,

b) Information on the status of the GPS satellites in view,

c) Corrections based upon the clock and ephemeris errors observed in the satellites in view

d) Corrections to take account of ionospheric effects,

e) Information on the variance of the clock, ephemeris and ionospheric corrections.

3.4.7 EGNOS functions as follows:

a) 33 Ranging and Integrity Monitoring Stations (RIMS), each containing 2 or 3 independent GPS/GLONASS/GEO[49] receivers and an atomic clock, measure the positions of the satellites (GPS/GLONASS/GEO) and monitor the transmissions from the satellites of the global positioning systems. Data on each satellite and details of detected anomalies, are sent to the Master Control Centres (MCC) via a Virtual Private Network (VPN).

b) The 4 MCCs collate the data received, monitor the integrity of the global positioning systems and determine the errors caused by the orbits, the clocks and the disturbances in the ionosphere. Correction messages and SBAS integrity flags for each satellite in the constellation, or for each monitored ionospheric grid point, are then sent to uplink stations, known as Navigation Land Earth Stations (NLES). The location of the ground stations is shown in Figure 3.

c) The 3 active NLES, out of a total of 7 operational NLES, transmit the corrections and SBAS integrity flags, or Wide Area Differential messages, together with synchronised GPS-like signals to the EGNOS space segment, located on 3 GEOs,

48 It is understood that India is also planning to develop a space-based augmentation service, called GAGAN.

49 In future this will include a Galileo receive capability as well.

d) The EGNOS space segment consists of transponders carried on board GEO INMARSAT III AOR-E[50], GEO INMARSAT IOR[51] and GEO ESA ARTEMIS[52]. The 3 GEOs re-broadcast the Wide Area Differential messages together with the GPS-like signals. The coverage provided by the GEOs is illustrated in Figure 4.

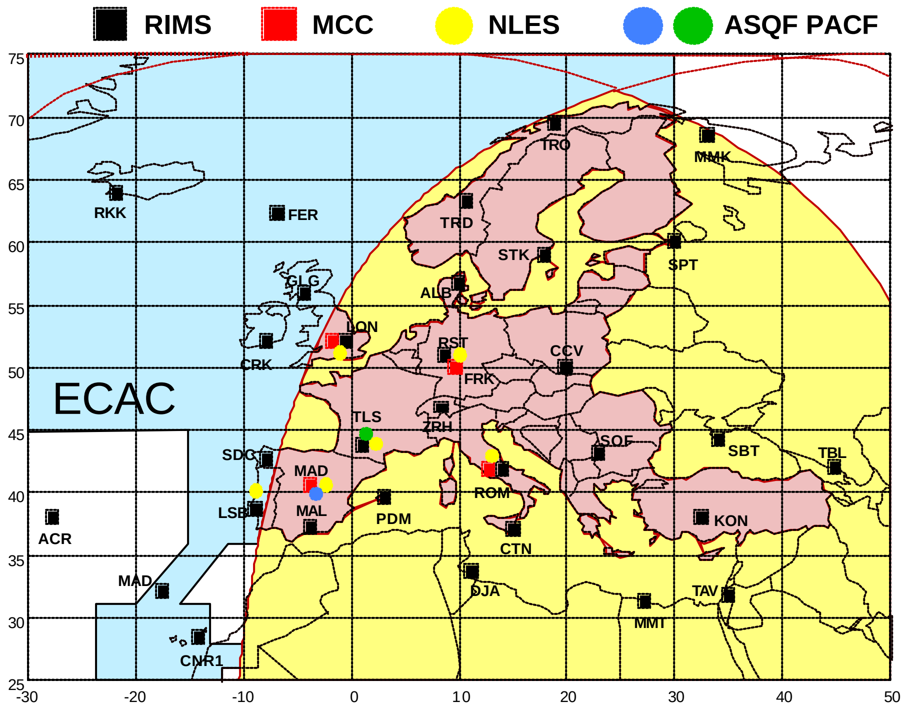

Figure 3 - EGNOS Ground Segment

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50 Located over the Eastern Atlantic Ocean.

51 Located over the Indian Ocean.

52 Currently being placed in an appropriate geostationary orbit over Africa.

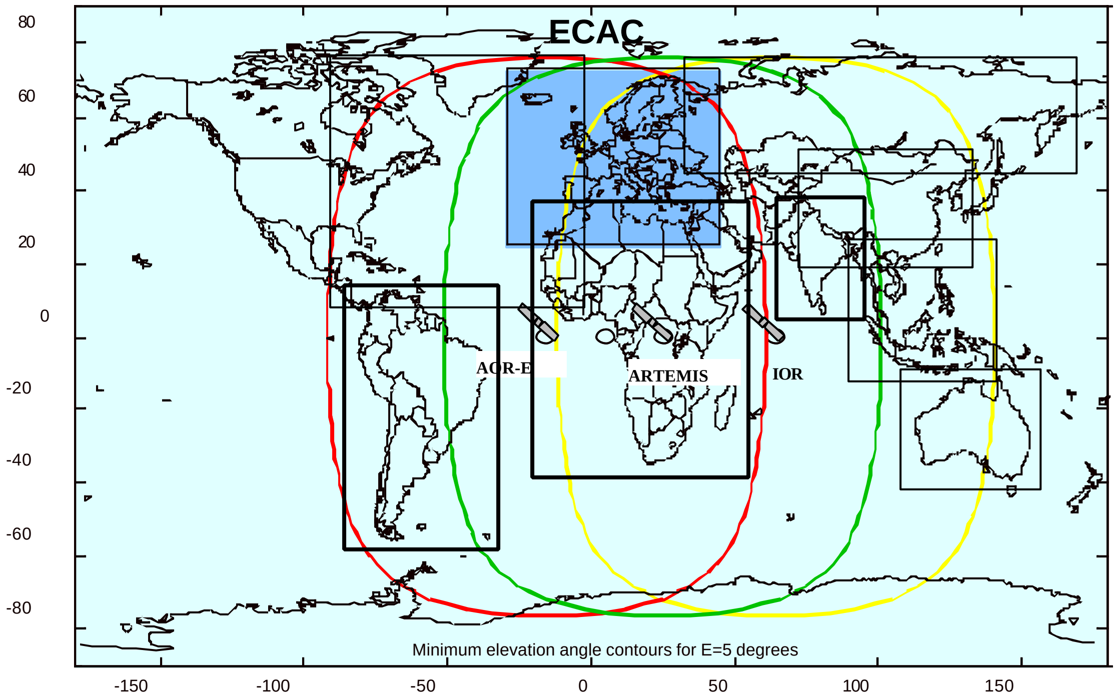

Figure 4 - GEO Coverage

e) The SBAS receiver still needs three satellites to fix a position in two dimensions (lat/long), and four for three dimensions (lat/long/altitude). The accuracy of the fix depends upon the geometry of the satellites in view, relative to the receiver, and the type of satellite (GEOs are less accurate than those in the global positioning system constellations). However, as the SBAS receiver is able to use additional ranging inputs from the GEOs and can apply the corrections obtained from the Wide Area Differential messages, it should usually achieve horizontal accuracies of ±3 meters and vertical accuracies of ±5m. The major difference between SBAS and GPS is expected to lie in the guaranteed level of service (integrity, continuity and availability) provided by EGNOS compared to that provided by the US GPS.

f) The system integrity is calculated by the SBAS receiver using the User Differential Range Estimates and the User Ionospheric Range Estimates transmitted by the SBAS together with the output from the satellite geometry computations conducted by the receiver. The time delay between the failure of a satellite in view of the RIMS and the transmission of the appropriate integrity flag should not exceed 6 seconds.

Note: The probability of excessive position error due to failure is a function of the failure rate of all signals (satellites) in view (10^{-4}failures per hour) and the probability of undetected failures. The probability of a satellite failure not being detected by SBAS is 10^{-7}. However, SBAS cannot detect localised effects such as jamming or multi-path. Jamming could be detected using a local ground-based receiver/monitor but this would not help against multipath. RAIM could be used to counter both and could be expected to detect 99.9% of such failures. The probability of such a local effect occurring and not being detected by SBAS, or by local monitor, or by flight checks, has not been quantified.

In SBAS, the RAIM function can operate on a satellite by satellite basis to identify receiver failures and multi-path. It cannot be used to identify any common mode failures that affect multiple corrections simultaneously. When the SBAS is unavailable, RAIM is used, as in GPS receivers, to check the consistency of the received ranging data. The existing standards do not clearly state that all SBAS receivers will use RAIM when SBAS is operational and there is a danger that some manufacturers will only activate the RAIM function when SBAS is unavailable.

3.4.8 The satellite navigation system can also be augmented using a Ground Based Augmentation System (GBAS) such as the US Local Area Augmentation System (LAAS). The GBAS consists of ground subsystem located on an aerodrome, or in the vicinity of an aerodrome, which transmits differential corrections by VHF data broadcast to the airborne subsystem. The airborne subsystem uses inputs from the VHF data broadcast and the GPS to compute a navigation solution that can be suitable for precision approach operations. The GBAS receiver can also use ranging data from any visible GEOs to supplement the calculation. The GBAS receiver is also capable of generating position/velocity/time (PVT) messages that may be used to augment RNAV operations outside of the final approach phase.

3.5 ILS

3.5.1 The ILS may be used as a sole source of navigation data for the final approach to a designated runway. The aircraft must be within the designated operational coverage of the facility. An ILS approach is not an RNAV procedure. The RNAV system may use localiser inputs to update the lateral navigation solution. However, once the ILS has been ‘captured’, the guidance inputs to the autopilot and flight director are not influenced by the RNAV system.

3.5.2 If an RNAV STAR terminates with an ILS approach, the database will contain separate descriptions of the STAR and the approach. The description switch over will usually occur at the IF while the system switch over may occur prior to or shortly after the IF.

3.6 IRS

3.6.1 The accuracy of navigation data provided by an IRS, is directly related to the accuracy of the last alignment/update and the time that has elapsed since that update. The growth in position error, that is inherent in every IRS, limits the amount of time that it can be used for RNAV operations. However, it is very useful for maintaining navigation accuracy for short periods during system outages[53]. Prior to this the RNAV system must have been receiving appropriate inputs from a suitable navigation sensor or from a 'runway update' function at the time of take-off.

[53] OCP12 determined that, based upon the certification drift rate for a single IRS (2 NM/hr) and maximum allowable XTT, a reversion from DME/DME to IRS only is allowed for up to 12 minutes on an approach, up

3.6.2 While manufacturers will point to the very accurate performance that can be achieved using triple IRS with multi-sensor updates and kalman filters, it is useful to know that individual IRS units can drift by significant amounts: in the first 30 minutes after an external update, the rate of drift can be up to 8.0 NM per hour while in the period from 30 minutes to 10 hours after an external update, the rate of drift can be up to 2NM per hour. Many IRS units are not replaced unless their drift rates exceed these values.

to 25 minutes in the TMA and up to 50 minutes during the en-route phase of flight. This has not been confirmed by the IRS and RNAV system manufacturers and procedure designers should always ensure that the navigation infrastructure provides adequate coverage. TGL 10 expects regulators to determine for how long a system may be used in IRS reversion and to define appropriate operating procedures for the pilots in this regard.

4 RNAV PROCEDURE DESIGN FACTORS

4.1 OVERVIEW

4.1.1 There are a number of factors that must first be considered when designing procedures for RNAV operations. These include:

a) Navigation Infrastructure.

b) Use of Waypoints

c) WGS 84 and Data Integrity

d) Environmental Effects.

e) Aircraft Performance.

4.2 NAVIGATION INFRASTRUCTURE

4.2.1 The navigation infrastructure is defined as the ground and/or space-borne equipment available for use within a designated airspace, together with the airborne equipment that is required to be carried within that airspace. The navigation infrastructure and the navaid availability determines the system accuracy and hence, the ½AW values. The actual airborne system requirements are detailed in appropriate JAA material.

4.2.2 The coverage provided by a DME infrastructure can be assessed using a software tool such as DEMETER[54]. This calculates the coverage using a terrain database and can be used to identify critical navaids. The infrastructure requirements upon which the design criteria for DME/DME RNAV are based are detailed in Table 14.

Ground System	At least two DME stations within promulgated maximum range and providing intersection angles between 30° and 150° WGS-84 co-ordinates
Airborne System[55]	RNAV system (with automatic reversion from DME/DME to updated IRS, with positive course guidance, if only two DME stations available) Navigation database containing the procedures that can be automatically loaded into the RNAV system. Turn anticipation functionality.

Table 14 - DME/DME Infrastructure Requirements

54 Developed for ECAC States by EUROCONTROL.

55 These requirements were developed by the OCP as assumptions upon which to base the obstacle clearance criteria. TGL 10 addresses the application of RNAV using either GNSS or DME/DME for departures, arrivals and approaches up to the intermediate approach segment. A TGL for RNAV approaches including Baro VNAV approaches and augmented VNAV approaches is expected to be published in 2003.

4.2.3 The infrastructure requirements upon which the design criteria for Basic GNSS RNAV are based are detailed in Table 15.[56]

Space System	Sufficient satellites to provide coverage with an HDOP ≤ 1.5[57], an elevation ≥ 5°, a global average availability of 99.75% for a 24 hour period, and a global average reliability of 99.97% WGS-84 co-ordinates
Airborne System[58]	Either GNSS Class A1/A2/B1/B2/C1/C2 with alternate means of navigation approved for IFR, or GNSS Class B3/B4/C3/C4 with alternate means of navigation approved for IFR and integrity monitoring equivalent to RAIM performed by the navigation system. Navigation database containing the procedures that can be automatically loaded into the RNAV system. Turn anticipation functionality
Ground System	If necessary, ground-based procedure navaids to Support GNSS Class B3/B4/C3/C4 Provide non-GNSS based approach at destination/alternate aerodrome

Table 15 - Basic GNSS Infrastructure Requirements

4.3 USE OF WAYPOINTS

4.3.1 Waypoints and Fixes

4.3.1.1 In ICAO Annex 11 and Doc 8168, the term ‘waypoint’ is only used to define ‘RNAV routes and flight paths of aircraft employing RNAV systems’, while the term ‘significant point’ is used, in Annex 11, to describe a ‘specified geographical location used in defining an ATS route or the flight path of an aircraft and for other navigation and ATS purposes’. It follows from this definition that all waypoints are significant points, even when additional waypoints are established for RNAV procedures on, or off-set from, the arrival/approach tracks, to allow the ATS provider to deconflict and sequence RNAV traffic.

4.3.1.2 In many other documents, a waypoint is also described as a fix[59]. This is especially the case in the terminal area where the initial approach fix (IAF), the intermediate fix (IF), the final approach fix (FAF) and the missed approach holding fix (MAHF) are commonly used terms. In order to avoid confusion, ICAO has decided to continue to use the terms IAF, IF, FAF and MAPt in both conventional and RNAV instrument approach definitions.

[56] Doc 8168 Vol. II Part III Chapter 31 Paragraph 31.1.4 and OCP/11-DP/2 Part II Attachment B to the draft report on Agenda Items 2 & 3

[57] DO 208 paragraph 1.4.2

[58] These requirements were developed by the OCP as assumptions upon which to base the obstacle clearance criteria. TGL 10 addresses the application of RNAV using either GNSS or DME/DME for departures, arrivals and approaches up to the intermediate approach segment. A TGL for RNAV approaches including Baro VNAV approaches and augmented VNAV approaches is expected to be published in 2003.

[59] EUROCAE 77 (DO 201A) Revision 8 Glossary ‘Fix: A fix is the generic name for a geographical position determined by: visual reference to the surface, by reference to one or more radio navigation aids, by

4.3.1.3 In the ECAC area it has been agreed that a waypoint associated with an RNAV terminal procedure may be known as a strategic waypoint or a tactical waypoint, depending upon the purpose that the waypoint serves.:

a) A strategic waypoint is a waypoint in the terminal area which is:

i) Either considered to be of such significance by the ATS provider that it must be identified in such a way that it can be easily remembered and stand out on any display.

ii) Or used as an 'activation point' to generate a message between computer systems when an aircraft passes it.

These waypoints are usually part of the SID/STAR route structure.

b) A tactical waypoint is a waypoint that is defined solely for use in the specific terminal area and has not been designated a strategic waypoint. These waypoints may be part of the SID/STAR route structure or they may be detached waypoints within the terminal area, either off-set from the procedures themselves or providing leg extensions. Tactical waypoints can be used to assist the controllers to sequence approaches and maintain appropriate separation by discrete vectoring. This is illustrated in Figure 46.

4.3.1.4 With the exception of legs associated with conditional transitions, such as a turn above a certain altitude or a transition onto an ILS, a waypoint must always be used to define the start and end of every RNAV route leg. The waypoint may designate a change in course, and/or speed and/or altitude.[60]

celestial plotting or by another navigation device. (Fix is a generic name for a geographical position and is referred to as a fix, waypoint, intersection, reporting point etc.)'

TERPS 1501 e.: 'Instrument Approach Waypoint: Fixes used in defining RNAV instrument approach procedures...'

TERPS 1505 a.: 'Waypoints shall be established...at holding fixes

EUROCAE 75 (RNP MASPS) Paragraph 1.5.6 'The desired path is defined by a series of geodesic tracks joining successive fixes.'

60 Conditional transitions will not always occur directly overhead the same point and, where appropriate, the designer must consider the earliest and latest turns possible when calculating the obstacle clearance. A waypoint may be used to mark the nominal turning point for planning purposes.

4.3.2 General Rules

4.3.2.1 The following general rules apply to the creation and use of waypoints for RNAV terminal procedures:

a) RNAV procedures must be designed, using the fewest number of waypoints possible, without any route gaps or discontinuities.

b) Waypoints must be established at:

i) Each end of an RNAV route.

ii) Points where the route changes course.[61]

iii) Points where speed restrictions apply/cease.

iv) Points where altitude restrictions apply/cease.

v) Holding fixes.

vi) Other points of operational benefit.

c) Fly-by waypoints should be used, wherever possible.

d) Fly-over waypoints must only be used when operationally necessary and should NOT be used for the IF or the FAF.[62]

e) RNAV waypoints must be defined as WGS 84 co-ordinates in latitude and longitude to the following accuracies:

i) Runway thresholds to $^{1}/_{100}$ second.

ii) MAPt to $^{1}/_{100}$ second.

iii) All other waypoints to $^{1}/_{10}$ second.[63]

4.3.2.2 Where tactical waypoints are used, it is imperative that every possible combination of waypoints is reviewed to ensure that the off-set, extension or short-cut transitions are consistent with the rules detailed in this document. The appropriate ATS provider must be informed of any waypoint combinations that do not meet these criteria. A typical application of tactical waypoints is illustrated in Figure 46.

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61 Conditional transitions do not have to be marked by a waypoint.

62 Notwithstanding the requirements of Appendix to Chapter 33 in DOC 8168 Vol 2 Part III, only the MAPt and the MAHWP are currently required to be fly-over for basic GNSS.

63 ICAO Annex 15 only requires 1 second accuracy for en-route, SID and STAR waypoints but the airborne systems are capable of displaying and processing this data to an accuracy of $^{1}/_{10}$ second.

4.3.2.3 When there is no radar service available or where GNSS procedures for Class A receivers have been published, it is likely that a simpler routing structure will be applied, such as the Terminal Approach Area (TAA) concept. This is illustrated in Figure 44. In this case, the aircraft is expected to follow the route without deviation.

4.3.2.4 In all cases the waypoint name that is displayed to the pilot on the RNAV system must be the same as that which is displayed to the controllers and that which is published on the charts and in the AIPs. There must therefore be a standard naming convention for the terminal area that meets the requirements of the RNAV systems, the pilots and the ATS.

4.3.3 Naming Conventions

4.3.3.1 As a general principle, the procedure designer should ensure that all RNAV waypoints are named and that the published names are appropriate for use in the navigation database.

4.3.3.2 Navigation databases can hold waypoint names but usually operate with waypoint (fix) identifiers which are five characters long, known as the 5 Letter Name Code (5LNC). In the past, where a waypoint was given a name that was longer than five characters, the database providers shortened the name to fit. Moreover, in coding FMS procedures to overlay existing conventional procedures, the database coders have often found it necessary to create additional waypoints to enable a particular system to follow the procedure. These additional waypoints are sometimes known as 'computer navigation-fixes'.[64] These problems should disappear once RNAV procedures are coded correctly and overlay procedures are removed from the databases.

4.3.3.3 ICAO requires that all significant points are identified by 5LNCs[65]. However, waypoints marked by the site of a navaid, should have the same name and coded designator as the navaid[66]. Navaids are usually annotated with the associated three letter designator on the aircraft displays but 5LNCs should be used where three letter designators are not available. The number of navaids that are overflown by RNAV procedures should diminish as overlay procedures are replaced and superseded.

64 These waypoints are not published on the charts and are specific to particular legacy RNAV systems. Different database providers calculate these points and generate different names for what is effectively the same point in the database.

65 ICAO Annex 11 Appendix 2 Paragraph 3

66 ICAO Annex 11 Appendix 2 Paragraph 2

4.3.3.4 There have been a number of cases in ECAC where navaid names have been found to be duplicates of existing waypoint 5LNCs and where waypoint names have been used more than once. While the responsibility for issuing waypoint names lies with the ICAO regional office, individual States should exercise great care when selecting new waypoint or navaid names to ensure that they are not already in use. ICAO has been provided with a software tool for assigning 5LNCs to waypoints in the ECAC area - it can be accessed via the internet on www.eurocontrol.int/icard.

4.3.3.5 Tactical waypoints, which are not marked by navaid locations, can be used by the ATC to give ‘direct to’ instructions to aircraft. They must be easy to understand and to enter into the RNAV system. Although there is, at present, no international standard for naming these waypoints, the European Air Navigation Planning Group (EANPG) is considering adopting the following convention as a regional solution for the European region[67]:

a) Throughout the terminal area, with three exceptions detailed in sub-paragraph b) below, the following waypoint naming convention is used - AAXNN, where AA contains the last two characters of the aerodrome location indicator; X is a numeric code from 0 to 9, although the letters N, E, W and S may be used instead if a State has a requirement for quadrantal information; and NN is a numeric code from 00 to 99[68].

b) The exceptions are:

   i) If a waypoint is collocated with a navaid, the navaid three letter identifier is used.

   ii) If the waypoint is collocated with the runway threshold, an identifier in the format RWNNA is used, where NN is a numeric code from 01 to 36 and A is an optional alphabetic code of ‘L’, ’C’ or ‘R’. [69]

   iii) If a waypoint is designated by the ATS provider as a Strategic TMA Waypoint, the 5LNC is used.

4.3.3.6 The Obstacle Clearance Panel has recommended a set of rules for waypoint naming which is detailed in Table 16 below:

67 OCP has endorsed a proposal to allow certain waypoints in the terminal area to be named using alphanumeric characters. However, the suitability of waypoint names for use in issuing direct to clearances is being reviewed by an ICAO multi-disciplinary group.

68 In order to ensure that there is no confusion between a direct to instruction and a radar vector, it is recommended that waypoint numbers start from 361 and do not include numbers which end in 0 or 5.

69 The FAA has a filed an exception to part of Amendment 37 to Annex 11, expressing an intention to name MAPts located at runway thresholds using a four or five character alphanumeric, e.g. RW09R.

Rule	Area of Application	General Usage	Name Type
1	En-route waypoints	En-route environment	5 letter globally unique pronounceable ICAO Namecode
2	Final waypoint SID	Terminal Airspace procedures and transition to en-route	5 letter globally unique pronounceable ICAO Namecode
3	Initial waypoint STAR	Terminal Airspace procedures and transition from en-route	5 letter globally unique pronounceable ICAO Namecode
4	Waypoints common to more than one Terminal Airspace or used in a procedure common to more than one airport in a single Terminal Airspace which are not used for en-route	Terminal Airspace procedures	5 letter globally unique pronounceable ICAO Namecode
5	Waypoints unique to an aerodrome, without a properly assigned 4 letter location indicator (iaw Doc 7910), used for Terminal Airspace procedures.	Terminal Airspace procedures	5 letter globally unique pronounceable ICAO Namecode
6	Tactical Terminal Airspace Waypoints Waypoints unique to an aerodrome, with a properly assigned 4 letter location indicator (iaw Doc 7910), used for Terminal Airspace procedures.	Terminal Airspace procedures	5 Alphanumeric Namecode specific to the Terminal Airspace.
7	Strategic Terminal Airspace Waypoints Waypoints unique to an aerodrome, used for Terminal Airspace procedures, and designated by the ATS provider as requiring prominent display or as having the function of an activation point. Based upon ATC preferences, these are usually waypoints that are very regularly used in ATC communication. They include any waypoints that are used for direct to vectors from the en-route.	Terminal Airspace procedures	5 letter globally unique pronounceable ICAO Namecode
8	Waypoints unique to an aerodrome, where Rule 6 cannot be applied due to the non-availability of a particular block, or blocks, of numbers, used for Terminal Airspace procedures. This should be restricted to domestic aerodromes or aerodromes with a low traffic density.	Terminal Airspace procedures	5 letter globally unique pronounceable ICAO Namecode

Table 16 - Waypoint Naming Rules

4.4 WGS 84 AND DATA INTEGRITY

4.4.1 Each leg of an air route is referenced to two specific geographical points which are, themselves, defined by co-ordinates of latitude and longitude.[70] These co-ordinates may have been calculated using, for example, the bearing and distance from another known point; they may have been surveyed; or simply defined by the airspace designer.

[70] Legs which terminate at conditional transitions may not have waypoints associated with those transitions.

4.4.2 Since January 1998, all co-ordinates published for civil aviation navigation purposes should be based upon WGS 84. The WGS-84 co-ordinates must be expressed as latitude and longitude and the height of the specific surveyed ground points must be expressed as height above mean sea level (MSL), or another specified datum. The geoidal undulation for all runway thresholds and aerodrome reference points must also be published. The geoidal undulation is the distance separating the geoid from the WGS-84 ellipsoid at a specified point.

4.4.3 It is imperative that adequate checks are carried out before the procedure is authorised for use. A flight check is required to ensure that the coverage provided by the navigation infrastructure is adequate, there is no interference or multi-path effects, and none of the visible navaids cause degradation of the navigation solution. Additional flyability checks must take account of the aircraft types for which the procedure has been planned. This can be achieved using trials flights with different aircraft supplied by participating operators, by simulation runs using commercial flight simulators or by analysis using specialist approved software.[71]

4.4.4 The minimum integrity checks that must be carried out should be detailed in Doc 8168[72]. They are listed in Table 17. EUROCONTROL is developing guidance material on validating RNAV procedures and is expected to develop a prototype validation tool which will check that adequate data has been provided to support database coding. EUROCONTROL is also developing a draft Minimum Aviation System Performance Specification for an RNAV Flight Check facility, together with supporting guidance material. The EUROCONTROL activities will generate the supporting documents but it will require additional involvement from industry to set in place the validation and flight check facilities.

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[71] At the time of publication, the only specialist tool that is known to be commercially available to support procedure validation is the PDT/PC Simulator facility provided by Smiths Aerospace.

[72] The OCP Working Group meeting, held at Recife 3-13 March 1998, considered that both simulator and live flight checks were mandatory but this has not been carried forward into an amendment in PANS-OPS.

Theoretical and operational integrity checks are required. Initial evaluation should be made using software tools and, where available, flight simulators. Evaluations should include assessments of the application of the procedure under extreme conditions and should address, inter alia: The continuity and repeatability of the route. The effect on the RNAV system performance of: The waypoint locations and the navaid availability. Descent profile Minimum and maximum IAS. Winds. Aircraft types and weights. RNAV system type. Pre-promulgation flight checks, from a number of different directions[73], and an analysis of the RNAV update history is recommended. For DME/DME procedures, if the RNAV system uses DME stations outside the promulgated radio range, a check is required on the effect of these stations. If a station is identified as having an adverse effect, its use in the procedure should be expressly prohibited. Although TACAN stations that do not meet Annex 10 requirements should not be included in the navigation databases, it is recommended that the commercial database providers be advised of any such TACANs that may affect the new procedures. If the procedures are based upon post 1989 DME criteria, the flight check must provide assurance that there is no possibility of pre-1989 DMEs being received during the procedure.

Table 17 - RNAV Procedure Design Integrity Checks

4.4.5 The integrity requirements for navigation data are based upon the use to which the data is put and the likely results that would occur should the data be corrupted. There are three classes of data:

a) Critical data - where there is a high probability that, as a result of using corrupted data, an aircraft would be placed in a life-threatening situation. The integrity requirement for critical data is 1×10^{-8} or better.[74]

b) Essential data - where there is a low probability that, as a result of using corrupted data, an aircraft would be placed in a life-threatening situation. The integrity requirement for essential data is 1×10^{-5} or better.

c) Routine data - where there is a very low probability that, as a result of using corrupted data, an aircraft would be placed in a life-threatening situation. The integrity requirement for routine data is 1×10^{-3} or better.

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73 For example, where tactical waypoints are used, they may be approached from different directions depending upon where the aircraft is when the direct to instruction is given.

74 EUROCAE 77 (DO 201A) Revision 8 Paragraph 2.4 An integrity requirement of 1×10^{-8} means that there must be no more than one instance of corrupted/incorrect data being used in every 10^{8} uses of that data item.

4.4.6 The problem of maintaining the integrity of navigation data throughout the navigation data process, from survey/calculation to final use, is addressed in a number of ways:

a) ICAO Annex 15 requires that a Cyclic Redundancy Check (CRC) is used to monitor the integrity of electronically stored aeronautical data. Different CRC algorithms may be used for the different data classes although it is anticipated that many States will employ the same algorithm for all navigation data. A CRC value is generated for a group of data items, such as the name, location and elevation of a runway threshold, when that data is originated. The CRC value remains with the data group throughout the navigation data process and is used, at various stages in the process, to verify that the data group has not been corrupted. If the data group is re-formatted, a new CRC value must be generated. This CRC process already exists as a general fault detection functionality in most databases and spreadsheets however it has still to be applied in earnest to meet the specific Annex 15 requirements. The new GBAS Cat I criteria require the Final Approach Segment data to be protected with a CRC. On a wider scale, EUROCONTROL is developing an XML data transfer tool which will incorporate CRC protection for individual data blocks.

b) EUROCAE 76 (RTCA DO 200) details the requirement for a suitable quality assurance system to be employed by all organisations involved in the navigation data production process. This includes all the procedures and standards necessary to ensure that the appropriate quality targets are met. One of those standards will be the application and maintenance of CRCs on all critical navigation data.

c) The JAA has issued TGL 9 - Recognition of EUROCAE Document ED-76 (RTCA DO-200A): Standards for Processing Aeronautical Data. They will shortly issue additional guidance on the production approval of navigation database suppliers. TGL 10 requires that data is obtained from a suitably qualified source and that navigation accuracy checks are carried out at appropriate times during the operation[75]. States should publish supplementary information in the form of radials/bearings and DME distances to specific waypoints in order to enable the flight crew to verify the RNAV performance during the procedure. (Additional checks must be carried out where the RNAV system is used for the final approach.)

[75] Raw data fixes should be provided for gross error checks at the IAF and at other waypoints on the procedure wherever it is deemed appropriate. See chapter 11.

4.4.7 The industry approach to TGL 9 and TGL 10 includes the use of a 'gold standard' database against which the production navigation database is checked every AIRAC. This serves to highlight all the changes made to the database during the cycle and provides assurance that data integrity is maintained.

4.4.8 The data originator/State may consider it has a 'duty of care' to obtain assurance that the data provided to the aircraft operator is an accurate reflection of the data published in the State AIP. This may be achieved through regular audit of the delivered databases or through a similar use of gold standard databases each AIRAC.

4.5 ENVIRONMENTAL EFFECTS

4.5.1 The increased flexibility associated with RNAV procedures means that new routes can be designed, not only to meet more specific needs, but also to reduce the environmental impact. For example, short-haul aircraft can climb faster and are more manoeuvrable immediately after take off, compared to some long-haul aircraft, and procedures can be designed to exploit these performance capabilities by earlier routing of departing flights away from populated areas. Every airport has its own procedures for liaising with noise abatement organisations and environmental pressure groups. However, it should be noted that, while the environmental benefits can often be clearly demonstrated and are generally welcomed by the community, there is a danger that, once it becomes apparent that the noise contours have been reduced, new buildings will encroach on the airport thereby reducing future flexibility. Moreover, it needs to be made clear to all participants that, if RNAV procedures are to be flown accurately, they must be designed to take account of the aircraft performance characteristics. It is not possible to simply draw a line on a map and expect every RNAV-equipped aircraft to be able to follow it.

4.6 AIRCRAFT PERFORMANCE

4.6.1 It is very important that the procedure designer is aware of the capabilities of the aircraft that are expected to use the procedure. It may be impossible for a large, long-haul jet to follow a departure procedure designed for a small, short-haul turboprop. Moreover, although more and more aircraft will have the capability to fly fixed radius turns, a significant percentage of the traffic will not have such a capability unless it is mandated throughout ECAC. The designer must also understand the performance criteria necessary to achieve the procedure - for example, certain models may not be able to follow the procedure, if turns in excess of 120° are used.[76]

[76] In the past, database coders have sometimes defined additional waypoints to enable a particular RNAV system to fly an RNAV overlay. This is unacceptable for RNAV procedures, in general, and it is encumbent upon the designer to liaise closely with the operators to ensure that their aircraft will be capable of using the proposed procedure.

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5 IMPLICATIONS FOR DATABASE CODERS

5.1 PATH TERMINATORS

5.1.1 Terminal area procedures, Standard Instrument Departures (SID), Standard Instrument Arrivals (STAR) and Approach procedures have traditionally been described in AIPs using charts and associated text. However, an aircraft navigation system must be provided with route data in a format that can be processed by a computer. All navigation data used by the RNAV system is held on a navigation database. Commercial navigation data suppliers collate the information provided in the States' AIPs, Aeronautical Information Circulars (AIC) and Notices to Airmen (NOTAMS) and provide formatted and regularly updated databases to airlines, tailored for use in the various navigation systems, flight planning systems and simulators. These databases are derived from data that is coded in accordance with the industry standard: ARINC 424 'Navigation System Database Specification'.

5.1.2 In order to achieve the translation of the text and the routes depicted on the charts into a code suitable for navigation systems, the industry has developed the 'Path and Termination' concept for terminal procedures. Path Terminator codes should be used to define each leg of an RNAV route from take off until the en-route structure is joined and from the point where the aircraft leaves the en-route airway until the end of the planned IFR flight.

5.1.3 The 'Path Terminator' codes have been steadily revised, over the years, to take account of improvements in navigation systems and variations in the application of PANS-OPS, or other conventions, by different States. There are, at present, 23 different Path Terminator codes, although most navigation systems only implement a sub-set of these.

5.1.4 A Path Terminator is defined by a set of two alphabetic characters. The first identifies the type of flight path and the second indicates how the route leg terminates. For example, a route from one waypoint to another waypoint would be coded as a track to a fix (TF), a constant radius turn between two waypoints would be coded as a radius to a fix (RF) and a holding pattern that is manually terminated by the aircrew would be coded as a holding/racetrack to a manual termination (HM). All the Path Terminators are listed in Table 18 and are described in more detail in Annex B.

5.1.5 The following Path Terminators, which are highlighted in bold italic in Table 18, have been identified as acceptable for RNAV use:

a) IF - Initial Fix.

b) CF - Course to a Fix. (This should be used with caution, as earth convergence and magnetic variation mismatches and the fact that the course is usually coded to the nearest degree may result in the course not being coincident with the transition waypoint. As a result, on a long CF leg (max 60NM), the aircraft may diverge sharply from track in order to capture the new course.)

c) DF - Computed track direct to a Fix. (This may be used in conjunction with fly-over transitions, or altitude transitions, but often results in larger obstacle clearance areas.)

d) FA - Course from a fix to an Altitude. (This involves a conditional transition and should be used with caution.)

e) VA – Heading to an Altitude (This is not required for P-RNAV or RNP-RNAV certification but is nevertheless available in most systems at present) It has been used in place of FA for departures from parallel runways in order to save space in the navigation database and it may be preferred in some DME/DME systems to guard against unnecessary track changes during the initial departure segment[77]. However, it is known that some database providers have a policy of not using VA and designers should not to use it all.

f) VM – Heading to a Manual Termination (This is not required for P-RNAV or RNP-RNAV certification but is nevertheless available in most systems at present) It is sometimes used to define the end of open procedures such as the end of a downwind STAR, to facilitate radar vectoring.

g) TF - Track to a Fix.

h) RF - Constant Radius Arc to a Fix. (This is only available in RNP-RNAV systems but can be used for turns from 2° to 300°)

i) HF - Hold/Racetrack to a Fix.

j) HM - Hold/Racetrack to a Manual Termination.

k) HA - Hold/Racetrack to an Altitude.

[77] This latter use is of questionable value as the initial leg is often sequenced by the time the radio updating has fully taken effect (about a 40 second time constant) and the bank angle response to the radio updating is usually very small.

First Character	Definition	Applicable Codes	Second Character	Definition	Applicable Codes
A	Constant DME arc	AF	A	Altitude	CA, ***FA***, ***HA***, ***VA***
C	Course to	CA, CD, ***CF***, CI, CR,	C	Distance	FC,
D	Computed track	***DF***	D	DME distance	CD, FD, VD
F	Course from fix to	***FA***, FC, FD, FM	F	Fix	AF, ***CF***, ***DF***, ***HF***, ***IF***, ***TF***, ***RF***
H	Holding pattern terminating at	***HA***, ***HF***, ***HM***	I	Next Leg	PI-CF, VI
I	Initial	***IF***	M	Manual termination	FM, ***HM*** , ***VM***
P	Procedure	PI-CF	R	Radial termination	CR, VR
R	Constant Radius	***RF***			
T	Track between	***TF***			
V	Heading to	***VA***, VD, VI, ***VM***, VR			

Table 18 - ARINC 424 Path Terminator Codes

5.1.6 Although the Path Terminator methodology is not in universal use in all RNAV systems, all aircraft approved for P-RNAV operations should be capable of flying the nominal tracks described by the following path terminators: IF TF, FA, CF and DF. Aircraft approved for RNP-RNAV operations will be capable of flying IF, TF, RF, FA, CF and DF legs.

5.1.7 In addition to the 23 path terminators, ARINC 424 subdivides SIDs and STARs into different categories (runway transitions, en-route transitions and route types) and allocates different subsets of path terminators to the different categories. The following simplified tables do not address all possible options available in ARINC 424 but are intended to provide sufficient guidance for procedure designers to code flyable procedures.

5.1.8 The following table defines the path terminators that may be used by procedure designers for the initial and final legs of a RNAV procedure.

Procedure	Start Leg	Finish Leg[78]
SID[79]	CF, FA,	CF, DF, HA, RF, TF, VM[80]
STAR	IF	CF, DF, HM, RF, TF, VM[81]
Approach	IF	CF, TF
Missed Approach	CF, DF, FA, HA, HM, RF, VM	CF, DF, HM, RF, TF, VM

Table 19 - Start and Finish Path Terminators

5.1.9 The following table defines the permitted leg sequences. A shaded space indicates the "current leg/next leg" sequence is not permitted.

		Next Leg									
		IF	**CF**	**DF**	**FA**	**HA**	**HF**	**HM**	**RF**	**TF**	**VM**
Current Leg	**CF**			¥							
	DF			¥							
	FA										
	HA										
	HF										
	HM										
	IF				§	§	§	§	‡		
	RF										
	TF										
	VM										

Table 20 - Path Terminator Sequences

¥ - A CF/DF or DF/DF sequence should only be used when the termination of the first leg must be overflown, otherwise alternative coding should be used.

§ - The IF leg is coded only when the altitude constraints at each end of the "FA," "HA", "HF" or "HM" leg are different.

‡ - The IF/RF combination is only permitted at the start of the final approach.

78 The 'Finish Leg' is the last leg of the procedure - for an App this would be the Final Approach leg.

79 The CA and VA path terminators are not included as a minimum requirement in TGL 10. This is an issue for the navigation database provider and, unless TGL 10 and ED75A are changed, neither should be used by the procedure designer. Few systems are capable of using DF as a starting path terminator and this should not be used by the procedure designer for the foreseeable future. The only valid starting path terminators for the SID, from a procedure design perspective are FA or CF.

80 VM only used in company contingency procedures in ECAC.

81 VM may be used to terminate 'Open STARs' when radar vectoring is provided to final approach. The VM path terminator is not included as a minimum requirement in TGL 10.

5.1.10 The following table defines the data required to support each path terminator:

Path Terminator	Waypoint Identifier	Fly-over	Turn Direction	Recommended Navaid	Distance from Navaid	Bearing from Navaid	Magnetic Course	Path Length	Altitude Restriction 1	Altitude Restriction 2	Speed Limit	Vertical Angle	Arc Centre
CF	✓	§	O	✓	✓	✓	✓	✓	O	O	O	O	
DF	✓	§	O	O	O	O			O	O	O		
FA	✓		O	✓	✓	✓	✓		+		O		
HA	✓		O	O	O	O	✓	✓	+		O		
HF	✓		O	O	O	O	✓	✓	O		O		
HM	✓		O	O	O	O	✓	✓	O		O		
IF	✓			O	O	O			O	O	O		
RF	✓	O	✓	O		q	¥	@	O	O	O	O	✓
TF	✓	O	O	O	O	O	O	O	O	O	O	O	
VM	O		O		O	O	‡		O		O		

Table 21 - Path Terminators (Required Data)

✓ - Required

O - Optional

§ - Required for CF/DF and DF/DF combinations only.

θ - Inbound tangential track

¥ - Outbound tangential track

‡ - Heading not course

@ - Along track distance

+ - Altitude 'at or above'

5.1.11 For operations involving systems using pre ARINC 424-16, the following additional constraints apply[82]:

a) TF to flyover can only be followed by TF or CF.

b) If a procedure requires a DF after a flyover then the previous leg must be coded CF or DF.

5.2 DESIGN CONSIDERATIONS

5.2.1 There are also a number of basic rules that designers should apply when interpreting the ARINC 424 use of Path Terminators:

a) FA should be followed by DF or CF. (DF recommended)

b) DF cannot follow a fly-by.

[82] At the time of publication, most systems are pre ARINC 424-16, and it is recommended that these constraints are applied as a matter of course.

c) RF which is followed by another RF must be in the same direction and with same radius. This is a procedure design limitation rather than a coding limitation at the moment. (i.e. the insertion of a waypoint during a fixed radius turn for altitude or speed restriction purposes)[83].

d) While most straight departures should start with an FA DF sequence for the initial straight segment, if the first fly-by waypoint is less than 3 NM from the DER, experience has shown that it is preferable to use just a CF to start the procedure.

e) Where an initial departure turn is constrained by a distance from the DER and a minimum altitude, the application of an altitude constraint at the turning waypoint will not ensure that both constraints are met. A better method is to code the first leg as an FA and the second as a CF with the second leg course arranged to ensure that the earliest turn to intercept occurs at or after required turning point.

f) Certain systems require an altitude constraint to be published for any waypoint where a speed constraint is applied.

5.2.2 The following points should be borne in mind as good practice for all RNAV procedure design:

a) With the exception of conditional transitions, every leg must proceed from a waypoint to a waypoint.

b) Large angle changes (>90°) should be avoided wherever possible.

c) Conditional transitions should be used sparingly and with care.

d) Procedures should be designed in such a way that they can be properly translated using the prescribed leg types and route types.

e) The procedure designer must be aware of the impact that specific types of transition will have on the aircraft expected to use the procedure.

f) All details of any specific restrictions applied to a procedure must be published.

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83 At present, RF is only available on the B-777, A-340 and A-330, B737 with the SI U10.2 software, B757 and B767 with Honeywell Pegasus software and aircraft with the Universal Super FMS.

g) A standard method for describing procedures should be adopted by all procedure designers. This will ensure that there is no ambiguity as far as the navigation database coder is concerned. The methodology for defining RNAV procedures is detailed in Chapter 11

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6 DEVELOPMENT OF TERMINAL PROCEDURES

6.1 INTRODUCTION

6.1.1 Terminal procedures must be designed in conjunction with the relevant ATS providers, the airport operator and one or more representatives from the major users. It is imperative that the procedure design meets the operational requirements of the aircraft operators and the air traffic service provider and takes account of any environmental constraints imposed by the State or local authority. These requirements should be clearly defined before starting the design process proper.

6.1.2 The logical steps in designing an RNAV procedure are:

a) Establish the intended purpose of the new procedure.

b) Identify the operators and aircraft types which will be expected to use the procedure.

c) Define the procedure based upon the navaid availability.

d) Establish the environmental impact of the proposed procedure.

e) Evaluate and validate the procedure using appropriate software tools, simulators and flight checks.

f) When publishing the procedure, use the standard terminology, detailed in chapter 11, and declare the speeds and altitudes used to calculate the procedure.

6.1.3 RNAV procedures must be defined in such a way that there are no ambiguities when the data is coded into a navigation database, regardless of the FMS/RNAV system that is installed. Furthermore, in general, RNAV procedure design should focus on safety, codability, flyability, repeatability, simplicity and noise abatement, where relevant.

6.2 NAVAIDS

6.2.1 The procedure designer must consider the availability of navaids and the effects that navaid outages may have on the proposed procedure. Most RNAV systems are able to select and deselect navaids automatically but there may be instances where the loss of a specific navaid will result in a loss of capability for a particular RNAV route.[84] It is, therefore, important that the impact of the loss of a navaid capability is addressed during the design stage. As the RNAV system may use inputs from a number of navaids, the accuracy of all the published navaid locations and station declinations is as critical as the accuracy of the signals transmitted by the navaids themselves.

6.2.2 The Airspace Provider must be aware of all the navaids that an aircraft flying the procedure may use. This may include navaids up to 200NM from the published track and located in neighbouring States. The Airspace Provider should seek to identify and correct potential sources of error such as two or more navaids using the same frequency within line of sight of the aircraft, military TACANs with common frequencies, inappropriate navaids in the navigation databases (DMEs with off-sets or limited DOCs) and unreliable navaids outside the control of the Airspace Provider. Close co-ordination with the commercial navigation database providers is essential to ensure the integrity of the navaid data in the databases. The Airspace provider should also seek to establish letters of agreement with the operators of navaids which affect the airspace to ensure availability and continuity of service to aircraft in the airspace.

6.3 ROUTE LEGS AND TRANSITIONS

6.3.1 Overview

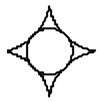
6.3.1.1 A terminal procedure is divided into a series of legs which may be straight lines or transition areas. Each waypoint on an RNAV route represents a location where the aircraft navigation system is usually required to effect an automatic transition from one leg to the next. This transition may involve changes in speed and/or altitude and/or direction. The exception is the holding procedure where a manual input may be required to transition from the hold.

[84] This is considered to be unlikely in Europe in the case of the en-route structure and the large TMAs where, in most cases, there are a large number of navaids available. However, the number of unbiased DME stations that can be used at the lower altitudes in the less complex TMAs and in mountainous areas may be very limited. Where ground-based navaids are operated by different service providers, there may be occasions when conflicts arise as a result of unscheduled maintenance or changes to hours of operation.

6.3.1.2 Where the transition involves a track angle change of 5°[85], or more, it may be effected in one of four ways:

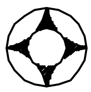
a) Fly-by transitions - where the navigation system anticipates the turn onto the next route leg. This is the preferred transition type for all RNAV transitions, except for MAPt waypoints. Fly-by transitions are not documented as specific legs - they are defined by the preceding and subsequent legs and their common waypoint. No additional waypoints are necessary to define the start or end of the fly-by transition itself. Furthermore, fly-by transitions shall not be used on B-RNAV SIDs and STARs or in procedures for aircraft with Class A GNSS equipment.

The ICAO charting symbol for fly-by waypoints is:



b) Fly-over transitions - where the aircraft overflies the waypoint before starting to turn onto the next route leg. A fly-over transition is used exclusively in terminal airspace and then only where it is not possible to use a fly-by or fixed radius transition, or where clear advantages can be gained from its use. As with fly-by transitions, they are defined by the preceding and subsequent legs and their common waypoint.

The ICAO charting symbol for fly-over waypoints is:



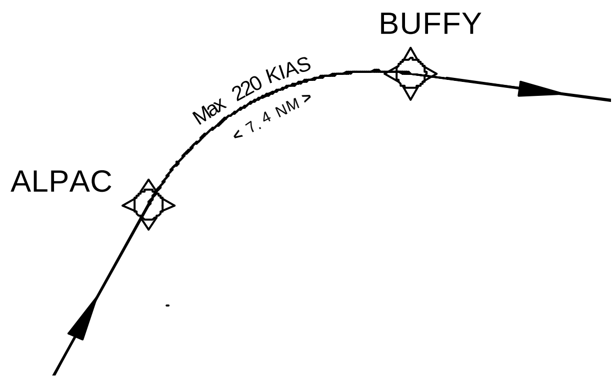
c) Constant radius arc to a fix - where the aircraft flies a specific turn with a defined radius. The constant radius arc to a fix transition, using the RF path terminator, provides the most accurate, predictable and repeatable turn and is, generally, the preferred method for transitions with track angle changes greater than 5° within the terminal area.[86] However, it is not possible to code RF transitions into any Class A GNSS equipment or into the majority of RNAV systems currently in service.[87] RF transitions are defined by a starting waypoint, defined for the preceding leg, an end waypoint, a turn centre and a fixed turn radius. An along track distance is also required as a validation check.

85 Certain systems do not recognise turns of less than 5° and do not apply turn logic in these cases.

86 The controlled turn, also known as a fixed radius transition, was first introduced for en-route applications with turn radii of 22.5NM above FL200 and 15NM below FL190. It is intended to provide separation between parallel routes, where the fly-by transition is not compatible with the separation criteria. Such functionality is not available on current aircraft types although it is expected to start appearing in new

The charting symbol for RF waypoints at the beginning and end of the turn has been the subject of much debate over the years. At OCP13 it was agreed that the fly-by symbol would be used. The co-ordinates of the centre-fix and the waypoints, the radius and the turn direction should be published in the AIP in tabular form only. They should not be included on the chart. Along track distance and any speed constraints should be shown both on the chart and in the table.

The proposed ICAO charting symbol for RF waypoints is:



d) Conditional transitions - where the RNAV system initiates a transition once a specific altitude has been reached. Conditional transitions that involve a turn are defined by the preceding leg, the subsequent leg and an altitude restriction. A waypoint on the nominal track may also be defined[88]. The subsequent leg may only be coded as CF or DF. Conditional transitions are usually used during the departure phase and care must be taken to ensure that adequate obstacle clearance is provided for the maximum and minimum climb gradients that may be anticipated. It is not possible to code conditional transitions into Class A GNSS equipment, however the transition may be flown manually with 'manual hold' selected. The required turn direction should be published for all conditional turns (i.e. Left or Right).

certain models delivered in 2003. The RF turn in terminal airspace may serve a similar purpose but is defined differently.

87 August 2002

88 The FA path terminator process does not use waypoint data and, hence, any systems that employ FA path terminators to comply with a turn based upon an altitude restriction cannot comply with a concomitant requirement to associate the turn with a specific waypoint, either as fly-by or as fly-over. This may be achieved, in part, using a TF leg with an altitude restriction, in which case the Lateral Navigation function flies via the waypoint while the VNAV function follows the altitude constraints - if the aircraft cannot achieve the altitude requirements, the Lateral Navigation function will continue to follow the prescribed track and the pilot will receive an indication that the vertical constraint cannot be met. It is not clear how many existing RNAV systems are able to process this. For departures, one solution is to code an FA followed by a CF where the course ensures that the aircraft does not commence the turn before a specific point. Another alternative is to code CF to a fly-over waypoint, followed by an FA followed by a DF – this ensures that the aircraft overflies the waypoint and then checks the altitude restriction before turning. Conditional transitions that involve an ILS transition are defined by the current leg and a textual annotation - obstacle clearance areas are defined in terms of the ILS surfaces, as detailed in Doc 8168 Vol 2 Part II Chapter 21.

6.3.1.3 Track angle changes must not exceed 120° in fly-by transitions. The fixed radius transition can be used for turns greater than 120° and should also be used for all turns in excess of 90°, wherever possible. In the departure phase, the designer should, wherever possible, not use fly-over or conditional turns involving track angle changes greater than 120° as the speed and climb performances of different aircraft types vary considerably and it is difficult to ensure that all types and situations are suitably catered for. [89]

6.3.1.4 The applicability of the three transition categories is detailed in Table 22 below.

WAYPOINT TYPE	FLY-BY	FLY-OVER	FIXED RADIUS
Approach			
IAF	✓	✗	✓
IF	✓	✗	✓
FAF	✓	✗	✗
MAPt	✗	✓	✗
HWP	✓[90]	✓[91]	✗
Departure			
DER	✗	✓	✗
DWP	✓	✓	✓
Terminal			
AWP	✓	✓	✓
HWP	✗	✓	✗
En-route	✓	✗	✓[92]

Table 22 - Allowable Turns[93]

6.3.1.5 A waypoint which does not involve a track angle change is usually coded as a 'fly-by' waypoint even though the aircraft will fly over it. The speed and altitude values, used in a specific procedure, must be published with the procedure.

89 In departures using a turn at altitude, the use of FA, followed by a DF or CF path terminator may result in aircraft changing track through more than 120°. Moreover, a fly-over transition with a large track angle change may result in a turn greater than 120° if the subsequent leg is coded as DF(or CF, if absolutely necessary).

90 RNP-RNAV procedures only.

91 Holding procedures using DME/DME and GNSS RNAV are performed in the same way as conventional holding.

92 The fixed radius turn in the en-route phase of flight does not use the RF path terminator concept. There are no aircraft systems at present that are capable of flying en-route fixed radius turns.

93 In ARINC 424 terms, the fly-by and fly-over transitions are coded by an 'Overflight Flag' which is present in every leg record. This flag can be 'set' (fly-over) or 'not set' (fly-by). Fixed radius transitions are coded as RF legs with the Overflight Flag 'not set'.

6.3.2 Speed

6.3.2.1 All turn calculations involving speed are based upon the maximum True Airspeed (TAS) allowed for the turn.[94] The maximum Indicated Air Speed (IAS) values, defined in Doc 8168, for different aircraft categories and different phases of flight are detailed in Table 23. If lower speeds are used in the calculations, the designer must ensure that the speed is adequate for the categories involved and appropriate speed restrictions must be published with the procedure.

Aircraft Category	**A**	**B**	**C**	**D**	**E**
Departure (Normal)[95]	121	165	264	292	303
Departure (Minimum)	110	143	176	204	253
Arrival (>25NM from IAF)	325	325	325	325	325
Arrival (£25NM from IAF), Initial and Intermediate Approach Segments[96]	150	180	240	250	250
Holding (Up to 14000 ft)[97]	Normal: 170 Turbulent: 170		Normal: 230 Turbulent: 280		
Final Approach Segment	100	130	160	185	230
Missed Approach Segment (Intermediate)	100	130	160	185	230
Missed Approach Segment (Final)	110	150	240	265	275

Table 23 - Procedure Calculation IAS Values (kts)

94 TAS = V = K x IAS = $IAS \times 171233 \times \left[(288 \pm VAR) - 0.00198H\right]^{0.5} \div (288 - 0.00198H)^{2.628}$

Where VAR = temperature variation about ISA in °C

and H - altitude in feet.

or

$$V = 55.1088\sqrt{T}\sqrt{\sqrt{1 + 0.0023157\,\frac{\mathrm{IAS}^2}{\mathrm{P}}\left(1 + \frac{IAS^2}{1750200}\right)} - 1}$$

Where T = temperature in K at ISA + 15

and P = pressure in hPa

95 Doc 8168 Vol. II Part II Paragraph 3.3.1.3 c)

96 Doc 8168 Vol. II Part III Table III-1-2

97 Doc 8168 Vol. II Part IV Table IV-1-1

6.3.3 Angle of Bank

6.3.3.1 Actual angle of bank (AOB) will vary according to the amount of track angle change, the aircraft type, the RNAV system, the height of the aircraft and the wind. The procedure designer should assume bank angles of one half the track angle change or one of the following values, whichever is the smaller, in all calculations pertaining to the obstacle protection areas:

a) 15° for all missed approach, departure and en-route phases of flight.

b) 25° for all other phases of flight.[98]

6.3.3.2 In departure procedures, it may be necessary to consider the nominal track that the majority of aircraft may be expected to follow, in order to identify any noise abatement or ATC problems. The nominal departure track is based upon a 7% departure gradient, statistical speed data, detailed in Table 35, and bank angles of one half the track angle change or one of the following values, whichever is the smaller:

a) 15° if the height is below 1000 ft.

b) 20° if the height is at or above 1000 ft but below 3000 ft.

c) 25° if the height is at or above 3000 ft.

6.3.4 Wind

6.3.4.1 Wind can affect an aircraft track significantly. Classical procedure design uses wind spirals, on the outside of turns, based upon a wind speed, 'w'[99], and either the rate of turn, or the bank angle and the TAS. Until now, it has generally been considered that a $\alpha/2$ cut-off on the inside of the turn will provide adequate protection, particularly as the pilot can reduce the bank angle during the turn, to counter strong cross-winds.

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[98] Many in the aviation industry consider 23° AOB to be a more appropriate value particularly as many autopilots/flight directors have bank authority limits of 27° AOB and this allows 4° to make adjustments for cross-winds etc. Similarly, as some less sophisticated gyroscopes have auto-erect cut-offs ≤6°, a minimum AOB of 10° is also recommended.

[99] 'w'=2h+47

Where h = aircraft altitude in Kft.

6.3.4.2 Many RNAV systems take account of the calculated, or forecast, wind when computing a turn. A strong tail wind will cause the turn to start early, with a larger than normal turn radius, while a strong head wind will result in a late turn and a smaller than normal radius. Some RNAV systems calculate the turn beforehand and only re-assess the situation as the turn is nearing completion when the following subsequent track is 'captured' - the turn itself is considered to be frozen - while others make continual reassessments and adjustments during the turn.

6.3.4.3 The tables produced, by the OCP, for Amendment 9 to Doc 8168, do not make allowance for wind, relying instead on the application of wind spirals to provide the appropriate protection for late turns and, on the inside of the turn, starting the primary area splay at a/2 from the earliest ATT.

6.3.5 Roll Anticipation and Pilot Delays

6.3.5.1 Roll anticipation is the distance travelled along the previous leg track from the point at which the roll starts to be applied until the point when the aircraft is considered to have started the turn. For the purposes of calculations, the assumption is made that the aircraft continues on the previous track until all the bank has been applied.

6.3.5.2 It is also assumed that every RNAV system will take account of the time necessary to apply the appropriate bank when calculating the turn anticipation. If the flight director is being used, the pilot should be given sufficient indications to execute the turn within the same timeframe as the autopilot. This is still the subject of some debate and analysis and, if the designer wishes to err on the side of caution, the following allowances for pilot-induced delays can be made:

a) 10 seconds during any en-route segment.

b) 6 seconds during any terminal segment other than a missed approach and departure segment.

c) 3 seconds during any missed approach or departure segment.

6.3.5.3 If the autopilot is coupled to the RNAV system, there may be a delay of up to one second for the RNAV system to update the autopilot prior to roll being applied. Distances associated with system and pilot induced delays are calculated by multiplying the aircraft TAS (or ground speed, if wind effect is included) by the pilot/system delay time.

6.3.5.4 Roll anticipation distances are calculated by multiplying the aircraft TAS (or ground speed, if wind effect is included) by the time taken to apply the appropriate amount of bank, according to the phase of flight and the mode of operation:

a) If the autopilot is coupled to the RNAV system, the bank will be applied at 3° per second. A worst case roll anticipation time would therefore be 25/3 = 8.3 seconds.

b) If the flight director is used, the bank can be expected to be applied by the pilot at 5° per second. A worst case roll anticipation time for terminal operations would therefore be 25/5 = 5 seconds.

6.3.5.5 The OCP are, currently, of the opinion that 5 seconds is sufficient time to account for all the delays associated with roll-in or roll-out, based upon the advice that they have received from the equipment manufacturers.[100] It is understood that they do not propose to make any allowances for pilot anticipation in RNAV procedure turns, at present. The tables provided in this document reflect the OCP position. The formulae provided in this document include a parameter for pilot delay should a designer wish to make additional allowances. Roll anticipation does not have to be accounted for in fixed radius turns.

6.3.6 Calculation Conventions

6.3.6.1 If different rounding conventions are used by the data producers and the data users then it is very likely that the users' solutions will differ from those intended by the producers/designers. Moreover, if a value is used for different applications which require different resolutions, there is a danger that double rounding will further distort the final value.

6.3.6.2 Measurements and calculations must always be made to at least one more decimal place than will be required in the final value. Where different resolutions are required, sufficient decimal places should be used to support the final value with the greater resolution. The extra decimal place(s) must be used to round the final value as follows:

a) If the first decimal place, after the last digit of the final value, has a value which is less than five, then the number may be truncated after the last digit.

b) If the first decimal place, after the last digit of the final value, has a value which is equal to or greater than five (5,6,7,8 or 9), then the last digit of the final value must be rounded up by one.

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[100] It is understood that Airbus Industries use 6 seconds as a rule of thumb.

6.3.7 Fly-by Transitions

6.3.7.1 The nominal track of a fly-by transition for RNAV operations can be defined by the following formulae:

Rate of turn: $R = \dfrac{3431 \tan f}{pV}$ or 3 /sec, whichever is smaller.

Radius of turn: $r = \dfrac{V}{20pR}$ [101]

Turn initiation distance: $Y = r \times \tan(0.5 \times a)$

Where

V = maximum TAS assumed for the transition (kts).

α = track angle change (degrees) {120°≥ α}.

ϕ = maximum bank angle (degrees) {½α or 15° or 25°}.

6.3.7.2 ED75(), the RNP MASPS, modifies the formula for turns above FL195:

(V+W) = 750 kts

ϕ = 5°, by default.

If 5° results in Y > 20 NM, then

Y = 20 NM and

$$r = \frac{20}{\tan(0.5 \times a)}$$

6.3.7.3 This has the effect of limiting the initiation of a turn to 20 NM. PANSOPS does not take account of this modification in any of its criteria. There is evidence that different aircraft types apply this turn logic in different ways.

a) Many Airbus and MD-11 aircraft employ the following criteria to determine the required angle of bank[102]:

i) If the aircraft trajectory at the bisector of the turn is predicted to be below FL200, then the angle of bank will be the track angle change or 25°, whichever is less. The turn anticipation distance is kept below 10NM.

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101 RNP MASPS uses the formula $r = (V + W)^2 \times (\tan f)^{-1} \times 1458 \times 10^{-5} NM$ which, although it does not take account of the requirement for a 3°/sec maximum rate of turn, nevertheless produces very similar results to one decimal place of a NM above 170 kts. The rate of turn formulae produce larger distances at the lower speeds -there is a difference of 0.3 NM at 120 track angle change, 25° AOB and 130 kts. The 3°/sec maximum rate of turn is only achieved below 172 Kts with 25° AOB, 135 kts with 20° AOB, and 100 kts with 15° AOB.

102 This is currently under review by the manufacturer.

ii) If the trajectory is predicted to be above FL200, the angle of bank is optimized to fly the aircraft over the point where a 5NM parallel track on the inside of the active leg intercepts a similar track on the next leg. The angle of bank is limited to a minimum of 5°. The turn anticipation is allowed to increase to a maximum of 20NM.

b) It is understood that other aircraft types either do not apply the high level formula at all or only apply it when the aircraft is above FL195.

6.3.7.4 An α value of 50 has been used in PANSOPS for all track angle changes between 15° and 50° for the calculation of the minimum leg distance as the corresponding changes in value for r and Y were not considered to be significant to warrant separate treatment. The values for 'r' and 'Y' for different TAS values and different angles of bank are illustrated in Table 24, Table 25 and Table 26. Note that the turn completion distance has the same value as the turn initiation distance but this does not include the distance travelled during the roll-out and stabilisation. The arc described by the radius, 'r', represents the nominal track associated with the transition for the given values of wind, TAS and angle of bank.

TAS (kts) V	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**240**	**260**	**280**	**300**	**320**	**340**	**360**	**380**	**400**	**420**	**440**
Radius of Turn (NM) r	0.9	1.1	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	3.1	3.7	4.3	4.9	5.6	6.3	7.1	7.9	8.7	9.6	10.5
Track Angle Change a	**Turn Initiation Distance (NM) Y**																				
£50	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.3	3.7	4.1	4.5	4.9
55	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.8	1.9	2.2	2.5	2.9	3.3	3.7	4.1	4.5	5.0	5.5
60	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.8	2.1	2.5	2.8	3.2	3.6	4.1	4.5	5.0	5.5	6.1
65	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.7	2.0	2.3	2.7	3.1	3.5	4.0	4.5	5.0	5.6	6.1	6.7
70	0.6	0.7	0.9	1.0	1.1	1.2	1.4	1.5	1.7	1.8	2.2	2.6	3.0	3.4	3.9	4.4	4.9	5.5	6.1	6.7	7.4
75	0.7	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.4	2.8	3.3	3.8	4.3	4.8	5.4	6.0	6.7	7.4	8.1
80	0.8	0.9	1.0	1.2	1.3	1.5	1.6	1.8	2.0	2.2	2.6	3.1	3.6	4.1	4.7	5.3	5.9	6.6	7.3	8.1	8.8
85	0.8	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.4	2.9	3.4	3.9	4.5	5.1	5.8	6.5	7.2	8.0	8.8	9.7
90	0.9	1.1	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	3.1	3.7	4.3	4.9	5.6	6.3	7.1	7.9	8.7	9.6	10.5
95	1.0	1.2	1.3	1.5	1.7	1.9	2.1	2.4	2.6	2.9	3.4	4.0	4.7	5.3	6.1	6.9	7.7	8.6	9.5	10.5	11.5
100	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.6	2.9	3.1	3.7	4.4	5.1	5.8	6.6	7.5	8.4	9.4	10.4	11.4	12.6
105	1.2	1.4	1.6	1.8	2.0	2.3	2.6	2.8	3.1	3.4	4.1	4.8	5.6	6.4	7.3	8.2	9.2	10.2	11.4	12.5	13.7
110	1.3	1.5	1.7	2.0	2.2	2.5	2.8	3.1	3.4	3.8	4.5	5.3	6.1	7.0	8.0	9.0	10.1	11.2	12.4	13.7	15.0
115	1.4	1.7	1.9	2.2	2.5	2.8	3.1	3.4	3.8	4.1	4.9	5.8	6.7	7.7	8.7	9.9	11.1	12.3	13.7	15.1	16.5
120	1.6	1.8	2.1	2.4	2.7	3.1	3.4	3.8	4.2	4.6	5.4	6.4	7.4	8.5	9.7	10.9	12.2	13.6	15.1	16.6	18.3

Table 24- Turn Initiation Distances and Turn Radii for Fly-by Turns (15° AOB)

TAS (kts) V	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**240**	**260**	**280**	**300**	**320**	**340**	**360**	**380**	**400**	**420**	**440**
Radius of Turn (NM) r	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.6	1.8	1.9	2.3	2.7	3.1	3.6	4.1	4.6	5.2	5.8	6.4	7.1	7.8
Track Angle Change a	**Turn Initiation Distance (NM) Y**																				
£50	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.1	1.3	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.3	3.6
55	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.3	1.4	1.6	1.9	2.1	2.4	2.7	3.0	3.3	3.7	4.0
60	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.3	1.6	1.8	2.1	2.4	2.7	3.0	3.3	3.7	4.1	4.5
65	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.2	1.5	1.7	2.0	2.3	2.6	3.0	3.3	3.7	4.1	4.5	4.9
70	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.6	1.9	2.2	2.5	2.9	3.2	3.6	4.1	4.5	5.0	5.4
75	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.8	2.1	2.4	2.8	3.1	3.6	4.0	4.4	4.9	5.4	6.0
80	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.9	2.3	2.6	3.0	3.4	3.9	4.4	4.9	5.4	5.9	6.5
85	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.8	2.1	2.5	2.9	3.3	3.8	4.2	4.8	5.3	5.9	6.5	7.1
90	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.6	1.8	1.9	2.3	2.7	3.1	3.6	4.1	4.6	5.2	5.8	6.4	7.1	7.8
95	0.7	0.9	1.0	1.1	1.3	1.4	1.6	1.7	1.9	2.1	2.5	3.0	3.4	3.9	4.5	5.1	5.7	6.3	7.0	7.8	8.5
100	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.3	2.7	3.2	3.7	4.3	4.9	5.5	6.2	6.9	7.6	8.4	9.2
105	0.9	1.0	1.2	1.3	1.5	1.7	1.9	2.1	2.3	2.5	3.0	3.5	4.1	4.7	5.3	6.0	6.8	7.5	8.4	9.2	10.1
110	1.0	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.8	3.3	3.9	4.5	5.1	5.9	6.6	7.4	8.3	9.2	10.1	11.1
115	1.1	1.2	1.4	1.6	1.8	2.0	2.3	2.5	2.8	3.0	3.6	4.3	4.9	5.7	6.4	7.3	8.1	9.1	10.1	11.1	12.2
120	1.2	1.4	1.6	1.8	2.0	2.2	2.5	2.8	3.1	3.4	4.0	4.7	5.4	6.2	7.1	8.0	9.0	10.0	11.1	12.2	13.4

Table 25 - Turn Initiation Distances and Turn Radii for Fly-by Turns (20° AOB)

TAS (kts) V	130	140	150	160	170	180	190	200	210	220	240	260	280	300	320	340	360	380	400	420	440
Radius of Turn (NM) r	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.8	2.1	2.5	2.8	3.2	3.6	4.1	4.5	5.0	5.5	6.1
Track Angle Change a	**Turn Initiation Distance (NM) Y**																				
£**50**	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	1.0	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.6	2.8
55	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	1.0	1.1	1.3	1.5	1.7	1.9	2.1	2.4	2.6	2.9	3.2
60	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.1	2.3	2.6	2.9	3.2	3.5
65	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.6	1.8	2.0	2.3	2.6	2.9	3.2	3.5	3.9
70	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.5	1.7	2.0	2.2	2.5	2.8	3.2	3.5	3.9	4.2
75	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.6	1.9	2.2	2.5	2.8	3.1	3.5	3.8	4.2	4.6
80	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.2	1.3	1.5	1.8	2.1	2.4	2.7	3.0	3.4	3.8	4.2	4.6	5.1
85	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.7	1.9	2.2	2.6	2.9	3.3	3.7	4.1	4.6	5.1	5.6
90	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.8	2.1	2.5	2.8	3.2	3.6	4.1	4.5	5.0	5.5	6.1
95	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.7	2.0	2.3	2.7	3.1	3.5	3.9	4.4	4.9	5.5	6.0	6.6
100	0.6	0.7	0.8	1.0	1.1	1.2	1.3	1.5	1.6	1.8	2.1	2.5	2.9	3.4	3.8	4.3	4.8	5.4	6.00	6.6	7.2
105	0.7	0.8	0.9	1.0	1.2	1.3	1.5	1.6	1.8	2.0	2.3	2.8	3.2	3.7	4.2	4.7	5.3	5.9	6.5	7.2	7.9
110	0.8	0.9	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.6	3.0	3.5	4.0	4.6	5.2	5.8	6.5	7.1	7.9	8.6
115	0.8	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.4	2.8	3.3	3.8	4.4	5.0	5.7	6.4	7.1	7.9	8.7	9.5
120	0.9	1.1	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	3.1	3.7	4.2	4.9	5.5	6.3	7.0	7.8	8.7	9.6	10.5

Table 26 - Turn Initiation Distances and Turn Radii for Fly-by Turns (25° AOB)

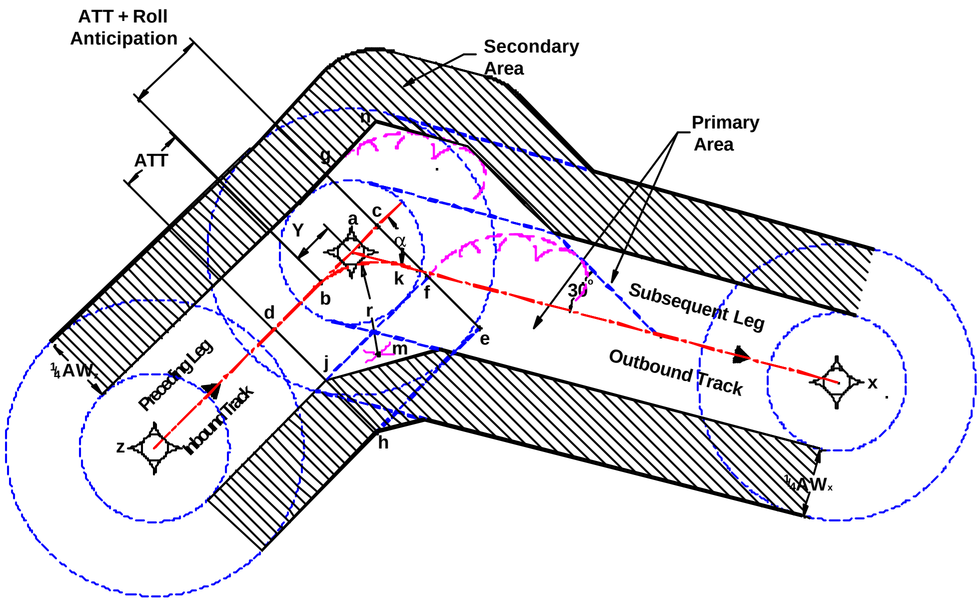

Figure 5 - Fly-by Transition Area (Track Angle Change£ 90°)

6.3.7.5 To construct the protection areas for a fly-by transition:

a) Draw a line representing the preceding leg track.

b) Locate point ‘a’ at the waypoint marking the point of transition. Locate point ‘z’ at the preceding waypoint.

c) Draw a second line through ‘a’ to subtend an angle ‘α‘ with the preceding leg track. This represents the subsequent leg track.

d) Locate point ‘x’ at the subsequent waypoint.

e) Draw circles of radius ½AW and ¼AW, appropriate to the minimum altitude and the navaid availability at each waypoint.[103]

f) Draw lines tangential to the circles and either side of the preceding and subsequent leg tracks. These represent the primary and secondary area edges outside of the transitional area.

g) Calculate the turn initiation distance ‘Y’ for the highest allowable/possible speed and altitude at ‘a’. Locate point ‘b’ at a distance ‘Y’, back from ‘a’, along the preceding leg track. This represents the nominal start of the turn.

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[103] For DME/DME navigation, the minimum usable altitude will determine the worst case maximum number of DME stations that can be used. It is assumed that, even at higher altitudes, the navigation performance of the RNAV system will be influenced by these stations and, hence, the ½AW value for the minimum altitude is applicable for all the usable altitudes at the waypoint.

h) Determine the minimum altitude at ‘b’, taking account of any applicable procedure design gradients, or descent gradients, associated with altitude limitations at the waypoints. Calculate the ATT at ‘a’ based upon the minimum altitude.[104]

i) Locate point ‘c’ beyond point ‘b’, on the preceding leg track, at a distance corresponding to the ATT at ‘a’, plus the distance appropriate to the assumed pilot delay and the maximum allowable/possible speed for the phase of flight and aircraft category. For turns greater than 90°, locate point ‘c’ on the preceding leg track, a distance from ‘a’ equal to the difference between the turn radius and the sum of the ATT and the distance corresponding to the pilot delay.[105] This is illustrated in Figure 6.

j) Locate point ‘d’ before point ‘b’, on the preceding leg track, at a distance corresponding to the ATT at ‘a’.

k) Draw lines ‘efcg’ and ‘hjd’, perpendicular to the preceding leg track, through points ‘c’ and ‘d’, to intersect the edges of the primary and secondary areas.

l) Locate ‘k’ at a distance, ‘Y’, along the subsequent leg track.

m) At points ‘b’ and ‘k’, draw arcs of distance ‘r’ to intersect at point ‘m’ inside the turn. (Where the track angle change is more than 90°, the outermost of the intersections should be used)

n) The point of intersection, ‘m’, represents the centre of the circle, of radius ‘r’, whose arc defines the nominal track during the transition.

o) Draw wind spirals from points ‘f’ and ‘g’ up to the point where the tangents become parallel to a line that intersects the subsequent leg track at an angle of 30°.[106]

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104 For DME/DME navigation, the ATT value increases with aircraft altitude to allow for the worst case assumption where the DME stations are at the maximum line of sight range. The lowest usable altitude will generally provide the best ATT value based upon closer stations. These stations will still be available to the aircraft at the higher altitudes and will be used by the RNAV systems if they provide the best solution, the additional stations that may become available at the higher altitudes should enhance the navigational accuracy and hence it should be safe to use the same ATT as for the lowest altitude.

105 This is necessary to accommodate slow aircraft.

106 $E = \frac{pwV}{137240 \tan f}$ Doc 8168 Vol. II Part III Attachment E

p) Draw a line from point ‘j’, at an angle of $\alpha/2°$ to the preceding track, to intercept the inner edge of the primary area on the subsequent track. Note that wind spirals are not used on the inside of the turn as it is assumed that the bank angle will be reduced during the turn to take account of any wind from outside the turn.

q) The outside edge of the inner secondary area is defined by a line drawn from ‘h’ parallel to the inner primary area edge.

r) Draw a line tangential to the wind spirals from ‘f’ and or ‘g’, whichever is furthest from the subsequent track, at an angle of 30° to the subsequent leg track, to intersect the ¼AW line on the outside of the subsequent leg. Draw tangents to the wind spirals, parallel to the subsequent leg track and the preceding leg primary area, to intersect at ‘n’.[107] This represents the outer edge of the primary area.

s) The outside edge of the outer secondary area is defined by a line drawn parallel to the outer edge of the primary area, offset by a distance equal to the outer secondary area width at the point of commencement of the wind spirals, until reaching the straight protection area of the next segment. Corners with acute angles should be defined by arcs centred on the corresponding corner of the outer edge of the primary area.

The containment areas for a fly-by transition are illustrated in Figure 5 and Figure 6.[108]

6.3.7.6 If the aircraft altitude at the fly-by transition is expected to be higher than FL190, the designer must take account of the likelihood of early turns by aircraft employing the ED75() high altitude turn criteria. Where such an early turn is unacceptable, this can be avoided by placing a waypoint on the nominal track about 8NM before the fly-by waypoint.

[107] This is to accommodate the problem caused by slow aircraft with a short turn anticipation distance and an ATT that extends beyond the waypoint.

[108] A fly-by transition is depicted in the navigation database as a TF/CF/DF leg up to point ‘a’, with the Overflight Flag ‘not set’, followed by any allowable leg type.

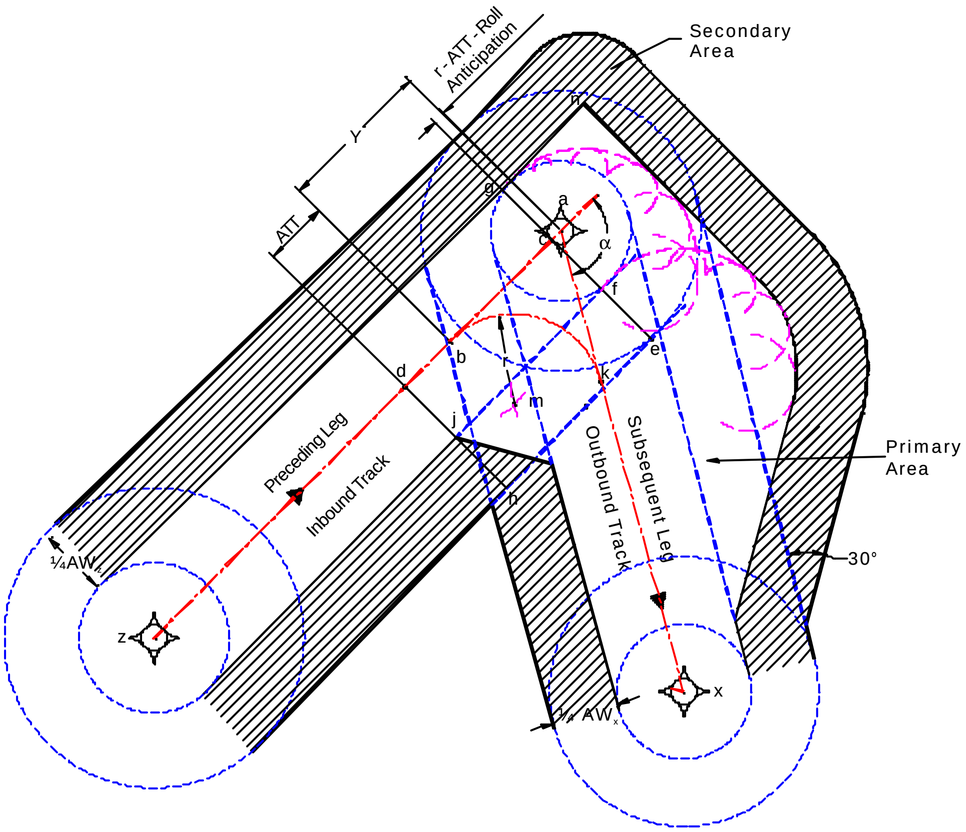


Figure 6 - Fly-by Transition Area (Track Angle Change > 90)

6.3.7.7 Where an altitude change is required at a waypoint, the K-K'-K'' line is defined by two lines:

a) K-K' is drawn perpendicular to the nominal track of the preceding leg at a distance equal to the ATT, back from the intersection between the nominal track and the angle bisector.

b) K'-K'' is drawn parallel to the angle bisector at a distance equal to the ATT.

If the K'-K'' line crosses the line 'djh', and an obstacle is located between the two lines, then it may be justifiable to disregard it[109].

[109] The aircraft system usually clears the altitude restriction when it thinks that it has reached the intersection of the angle bisector and the nominal track (half-way through the turn). If the XTE in the system is such that it places the aircraft on the inside edge of the area, the along track error should be minimal.

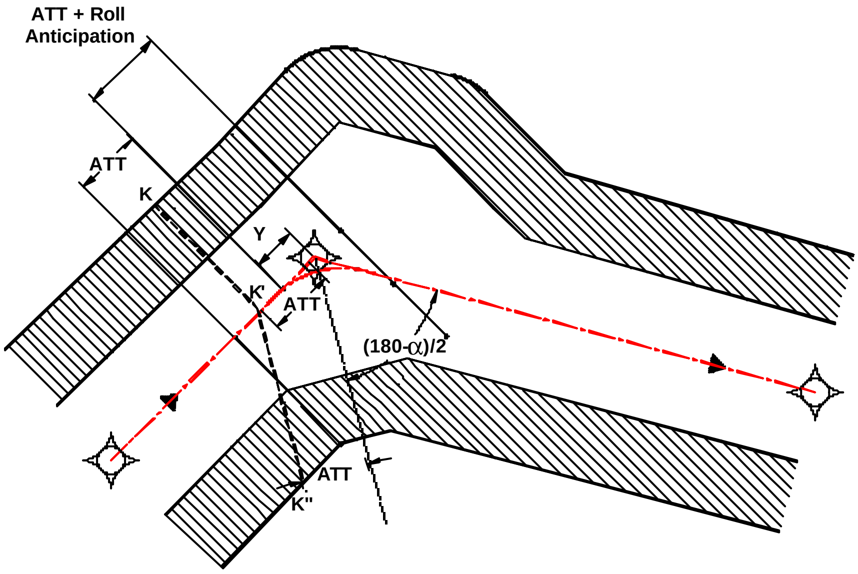


Figure 7 - K-K'-K" for Fly-by < 90

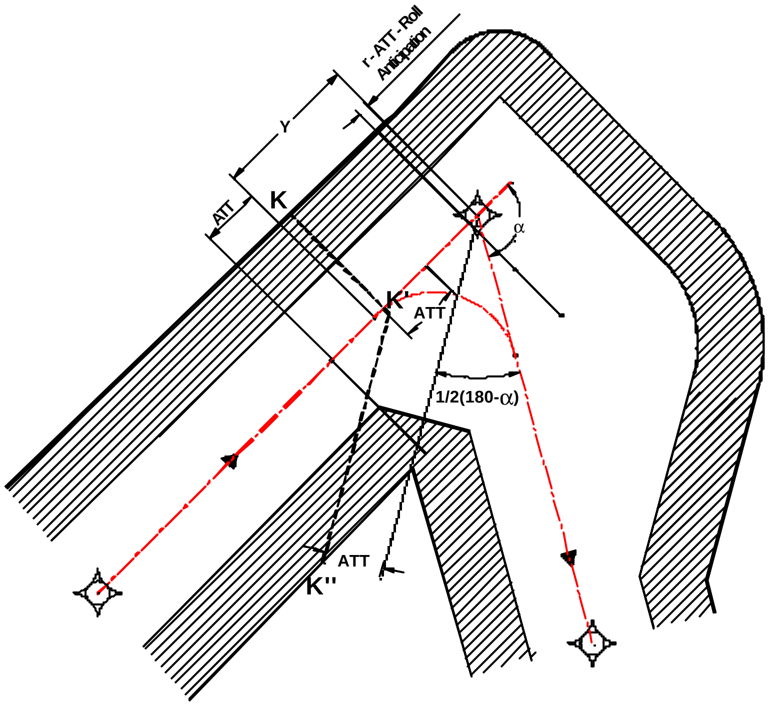


Figure 8 - K-K'-K" for Fly-by > 90

6.3.8 Fly-over Transitions

6.3.8.1 Fly-over transitions that involve course changes may only be used for terminal procedures and must be notified as such, by the issuing authority.

6.3.8.2 The fly-over transition is neither predictable nor repeatable. Furthermore, if the fly-over waypoint is located at a navaid, the navaid itself is unlikely to be used by the RNAV system for that part of the route. This is because the radius of the cone effect, or no update zone, associated with the navaid, may be greater than the XTT and ATT achieved by the RNAV system, using inputs from other DME stations. If there is a need to overfly a specific point, for example, in order to obtain appropriate obstacle clearance, this can often be achieved by establishing a fly-by waypoint at a distance greater than the turn anticipation distance plus the ATT, down-route from the critical point. In future, fixed radius transitions should make fly-over transitions with track angle changes redundant.

6.3.8.3 The fly-over protection area will always be significantly larger than fly-by or fixed radius protection areas for similar track angle changes. Moreover, the greater the track angle change, the greater will be the difference in size.

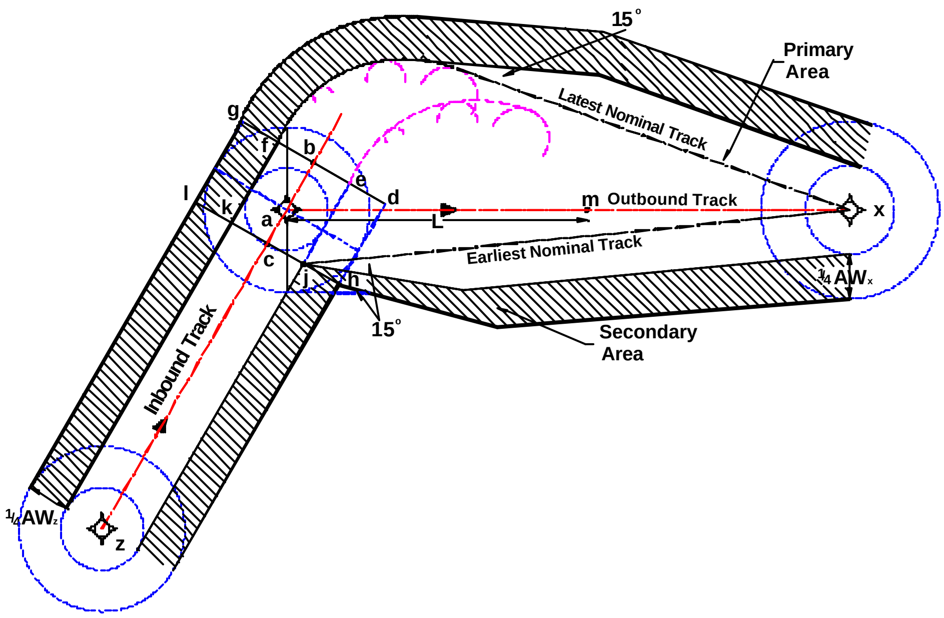


Figure 9 - Fly-over Transition Area - DF Path Terminator

6.3.8.4 To construct the protection area for a fly-over transition:

a) Draw a line representing the preceding leg track.

b) Locate point ‘a’ at the waypoint marking the point of transition. Locate point ‘z’ at the preceding waypoint.

c) Draw a second line through ‘a’ to subtend an angle ‘α‘ with the preceding leg track. This represents the subsequent leg track.

d) Draw circles of radius ½AW and ¼AW, appropriate to the minimum usable altitude and navaid availability at ‘a’ and ‘z’.

e) Draw lines tangential to the circles and either side of the preceding leg track. This represents the primary and secondary area edges of the preceding leg outside of the transitional area.

f) Determine the minimum altitude at ‘a’, taking account of any applicable procedure design gradients, or descent gradients, associated with altitude limitations at the waypoints. Calculate the ATT at ‘a’, based upon the minimum altitude.

g) Locate point ‘b’ beyond point ‘a’ on the extended track of the preceding leg, at a distance corresponding to the ATT at ‘a’, plus the roll anticipation distance, based upon the maximum allowable/possible speed at the waypoint for the phase of flight and aircraft category.

h) Locate point ‘c’ before point ‘a’, on the preceding leg, at a distance corresponding to the ATT at ‘a’.

i) Draw lines ‘debfg’ and ‘hjckl’, perpendicular to the preceding leg, through points ‘b’ and ‘c’, to intersect the edges of the primary and secondary areas.

j) The intercept track to the subsequent leg, after the initial turn, is assumed to be $\alpha/2$ or 30°, whichever is less. The different RNAV systems that are currently in service do not all apply the same logic to turns, and to fly-over turns in particular. Some perform regular updates during the turn, while others do not, and some employ a recovery turn of $\alpha/2$, while others follow an asymptotic path to recover the subsequent track. This means that the actual tracks, flown by different aircraft, can be very different.

k) Extract the appropriate minimum segment length, ‘L’, from Table 30, Table 31 or Table 32. These tables have been developed from data gathered during a series of trials conducted by the FAA and the DGAC using a number of different aircraft types. It is also possible to calculate the minimum segment length using one of the formulae detailed in the endnotes to this document.

l) Locate a point ‘m’, on the subsequent leg track, a distance ‘L’ from ’a’.

m) The next waypoint, ‘x’, may be located at any point from ‘m’ onwards.

n) Draw circles of radius $\frac{1}{2}AW_x$ and $\frac{1}{4}AW_x$, appropriate to the minimum usable altitude and navaid availability at ‘x’.

o) Draw lines tangential to the circles at ‘a’ and ‘x’ and either side of the subsequent leg track. This represents the primary and secondary area edges of the subsequent leg outside of the transitional area.

p) Draw wind spirals from points ‘e’ and ‘f’.

q) On the inside of the turn, the primary area edge of the subsequent leg track is defined as follows:

- If the line drawn tangentially to the ¼AW circles at ‘a’ and ‘x’ intersects the line ‘ej’, draw a line from ‘j’, at an angle of $\alpha/2°$ to the subsequent leg track, to intersect the tangent and join the two inner primary area edges.

- If the line drawn tangentially to the ¼AW circles at ‘a’ and ‘x’ intersects the inner primary area edge before the point ‘j’, draw a line from ‘k’ at an angle of 15° to the subsequent leg track, to intersect the tangent and join the two inner primary area edges. (This intersection may occur after the intersection of the inner primary area edges themselves, in which case the line from ‘k’ should be discarded)

- If the line drawn tangentially to the ¼AW circles at ‘a’ and ‘x’ passes through the point ‘j’, this represents the join between the two inner primary area edges.

r) The outside edge of the inner secondary area is defined by the line drawn tangentially to the ½AW circles at ‘a’ and ‘x’ and a line drawn from ‘h’, splayed at an angle of 15° to the subsequent leg track.

s) The leg after the fly-over waypoint may be designated as a DF, a TF or a CF leg.

i) The DF path terminator is usually used for departures as it allows a smoother turn and results in a slightly shorter track distance. However, it requires a greater protected area as the aircraft flies direct to the next waypoint, ’x’, once it has completed the initial turn. To provide appropriate protection:

- Draw the earliest nominal track from point 'j' to 'x', for turns <90°, or from point 'k' to 'x' for turns >90°;

- Draw the latest nominal track from 'x' tangentially to the wind spirals from ‘e’ and ‘f’;

- The inner edge of the outer secondary area is a line parallel to the latest nominal track and off-set by ¼AW_x and a line tangential to the wind spirals from ‘e’ or ‘f’ splayed at 15° from the latest nominal track;

- The inner edge of the inner secondary area is a line parallel to the earliest nominal track and off-set by ¼AW_x and a line drawn from 'j' or 'k' splayed at 15° from the earliest nominal track.

ii) The TF path terminator is usually used if it is necessary for the aircraft to regain the subsequent leg track as soon as possible after flying over the waypoint. The outer primary area edge is defined by a line drawn at an angle of 30° to the subsequent leg track and tangential to the wind spirals from ‘e’ and ‘f’.

iii) The CF path terminator may be used for transitions on the final approach segment to capture the ILS and for conditional transitions on departure where airspace constraints dictate. The outer primary area edge is defined by a line drawn at an angle of 30° to the subsequent required course and tangential to the wind spirals from ‘e’ and ‘f’.

t) The outer primary area edge around the rest of the turn is defined by the wind spirals and joining tangential lines, where necessary.

u) The outside edge of the outer secondary area is defined by a line drawn parallel to the outer edge of the primary area, offset by a distance equal to the outer secondary area width at the point of commencement of the wind spirals, until reaching the straight protection area of the next segment. Corners with acute angles should be defined by arcs centred on the corresponding corner of the outer edge of the primary area.

6.3.8.5 The containment area for fly-over transitions is illustrated in Figure 9 and Figure 10. Figure 9 has been drawn for a 60° turn with 15° AOB and a DF Path Terminator. Figure 10 has been drawn for a 60° turn with 25° AOB and a TF Path Terminator.[110]

[110] A fly-over transition is depicted in the navigation database as a TF leg up to point ‘a’, with the Overflight Flag ‘set’, followed by any allowable leg type to the next waypoint.

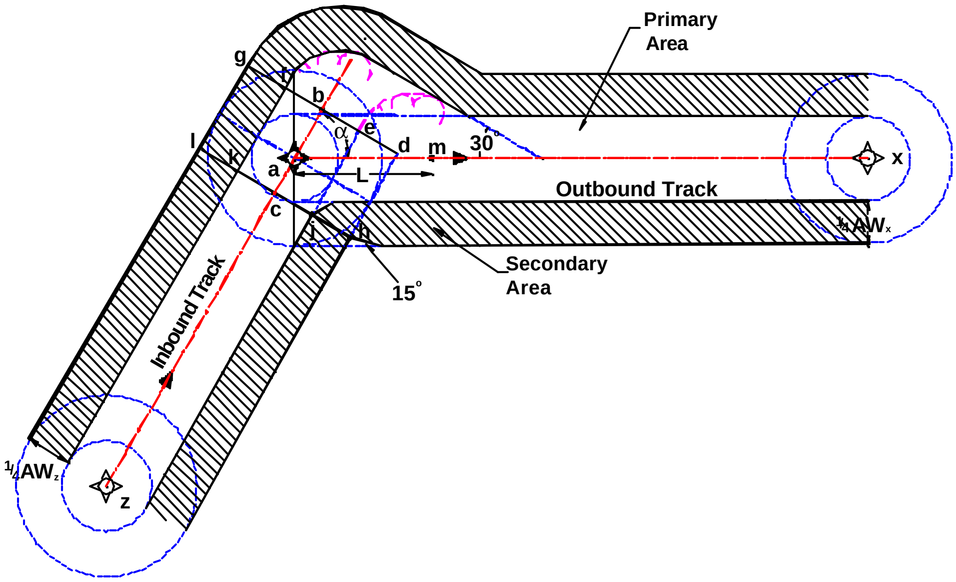


Figure 10 - Fly-over Transition Area - TF Path Terminator

6.3.9 RF Turn Transitions

6.3.9.1 When separation between parallel routes is required, where airspace conservation or track-keeping is critical, or where large angle track changes are required, the designer may wish to consider specifying a fixed radius turn.

6.3.9.2 RF turns in terminal airspace are described as transitions but are defined by a unique path terminator, RF, and are treated as separate legs. As a minimum an RF turn requires a start waypoint, a finish waypoint and a point defining the centre of the turn. The start point is always the end waypoint from the preceding leg. [111]

6.3.9.3 In defining the obstacle clearance area for RF turns, the OCP adopted a conservative approach and increased the area on the outside of the turn by a factor of 1.414 to protect against inadvertent unforeseen excursions[112], particularly under extreme weather conditions with small turn radii.

[111] A fixed radius transition is depicted in the navigation database as a TF leg up to the start waypoint, with the Overflight Flag 'not set', followed by an RF leg to the finish waypoint, with the Overflight Flag 'not set'.

[112] The aircraft has to start applying bank before it reaches the waypoint at the start of the turn, this means that it may not follow the nominal track exactly at this point. Moreover, the turn radius is based upon a bank angle value which is 5° greater than the maximum used for the phase of flight. The additional protection provided by the factor of 1.414 is considered to be more efficient than protection used by limiting the bank angle to the current maximum.

6.3.9.4 An aircraft flying a RF turn will have to vary the bank angle during the turn to compensate for wind effect and keep within the RNP. The radius of a RF turn is calculated using the formula:

$$r = \frac{(V+W)^2}{68626 \times \tan f}$$

Where

V = maximum TAS assumed for the transition (kts).
W = the wind effect for the appropriate altitude (kts).
ϕ = maximum bank angle for the altitude/phase of flight[113] plus 5°(degrees).

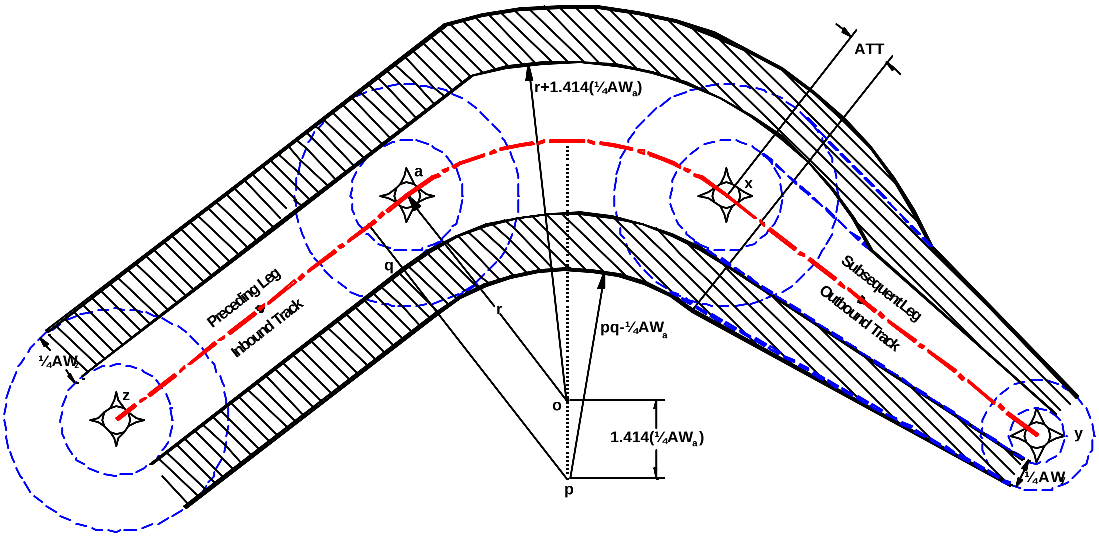


Figure 11 - RF Transition Area

6.3.9.5 To construct the protection areas for a RF transition:

a) Draw a line representing the preceding leg track.

b) Locate point ‘a’ at the waypoint marking the start of the fixed radius turn. Locate point ‘z’ at the preceding waypoint.

c) Determine the optimum radius for the planned speed and altitude using the formula in paragraph 6.3.9.4.

d) Locate the centre of the turn ‘o’ at a point a distance ‘r’ from ‘a’, perpendicular to the preceding leg track.[114]

[113] See paragraph 6.3.3.

[114] Alternatively, locate point ‘x’, draw the subsequent track and locate the centre of the turn ‘o’ at the intersection of the lines drawn from ‘a’ and ‘x’ perpendicular to the preceding and subsequent tracks respectively. Compare the distance ‘ao’ (or ‘xo’) with the optimum radius and determine whether any speed or altitude constraints are necessary. Note that turns with low angles of bank (less than 5°) are operationally unacceptable.

e) Draw an arc of radius ‘r’ through ‘a’. This represents the fixed radius leg track.

f) Locate point ‘x’ on the arc at the subsequent waypoint and point ‘y’ at the waypoint after that.

g) Draw circles of radius ½AW and ¼AW, appropriate to the RNP for the legs at ‘z’, ‘a’, ‘x’ and ‘y’. The RNP values at ‘a’ and ‘x’ should be same.

h) Draw lines tangential to the circles and either side of the preceding and subsequent leg tracks. These represent the preceding and subsequent primary and secondary area edges.

i) Draw a line through ‘o’ that bisects the angle ‘aox’.

j) On the outside of the turn, draw arcs, centred on ‘o’, of radii ‘r+1.414(¼AW_a)’ and ‘r+1.414(¼AW_a)+ ¼AW_a’ to intersect the preceding and subsequent primary and secondary area edges. Note that the preceding primary and secondary areas intersect the arcs beyond ‘a’ and not before ‘a’.

k) Locate a point ‘p’ on the bisector through ‘o’, a distance ‘1.414(¼AW_a)’ on the opposite side of ‘o’ from the turn.

l) Draw a line from ‘p’, perpendicular to the preceding track, to intersect the preceding inner primary area edge at ‘q’.

m) On the inside of the turn, draw arcs, centred on ‘p’, of ‘pq’ and ‘pq -¼AW_a’ to intersect the preceding and subsequent primary and secondary area edges. If the subsequent or preceding waypoints have lower RNP values, draw a line perpendicular to the appropriate leg track, at a distance corresponding to the ATT (RNP) for the turn. Draw the primary and secondary edges for the appropriate leg track from the points where the ATT line intersects the primary and secondary arcs inside the turn.

6.3.9.6 The containment areas for a fixed radius transition are illustrated in Figure 11.

6.3.10 Conditional Transitions

6.3.10.1 Where a turn at altitude is prescribed, the affected route legs cannot be defined, in such a way, that they are either predictable or repeatable. In order to specify the Obstacle Identification Surface (OIS) boundaries, the designer should calculate the earliest turning point, based upon the steepest anticipated climb gradient, and the latest turning point, based upon the PDG. Obstacle clearance areas should be constructed for both turning point limits, in accordance with the fly-over transition criteria, detailed in paragraph 6.3.7.7, with the ATT value set to zero. The OIS for the turn comprise an amalgam of all the lowest surfaces defined for the two waypoints.

6.3.10.2 Conditional transitions, after the initial leg of a departure procedure, are already addressed in Doc 8168, Vol 2 Part II, Chapter 7, Paragraph 7.4.4. The described methodology is specific to initial leg transitions but produces very similar obstacle clearance areas to the generic method described in paragraphs 6.3.10.1 and 0.

6.4 GROUND RULES FOR CONVERGING PROTECTED AREAS

6.4.1 Converging protected areas can often pose problems for designers. This section is intended to highlight some of the ground rules that should be applied. This is not an exhaustive list of such occasions and it will probably grow with successive editions of this document.

a) Converging protected areas should reach the straight leg protection value before commencing a fly-over or fixed radius turn.

b) If protected areas converge to a waypoint and the latest limit of the turn initiation area occurs after the waypoint, the protected areas must retain the width associated with the waypoint until the latest limit of the turn initiation area.

c) If protected areas converge beyond the FAF, the additional protected areas should at least be considered to protect against aircraft overshooting the turn when determining the MOCA for the intermediate segment.

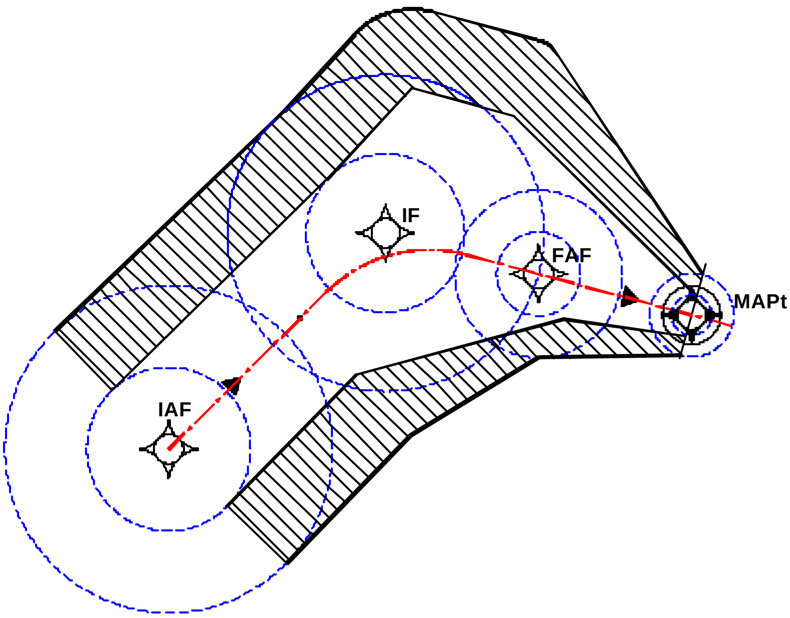


Figure 12 - Converging Protected Areas

d) Areas that converge after a fixed radius turn should start on the inside of the turn from the point where a line corresponding to the ATT for the turn intersects the inner arcs of the primary and secondary areas.

6.4.2 When connecting the outer edge of the turn protection area to the subsequent straight protection area, two cases can occur:

a) When the outer edge of the turn protection area is inside the subsequent straight protection area, the connecting line should be splayed at 15° to the subsequent nominal track.

b) When the outer edge of the turn protection area is outside the subsequent straight protection area, the connecting line should converge at 30° to the subsequent nominal track.

6.5 MINIMUM DISTANCES

6.5.1 Each leg must be long enough to allow the aircraft to stabilise after the first turn before commencing the next. The minimum distance between waypoints is determined by the intercept angle with the previous leg and the type of transition at each end of the leg. However, it is unwise to have consecutive legs of minimum length, as certain RNAV systems define an optimised course, which may contravene the obstacle clearance area boundaries. Moreover, the designer should note that some RNAV systems will not accept leg distances which are less than 2NM, regardless of the turn logic.

6.5.1.1 Fly-by to Fly-by

The minimum leg length for fly-by to fly-by legs is also determined by the direction of the second turn:

a) If the second turn is in the opposite direction to the first turn, then the minimum leg length is the sum of the turn anticipation distances and the roll anticipation distances for the first and second turn. This is illustrated in Figure 13.

Values for the sum of the turn initiation distance and a 5 second roll-in/roll-out distance[115], for different TAS values and different angles of bank, are provided in Table 27, Table 28 and Table 29. The value may also be calculated using the following formula:

Min leg length = (Turn Initiation dist)$_1$+(Roll-out dist)$_1$+(Turn Initiation dist)$_2$+(Roll-in dist)$_2$

$$MinLegLength = r \times \tan(0.5 \times a_1) + \left(\frac{\left(Pilot\ /\ SystemDelay + f/_{3or5} \right)(V + W)}{3600} \right) + r \times \tan(0.5 \times a_2) + \left(\frac{\left(Pilot\ /\ SystemDelay + f/_{3or5} \right)(V + W)}{3600} \right)$$

[115] The tables in amendment 10 to Doc 8168 are based upon a 5 second roll-in/roll-out time. Using the assumptions in this guidance material, the roll-in/roll-out time could range from 6 seconds to 11 seconds depending on the mode of operation and the AOB. This represents a 0.2 NM difference, at 130 kts, rising to a 0.8 NM difference, at 440 kts.

Where:
r = Radius of turn
α_1 = First turn track angle change
α_2 = Second turn track angle change

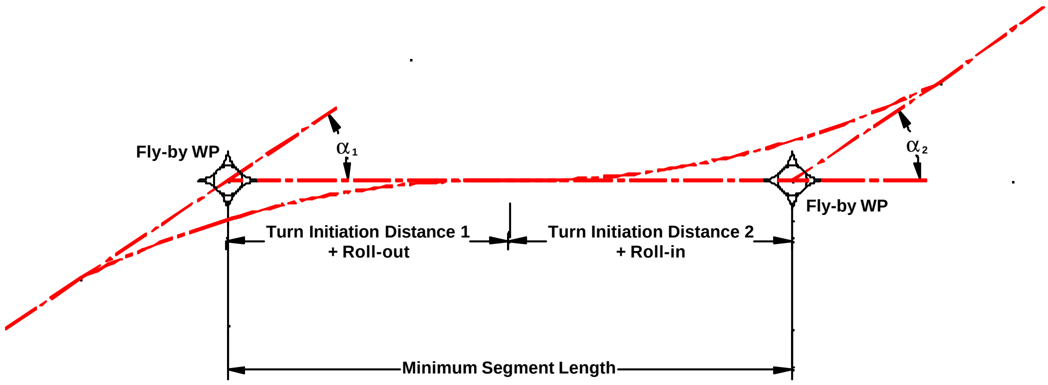


Figure 13 - Minimum Segment Length - Fly-by to Fly-by (Opposite directions)

b) If both turns are in the same direction, it could be argued that the minimum leg may be reduced by the roll-out distance for the first turn and the roll-in distance for the second turn. This is illustrated in Figure 14.

The designer should however note that experience has shown that some systems treat each turn separately and require the aircraft to stabilise between turns - in such a case the minimum turn distance must continue to make allowances for roll-out and roll-in.

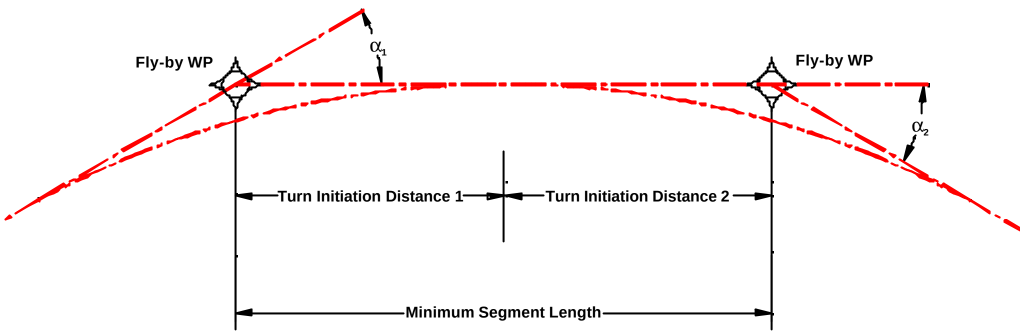


Figure 14 - Minimum Segment Length - Fly-by to Fly-by (Same direction)

TAS (kts) V	130	140	150	160	170	180	190	200	210	220	240	260	280	300	320	340	360	380	400	420	440
Track Angle Change a	**Minimum Stabilization Distance (NM)**																				
£50	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.8	2.1	2.4	2.7	3.0	3.4	3.8	4.2	4.6	5.1	5.5
55	0.7	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.7	2.0	2.3	2.6	3.0	3.3	3.7	4.2	4.6	5.1	5.6	6.1
60	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.7	1.8	2.1	2.5	2.9	3.2	3.7	4.1	4.6	5.1	5.6	6.1	6.7
65	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.3	2.7	3.1	3.5	4.0	4.5	5.0	5.5	6.1	6.7	7.3
70	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.8	2.0	2.1	2.5	2.9	3.4	3.8	4.3	4.9	5.4	6.0	6.6	7.3	8.0
75	0.9	1.0	1.1	1.3	1.4	1.6	1.8	1.9	2.1	2.3	2.7	3.2	3.7	4.2	4.7	5.3	5.9	6.6	7.2	7.9	8.7
80	1.0	1.1	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.5	3.0	3.4	4.0	4.5	5.1	5.7	6.4	7.1	7.9	8.6	9.4
85	1.0	1.2	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	3.2	3.7	4.3	4.9	5.5	6.2	7.0	7.7	8.5	9.4	10.3
90	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.5	2.7	2.9	3.5	4.0	4.7	5.3	6.0	6.8	7.5	8.4	9.3	10.2	11.1
95	1.2	1.4	1.5	1.7	2.0	2.2	2.4	2.7	2.9	3.2	3.8	4.4	5.0	5.8	6.5	7.3	8.2	9.1	10.1	11.1	12.1
100	1.3	1.5	1.7	1.9	2.1	2.4	2.6	2.9	3.2	3.4	4.1	4.7	5.5	6.3	7.1	8.0	8.9	9.9	10.9	12.0	13.2
105	1.4	1.6	1.8	2.0	2.3	2.5	2.8	3.1	3.4	3.7	4.4	5.2	5.9	6.8	7.7	8.7	9.7	10.8	11.9	13.1	14.3
110	1.5	1.7	2.0	2.2	2.5	2.8	3.1	3.4	3.7	4.1	4.8	5.6	6.5	7.4	8.4	9.5	10.6	11.7	13.0	14.3	15.6
115	1.6	1.9	2.1	2.4	2.7	3.0	3.3	3.7	4.1	4.4	5.3	6.1	7.1	8.1	9.2	10.3	11.6	12.9	14.2	15.6	17.1
120	1.8	2.0	2.3	2.6	3.0	3.3	3.7	4.0	4.4	4.9	5.8	6.7	7.8	8.9	10.1	11.4	12.7	14.1	15.6	17.2	18.8

Table 27 - Minimum Segment Lengths (5 second roll-in/out) for Fly-by Transitions (15° AOB)

TAS (kts) V	130	140	150	160	170	180	190	200	210	220	240	260	280	300	320	340	360	380	400	420	440
Track Angle Change a	**Minimum Stabilization Distance (NM)**																				
£50	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.2	1.4	1.6	1.9	2.1	2.4	2.6	2.9	3.2	3.5	3.9	4.2
55	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.8	2.0	2.3	2.6	2.9	3.2	3.5	3.9	4.3	4.6
60	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.7	1.9	2.2	2.5	2.8	3.1	3.5	3.9	4.3	4.7	5.1
65	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.8	2.1	2.4	2.7	3.1	3.4	3.8	4.2	4.6	5.1	5.5
70	0.7	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.5	1.7	1.9	2.3	2.6	2.9	3.3	3.7	4.1	4.6	5.0	5.5	6.0
75	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.6	1.8	2.1	2.4	2.8	3.2	3.6	4.0	4.5	5.0	5.5	6.0	6.6
80	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.8	1.9	2.3	2.6	3.0	3.4	3.9	4.4	4.9	5.4	5.9	6.5	7.1
85	0.8	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.9	2.1	2.4	2.8	3.3	3.7	4.2	4.7	5.3	5.8	6.4	7.1	7.7
90	0.9	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.2	2.6	3.1	3.5	4.0	4.5	5.1	5.7	6.3	7.0	7.6	8.4
95	0.9	1.1	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.4	2.9	3.3	3.8	4.3	4.9	5.5	6.2	6.8	7.5	8.3	9.1
100	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.2	2.4	2.6	3.1	3.6	4.1	4.7	5.3	6.0	6.7	7.4	8.2	9.0	9.8
105	1.1	1.2	1.4	1.6	1.7	1.9	2.1	2.4	2.6	2.8	3.3	3.9	4.5	5.1	5.8	6.5	7.3	8.1	8.9	9.8	10.7
110	1.2	1.3	1.5	1.7	1.9	2.1	2.3	2.6	2.8	3.1	3.6	4.2	4.9	5.6	6.3	7.1	7.9	8.8	9.7	10.7	11.7
115	1.3	1.4	1.6	1.8	2.1	2.3	2.5	2.8	3.1	3.3	4.0	4.6	5.3	6.1	6.9	7.7	8.6	9.6	10.6	11.7	12.8
120	1.4	1.6	1.8	2.0	2.2	2.5	2.8	3.1	3.3	3.7	4.3	5.0	5.8	6.7	7.5	8.5	9.5	10.5	11.7	12.8	14.0

Table 28- Minimum Segment Lengths (5 second roll-in/out) for Fly-by Transitions (20° AOB)

TAS (kts) V	130	140	150	160	170	180	190	200	210	220	240	260	280	300	320	340	360	380	400	420	440
Track Angle Change a	**Minimum Stabilization Distance (NM)**																				
£50	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1.0	1.2	1.3	1.5	1.7	1.9	2.2	2.4	2.6	2.9	3.2	3.4
55	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1.0	1.1	1.3	1.5	1.7	1.9	2.1	2.4	2.6	2.9	3.2	3.5	3.8
60	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.4	1.6	1.8	2.0	2.3	2.6	2.8	3.1	3.4	3.8	4.1
65	0.6	0.7	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.1	4.5
70	0.7	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.1	2.4	2.7	3.0	3.3	3.7	4.1	4.4	4.8
75	0.7	0.8	0.8	0.9	0.9	1.0	1.1	1.2	1.3	1.5	1.7	2.0	2.3	2.6	2.9	3.2	3.6	4.0	4.4	4.8	5.3
80	0.8	0.8	0.9	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.1	2.4	2.8	3.1	3.5	3.9	4.3	4.8	5.2	5.7
85	0.8	0.9	0.9	1.0	1.1	1.2	1.3	1.4	1.6	1.7	2.0	2.3	2.6	3.0	3.4	3.8	4.2	4.7	5.1	5.6	6.2
90	0.9	0.9	1.0	1.1	1.1	1.3	1.4	1.5	1.7	1.8	2.1	2.5	2.8	3.2	3.6	4.1	4.6	5.0	5.6	6.1	6.7
95	0.9	1.0	1.1	1.1	1.2	1.4	1.5	1.6	1.8	2.0	2.3	2.7	3.1	3.5	3.9	4.4	4.9	5.5	6.0	6.6	7.2
100	1.0	1.1	1.2	1.2	1.3	1.5	1.6	1.8	1.9	2.1	2.5	2.9	3.3	3.8	4.3	4.8	5.3	5.9	6.5	7.2	7.8
105	1.1	1.2	1.2	1.3	1.4	1.6	1.7	1.9	2.1	2.3	2.7	3.1	3.6	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.5
110	1.2	1.3	1.3	1.4	1.5	1.7	1.9	2.1	2.3	2.5	2.9	3.4	3.9	4.4	5.0	5.6	6.3	7.0	7.7	8.5	9.3
115	1.3	1.4	1.5	1.6	1.7	1.8	2.0	2.2	2.5	2.7	3.2	3.7	4.2	4.8	5.5	6.1	6.9	7.6	8.4	9.2	10.1
120	1.4	1.5	1.6	1.7	1.8	2.0	2.2	2.4	2.7	2.9	3.5	4.0	4.6	5.3	6.0	6.7	7.5	8.3	9.2	10.1	11.1

Table 29 - Minimum Segment Lengths (5 second roll-in/out) for Fly-by Transitions (25° AOB)

6.5.1.2 Fly-by to Fly-over/Fixed Radius

The minimum leg length for fly-by to fly-over, or fixed radius, legs is determined by the turn anticipation distance of the first turn. This is illustrated in Figure 15. The designer should also ensure that the protected area converges to the straight leg value before the following waypoint.

Values for the sum of the turn initiation distance and a 5 second roll-in/roll-out distance, for different TAS values and different angles of bank, are provided in Table 27, Table 28 or Table 29.

The minimum segment length value may also be calculated using the following formula:

Min leg length = (Turn Initiation dist)$_1$+(Roll-out dist)$_1$

$$MinLegLength = r \times \tan(0.5 \times \alpha_1) + \left(\frac{\left(Pilot\ /\ SystemDelay + f/_{3 or 5} \right)(V + W)}{3600} \right)$$

Where:
r = Radius of turn
α_1 = First turn track angle change

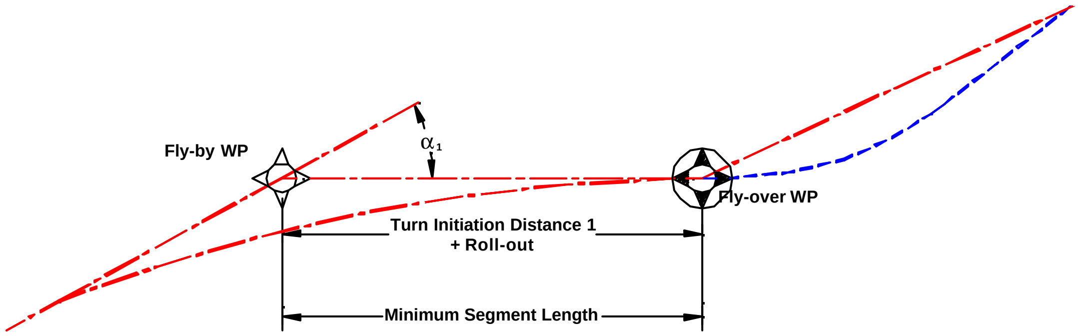


Figure 15 - Minimum Segment Length - Fly-by to Fly-over

6.5.1.3 Fly-over to Fly-over/Fixed Radius

The minimum leg length for fly-over to fly-over, or fixed radius, legs is determined only by the minimum turn distance of the first turn. (There is no minimum leg length for fixed radius to fly-over legs.) This is illustrated in Figure 16.

Min leg length = (Minimum Segment Length)$_1$

This may be extracted from Table 30, Table 31 or Table 32, or it may be calculated using the ICAO or General Purpose formulae:

ICAO formula: $L = r_1 \sin\alpha + r_1 \cos\alpha \tan 30 + r_1 \left(\frac{1}{\sin 30} - \frac{2\cos\alpha}{\sin 60} \right) + r_2 \tan 15 + \frac{10V}{3600}$

GP formula: $L = r_1 \sin a + r_1 \cos a \tan b + r_1 \left(\dfrac{1 - \cos a / \cos b}{\sin b} \right) + r_2 \tan\left(\dfrac{b}{2}\right) + a_1 + a_2$

Where
α = First turn track angle change
β or 30° = Recovery turn

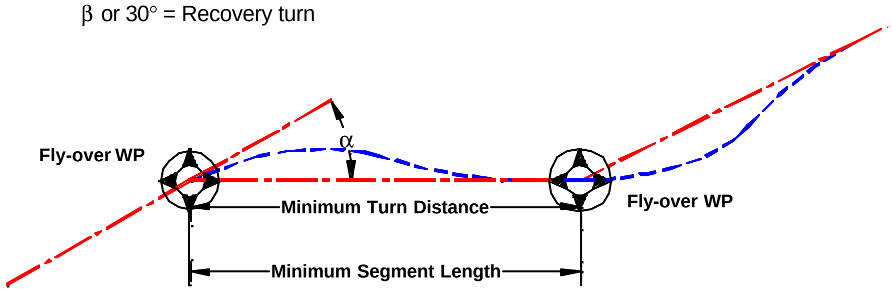


Figure 16 - Minimum Segment Length - Fly-over to Fly-over

6.5.1.4 Fly-over to Fly-by

The minimum leg length for fly-over to fly-by legs is determined only by the minimum turn distance of the first turn and the turn anticipation distance for the second turn. This is illustrated in Figure 17.

Min leg length = (Minimum Segment Length)$_1$+(Turn Initiation dist)$_2$+(Roll-in dist)$_2$

This may be extracted from Table 30, Table 31 or Table 32, and Table 27, Table 28 or Table 29, or it may be calculated using one of the following formulae:

$$L = r_1 \sin a_1 + r_1 \cos a_1 \tan 30 + r_1\left(\frac{1}{\sin 30} - \frac{2\cos a_1}{\sin 60} \right) + r_2 \tan 15 + \frac{10V}{3600} + r_3 \tan(0.5 \times a_2) + \left(\frac{\left(Pilot / SystemDelay + f/3or5\right)(V+W)}{3600} \right)$$

$$L = r_1 \sin a_1 + r_1 \cos a_1 \tan b + r_1 \left(\frac{1 - \cos a_1 / \cos b}{\sin b} \right) + r_2 \tan\left(\frac{b}{2}\right) + a_1 + a_2 + r_3 \tan(0.5 \times a_2) + \left(\frac{\left(Pilot / SystemDelay + f/3or5\right)(V+W)}{3600} \right)$$

Where
r_3 = Radius of the second turn.
α_1 = First turn track angle change
α_2 = Second turn track angle change

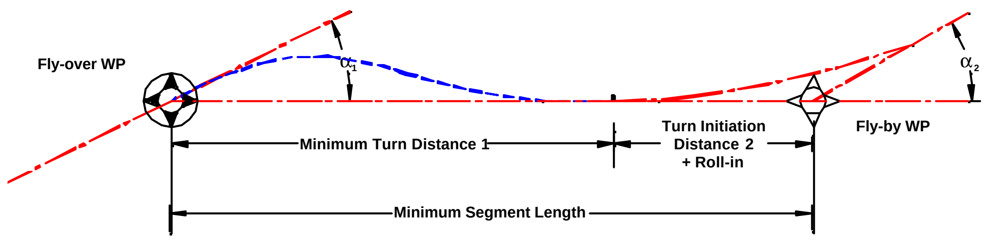


Figure 17 - Minimum Segment Length - Fly-over to Fly-by

Track Angle Change	TAS (kts)														
a	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**240**	**260**	**280**	**300**	**340**
£50	2.1	2.4	2.8	3.1	3.5	3.9	4.3	4.7	5.2	5.7	6.7	7.8	9.0	10.2	13.0
55	2.3	2.6	3.0	3.4	3.8	4.2	4.6	5.1	5.6	6.1	7.2	8.4	9.7	11.1	14.1
60	2.4	2.8	3.2	3.6	4.0	4.5	5.0	5.5	6.0	6.6	7.8	9.1	10.4	11.9	15.2
65	2.6	3.0	3.4	3.8	4.3	4.8	5.3	5.9	6.4	7.0	8.3	9.7	11.2	12.8	16.3
70	2.8	3.2	3.6	4.1	4.6	5.1	5.7	6.2	6.9	7.5	8.9	10.3	11.9	13.6	17.4
75	2.9	3.4	3.8	4.3	4.8	5.4	6.0	6.6	7.3	7.9	9.4	11.0	12.7	14.5	18.5
80	3.1	3.5	4.0	4.6	5.1	5.7	6.3	7.0	7.7	8.4	9.9	11.6	13.4	15.3	19.5
85	3.2	3.7	4.2	4.8	5.4	6.0	6.6	7.3	8.0	8.8	10.4	12.2	14.1	16.1	20.5
90	3.4	3.9	4.4	5.0	5.6	6.3	6.9	7.7	8.4	9.2	10.9	12.7	14.7	16.8	21.5
95	3.5	4.0	4.6	5.2	5.8	6.5	7.2	8.0	8.8	9.6	11.4	13.3	15.3	17.5	22.4
100	3.6	4.2	4.8	5.4	6.1	6.8	7.5	8.3	9.1	10.0	11.8	13.8	15.9	18.2	23.3
105	3.7	4.3	4.9	5.6	6.3	7.0	7.8	8.6	9.4	10.3	12.2	14.3	16.5	18.9	24.1
110	3.9	4.4	5.1	5.7	6.4	7.2	8.0	8.8	9.7	10.6	12.6	14.7	17.0	19.4	24.8
115	4.0	4.6	5.2	5.9	6.6	7.4	8.2	9.1	10.0	10.9	12.9	15.1	17.4	20.0	25.5
120	4.0	4.7	5.3	6.0	6.8	7.5	8.4	9.3	10.2	11.1	13.2	15.4	17.8	20.4	26.1

Table 30 - Minimum Segment Lengths for Fly-over Transitions (15° AOB)

Track Angle Change a	TAS (kts)														
	130	140	150	160	170	180	190	200	210	220	240	260	280	300	340
£50	1.7	2.0	2.2	2.5	2.8	3.1	3.4	3.8	4.1	4.5	5.3	6.2	7.1	8.1	10.3
55	1.9	2.1	2.4	2.7	3.0	3.3	3.7	4.1	4.4	4.9	5.7	6.6	7.6	8.7	11.1
60	2.0	2.2	2.5	2.9	3.2	3.6	3.9	4.3	4.8	5.2	6.1	7.1	8.2	9.3	11.9
65	2.1	2.4	2.7	3.0	3.4	3.8	4.2	4.6	5.1	5.5	6.5	7.6	8.7	10.0	12.7
70	2.2	2.5	2.9	3.2	3.6	4.0	4.4	4.9	5.4	5.9	6.9	8.1	9.3	10.6	13.5
75	2.3	2.6	3.0	3.4	3.8	4.2	4.7	5.2	5.7	6.2	7.3	8.5	9.8	11.2	14.3
80	2.5	2.8	3.2	3.6	4.0	4.5	4.9	5.4	6.0	6.5	7.7	9.0	10.3	11.8	15.1
85	2.6	2.9	3.3	3.7	4.2	4.7	5.2	5.7	6.2	6.8	8.1	9.4	10.9	12.4	15.8
90	2.7	3.0	3.4	3.9	4.4	4.9	5.4	5.9	6.5	7.1	8.4	9.8	11.3	13.0	16.5
95	2.8	3.1	3.6	4.0	4.5	5.1	5.6	6.2	6.8	7.4	8.8	10.2	11.8	13.5	17.2
100	2.9	3.3	3.7	4.2	4.7	5.2	5.8	6.4	7.0	7.7	9.1	10.6	12.2	14.0	17.8
105	3.0	3.4	3.8	4.3	4.8	5.4	6.0	6.6	7.3	7.9	9.4	10.9	12.6	14.4	18.4
110	3.0	3.4	3.9	4.4	5.0	5.6	6.2	6.8	7.5	8.2	9.7	11.3	13.0	14.9	19.0
115	3.1	3.5	4.0	4.5	5.1	5.7	6.3	7.0	7.7	8.4	9.9	11.6	13.3	15.3	19.5
120	3.2	3.6	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.5	10.1	11.8	13.6	15.6	19.9

Table 31- Minimum Segment Lengths for Fly-over Transitions (20° AOB)

Track Angle Change a	**TAS (kts)**														
	130	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**240**	**260**	**280**	**300**	**340**
£**50**	1.7	1.9	2.1	2.2	2.4	2.6	2.9	3.2	3.5	3.8	4.5	5.2	6.0	6.8	8.6
55	1.9	2.0	2.2	2.4	2.5	2.8	3.1	3.4	3.7	4.1	4.8	5.6	6.4	7.3	9.2
60	2.0	2.2	2.3	2.5	2.7	3.0	3.3	3.6	4.0	4.3	5.1	5.9	6.8	7.8	9.9
65	2.1	2.3	2.5	2.7	2.9	3.2	3.5	3.9	4.2	4.6	5.4	6.3	7.2	8.3	10.5
70	2.2	2.4	2.6	2.8	3.0	3.3	3.7	4.1	4.5	4.9	5.7	6.7	7.7	8.7	11.1
75	2.3	2.5	2.7	3.0	3.2	3.5	3.9	4.3	4.7	5.1	6.0	7.0	8.1	9.2	11.7
80	2.5	2.7	2.9	3.1	3.3	3.7	4.1	4.5	4.9	5.4	6.3	7.4	8.5	9.7	12.3
85	2.6	2.8	3.0	3.2	3.5	3.9	4.3	4.7	5.1	5.6	6.6	7.7	8.9	10.1	12.9
90	2.7	2.9	3.1	3.4	3.6	4.0	4.4	4.9	5.4	5.9	6.9	8.0	9.3	10.6	13.5
95	2.8	3.0	3.2	3.5	3.7	4.2	4.6	5.1	5.6	6.1	7.2	8.4	9.6	11.0	14.0
100	2.9	3.1	3.4	3.6	3.9	4.3	4.8	5.2	5.8	6.3	7.4	8.6	10.0	11.4	14.5
105	3.0	3.2	3.5	3.7	4.0	4.4	4.9	5.4	5.9	6.5	7.7	8.9	10.3	11.7	15.0
110	3.0	3.3	3.6	3.8	4.1	4.5	5.0	5.6	6.1	6.7	7.9	9.2	10.6	12.1	15.4
115	3.1	3.4	3.6	3.9	4.2	4.7	5.2	5.7	6.2	6.8	8.1	9.4	10.8	12.4	15.8
120	3.2	3.4	3.7	4.0	4.3	4.8	5.3	5.8	6.4	7.0	8.2	9.6	11.1	12.6	16.1

Table 32- Minimum Segment Lengths for Fly-over Transitions (25° AOB)

6.5.1.5 Fixed Radius to Fly-by

The minimum leg length for fixed radius to fly-by legs is determined only by the turn anticipation distance for the second turn. This is illustrated in Figure 18.

Min leg length = (Turn Initiation dist)$_2$+(Roll-in dist)$_2$

This may be extracted from Table 27, Table 28 or Table 29, or it may be calculated using the following formula:

$$MinLegLength = r \times \tan(0.5 \times a_2) + \left(\frac{\left(Pilot\,/\,SystemDelay + f\!\!\big/_{3 or 5} \right)(V + W)}{3600} \right)$$

Where:
r = Radius of second turn.
α_2 = Second turn track angle change

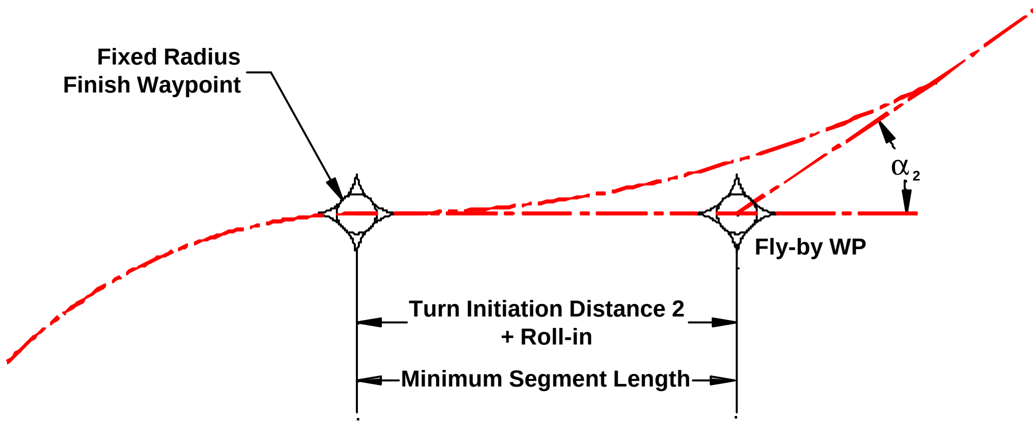


Figure 18 - Minimum Segment Length - Fixed Radius to Fly-by

6.5.1.6 Minimum Distances for B-RNAV Procedures

Where B-RNAV criteria are used in SIDs and STARs, the designer must also take account of the minimum distance between waypoints. Moreover, although the ATT is not applied in the calculation of minimum turn distances for P-RNAV procedures, it must be taken into account for B-RNAV. When fly-by waypoints are used on B-RNAV routes the minimum turn distance is calculated by adding 5NM to the sum of the turn anticipation distances and the roll anticipation distances for the first and second turn, extracted from Table 27, Table 28 or Table 29.[116]

[116] Normally ATT is not used to calculate nominal tracks but in this case the ATT is of a similar order of size to the turn expansion associated with the obstacle clearance calculations.

6.6 NOMINAL TRACK DISTANCES

6.6.1 The calculation of the actual gradients associated with arrival, approach and departure legs should be based upon the shortest possible track distance. The fastest aircraft speed should be used to calculate the shortest track distance for fly-by transitions and the slowest aircraft speed should be used to calculate the shortest track distance for fly-over transitions.

6.6.1.1 Fly-by to Fly-by

The shortest track distance between two fly-by waypoints is calculated as follows:

$$TrackDist = Legdist - (Y_a + Y_b) + \frac{r_a \pi \alpha_a + r_b \pi \alpha_b}{360}$$

Where

Legdist = Geodesic distance between waypoints 'a' and 'b'.
Y_a = Turn initiation distance at waypoint 'a' for the fastest aircraft
Y_b = Turn initiation distance at waypoint 'b' for the fastest aircraft
r_a = Radius of turn for the fastest aircraft at waypoint 'a'
r_b = Radius of turn for the fastest aircraft at waypoint 'b'
α_a = Track angle change (degrees) at waypoint 'a'
α_b = Track angle change (degrees) at waypoint 'b'

This is illustrated in Figure 19.

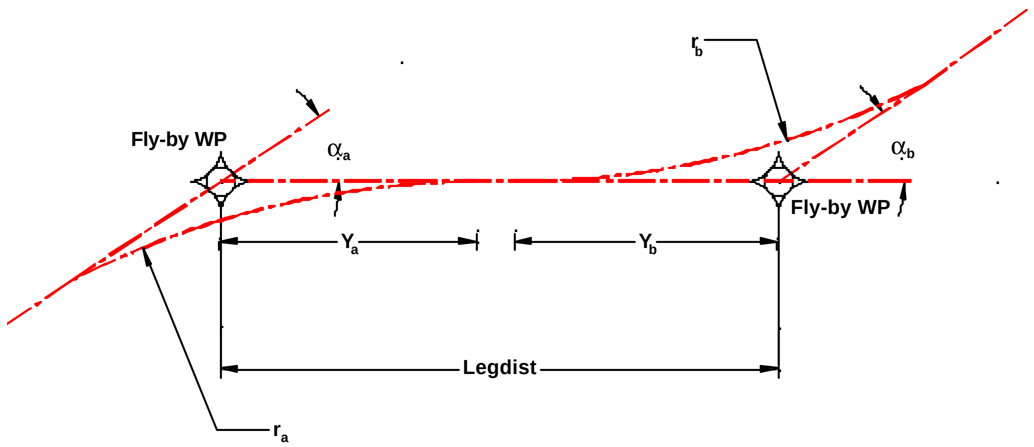


Figure 19 - Nominal Track Distance - Fly-by to Fly-by

6.6.1.2 Fly-by to Fly-over/Fixed Radius

The shortest track distance between a fly-by waypoint and a fly-over/initial fixed radius waypoint is calculated as follows:

$$TrackDist = Legdist - Y_a + \frac{r_a \pi \alpha_a}{360}$$

Where

Legdist = Geodesic distance between waypoints 'a' and 'b'.
Y_a = Turn initiation distance at waypoint 'a' for the fastest aircraft
r_a = Radius of turn for the fastest aircraft at waypoint 'a'
α_a = Track angle change (degrees) at waypoint 'a'

This is illustrated in Figure 20.

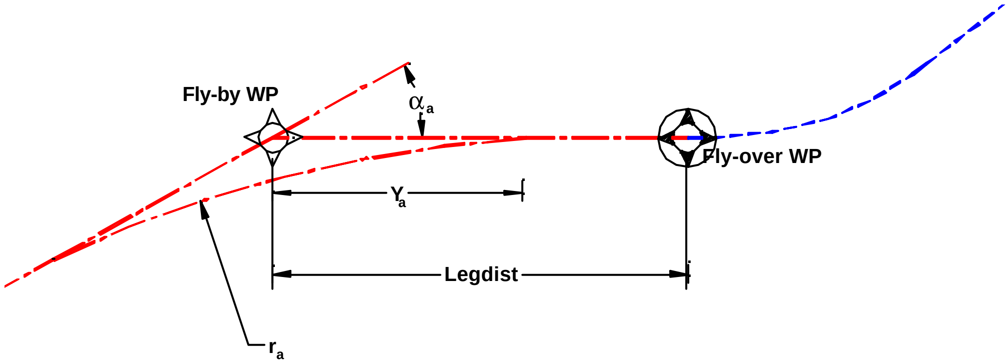


Figure 20 - Nominal Track Distance - Fly-by to Fly-over

6.6.1.3 Fly-over to Fly-over/Fixed Radius

The calculation of the shortest track distance between a fly-over waypoint and another fly-over/initial fixed radius waypoint is also based upon the application of a DF path terminator as follows:

$$TrackDist = \frac{r_{a1}\pi\alpha_a}{360} + \sqrt{\left(r_{a1}(1-\cos\alpha_a)\right)^2 + \left(Legdist - r_{a1}\sin\alpha_a\right)^2}$$

Where

Legdist = Geodesic distance between waypoints 'a' and 'b'.
r_{a1} = Radius of initial turn for the slowest aircraft at waypoint 'a'
α_a = Track angle change (degrees) at waypoint 'a'

This is illustrated in Figure 21.

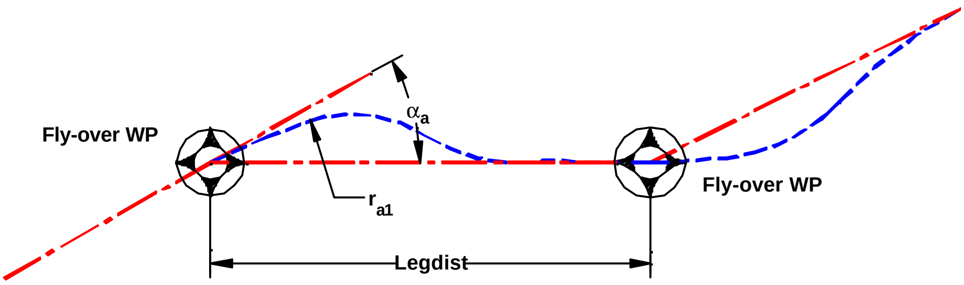


Figure 21 - Nominal Track Distance - Fly-over to Fly-over

6.6.1.4 Fly-over to Fly-by

The calculation of the shortest track distance between a fly-over waypoint and a fly-by waypoint is based upon the application of a TF path terminator as follows:

$$TrackDist = \frac{r_{a1}\pi\alpha_a}{360} - Y_b + \sqrt{\left(r_{a1}(1-\cos\alpha_a)\right)^2 + \left(Legdist - Y_b - r_{a1}\sin\alpha_a\right)^2} + \frac{r_{b1}\pi\alpha_b}{360}$$

Where

Legdist = Geodesic distance between waypoints 'a' and 'b'.
Y_b = Turn initiation distance at waypoint 'b' for the fastest aircraft
r_{a1} = Radius of initial turn for the slowest aircraft at waypoint 'a'
r_b = Radius of turn for the fastest aircraft at waypoint 'b'
α_a = Track angle change (degrees) at waypoint 'a'
α_b = Track angle change (degrees) at waypoint 'b'

This is illustrated in Figure 22.

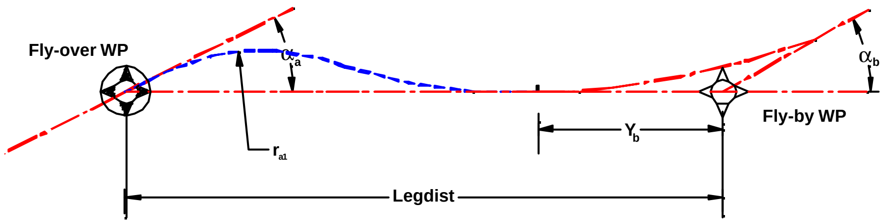


Figure 22 - Nominal Track Distance - Fly-over to Fly-by

6.6.1.5 Fixed Radius to Fly-by

The shortest track distance between a final fixed radius waypoint and a fly-by waypoint is calculated as follows:

$$TrackDist = Legdist - Y_b + \frac{r_b p a_b}{360}$$

Where

Legdist = Geodesic distance between waypoints 'a' and 'b'.
Y_b = Turn initiation distance at waypoint 'b' for the fastest aircraft
r_b = Radius of turn for the fastest aircraft at waypoint 'b'
α_b = Track angle change (degrees) at waypoint 'b'

This is illustrated in Figure 23.

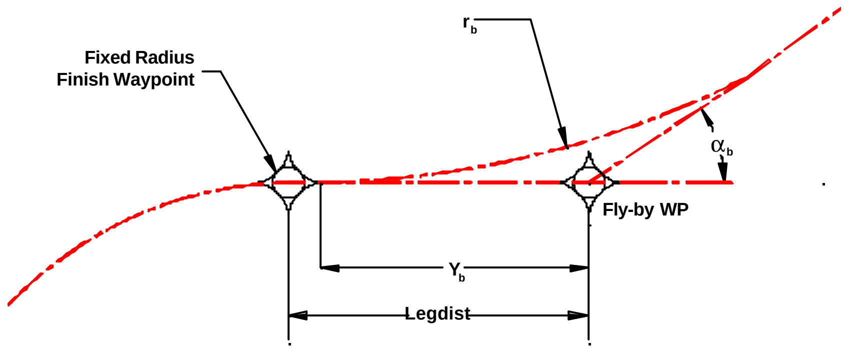


Figure 23 - Nominal Track Distance - Fixed Radius to Fly-by

6.6.1.6 Fixed Radius

For fixed radius transitions, the turn itself represents a leg between two waypoints and it is the same length for all aircraft speeds. The length is calculated as follows:

$$TrackDist = \frac{rpa}{360}$$

For conditional transitions, the shortest distance is calculated from the earliest turning point using the 'fly-over to fly-by' or 'fly-over to fly-over' formulae as appropriate.

7 HOLDING PROCEDURES

7.1 GENERAL

7.1.1 Holding procedures provide:

a) Separation between aircraft in the holding pattern.

b) Clearance of holding aircraft from obstacles.

c) Where specified, separation between aircraft in the holding pattern and aircraft on other designated routes.

7.1.2 RNAV holding procedures are defined by:

a) A waypoint (Latitude and longitude to a tenth of a second)

b) An altitude' (Feet or meters above mean sea level (100 ft or 50m increments) (Minimum and maximum altitudes required for RNP-RNAV holding procedures)

c) A maximum IAS (Knots)

d) The bearing of the inbound track to the waypoint (Tenths of a degree relative to True North)

e) Turn diameter (Nautical miles to one tenth of a nautical mile), for RNP-RNAV holding procedures only.

f) The distance of the inbound track to the waypoint (Nautical miles to one tenth of a nautical mile) The inbound track distance must be greater than the diameter of the turn at each end of the holding pattern.

g) Direction of turn at the waypoint.

h) RNP value, for RNP-RNAV holding procedures only.

7.1.3 At present there are no aircraft systems that are capable of flying RNP-RNAV holds and it seems unlikely that such holding patterns will be introduced into operational service before 2015.

7.2 HOLDING AREA CONSTRUCTION

7.2.1 The construction and application of RNAV holding procedures is detailed in Doc 8168, Vol. II Pt IV, Chapter 2 and Attachment C to Part III, Paragraph 3.6. This is based on the assumption that all RNAV systems are capable of correcting for drift on the straight segments of a holding procedure and reducing bank angles, during the turns, to compensate for wind from outside the turn. Wind from inside the turn is still addressed, as some aircraft may not be able to increase the angle of bank beyond 25° to compensate satisfactorily. The containment area defined for the holding procedure does not address fly-by transitions for joining the hold and, hence, all hold waypoints must be designated fly-over.

7.2.2 Not all aircraft are capable of conducting RNAV holds and no international SARPs are available to define how aircraft should perform this function. Designers wishing to implement RNAV holds should use conventional hold templates based upon the waypoint location and the ATT and XTT values associated with the DME/DME or GNSS as appropriate. Conventional holds based on VOR and VOR/DME should be used in all other cases.

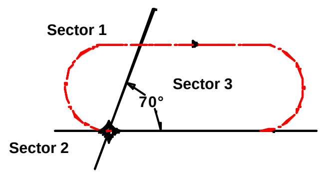
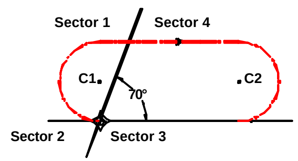
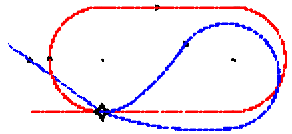
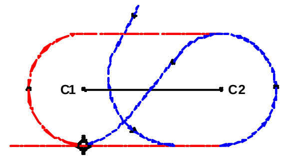
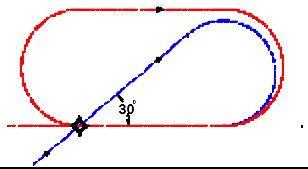
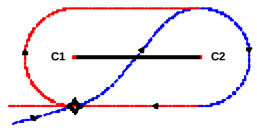
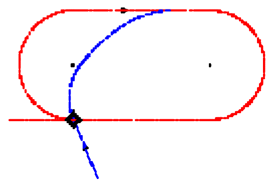
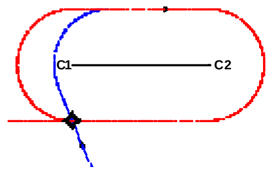
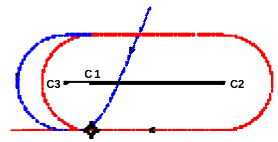
7.2.3 The construction and application of RNP-RNAV holding procedures is addressed in Doc 8168, Vol II Pt IV, Chapter 3. The obstacle clearance criteria are based upon distance, speed, altitude and navigation performance constraints. The aircraft systems are required to take account of wind effect and to maintain the RNP throughout the hold. The nominal track is defined by two semi-circles, diameter ‘d2’, joined by two straight segments, length ‘d1’. The value of ‘d2’ is calculated using the following formula:

$$d2 = \frac{(V+W)^2}{34313 \times \tan f}$$

Where

V = maximum TAS assumed for the transition (kts).
W = the wind effect for the maximum holding altitude (kts)
ϕ = bank angle (degrees) {15° for FL>245 or 23° for FL<245}.

7.2.4 The Hold waypoint is located at the end of the inbound straight segment. The aircraft are not required to overfly the Hold waypoint but rather to follow the entry procedures shown in the following table.

	Conventional ENTRY PROCEDURE		**RNP-RNAV ENTRY PROCEDURE**	
Entry Sectors	Divide the pattern into three entry sectors as shown. Allow a zone of flexibility 5º either side of the sector boundaries. Where a VOR is used to fix position, entries are limited to the radials. If specifically required for operational purposes, entry along DME arcs may also be provided for.		Component parts of the holding pattern comprise two half circles, C1 and C2, and two straight sections drawn tangentially to the circles. Four entry sectors are constructed by drawing a line through the waypoint at an angle of 70º to the inbound leg.	
Sector 1 Parallel entry	Turn outbound over waypoint; fly for appropriate period of time and distance; turn left onto holding side to intercept inbound track or to return to waypoint; on second arrival over waypoint, turn right and follow the holding pattern		Turn along the arc of a circle centred on the line between the centres of C1 and C2; intercept the reciprocal of the inbound track; intercept and follow circle C2 until intercepting the straight line which forms a tangent between C2 and C1 and bisects the line between the centres of C1 and C2; intercept and follow C1; on arrival over the waypoint, turn right and follow the holding pattern.	
Sector 2 Offset Entry	Turn onto a heading to make good a track making an angle of 30º from the reciprocal of the inbound track on the holding side; fly for appropriate period of time and distance; turn right to intercept the inbound track and follow the holding pattern.		Overfly the waypoint, tangentially intercept C2 and follow C2 until intercepting the inbound track.	
Sector 3 Direct Entry	Turn right over the waypoint and follow the holding pattern.		Overfly the waypoint; continue on the same course until intercepting C1 or a circle centred on the line between the centres of C1 and C2; follow the circle until intercepting the outbound track.	
Sector 4 Direct Entry RNP-RNAV	Not Used		On the track to the waypoint, intercept C3 (the circle centred on the extended line between the centres of C1 and C2) tangentially and follow the circle until intercepting the outbound track.	

7.2.5 The Sector 4 entry procedure is effectively a fly-by turn which results in the out bound turn starting at a distance equal to the turn initiation distance after the Hold waypoint. In order to accommodate this, the nominal hold track is extended by a distance ‘d4’ as shown in the Figure 24. This distance is calculated as follows:

$$d4 = \frac{d2}{2\cos 20}(1 - \sin 20)$$ [117&118]

Where d2 is the diameter of the hold semi-circle.

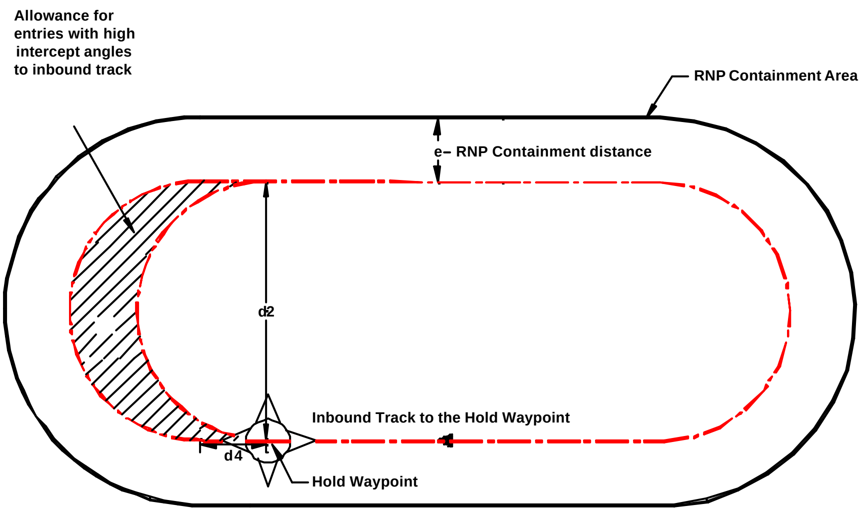


Figure 24 - RNP-RNAV Hold Containment

7.3 CONSTRUCTION OF HOLDING AREAS [119]

7.3.1 Draw a line representing the axis of the procedure . Locate point ‘a’ at the waypoint. Locate point ‘b’ at a distance ‘L’ from ‘a’ along the procedure axis. The distance should equate to one minute of flying time, in still air, at the maximum IAS value, at or below 4250 m (14 000 ft), and one and a half minutes flying time above 4250 m (14 000 ft).

7.3.2 The radius of turn, ‘r’, is one half of ‘d_2’, which is calculated using the maximum IAS values, detailed in Table 33, in the formula given in paragraph 7.2.2.

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117 This formula is used in ED75/DO 236A and produces exactly the same result as $r \times \tan 35$.

118 20° is used as a nominal bank angle, between 15° and 23°. At low altitudes, where the bank angle is 23°, it results in a slightly larger area and hence increased safety.

119 This is the current OCP proposal for RNP Holding procedures.

Altitude/Level	IAS
Up to and including 4250 m (14000 ft)	230 kts (In turbulent conditions: 280 kts)[120] 170 kts (Cat A & B only)
Above 4250 m (14000 ft) up to and including 6100 m (20000 ft)	240 kts (In turbulent conditions: 280 kts or 0.8 Mach, whichever is less)
Above 6100 m (20000 ft) up to and including 10350 m (34000 ft)	265 kts (In turbulent conditions: 280 kts or 0.8 Mach, whichever is less)
Above 10350 m (34000 ft)	0.83 Mach

Table 33 - PANS-OPS Vol. II Maximum Holding IAS

7.3.3 Draw an arc of 180° with radius ‘r’ tangential to the procedure axis at ‘b’. This represents the inbound turn, taking account of a continuous tail wind throughout the turn[121]. Draw parallel arcs with radii of ‘r+1.414*RNP’ and ‘r+1.414*RNP+RNP+2’ (or ‘r+1.414*RNP+5’, whichever is greater). Draw lines parallel to ‘ba’, off-set ‘RNP’ and ‘2*RNP+2’ (or ‘RNP+5’, whichever is greater). This represents the inbound end of the obstacle assessment area associated with the procedure. See Figure 25 below:

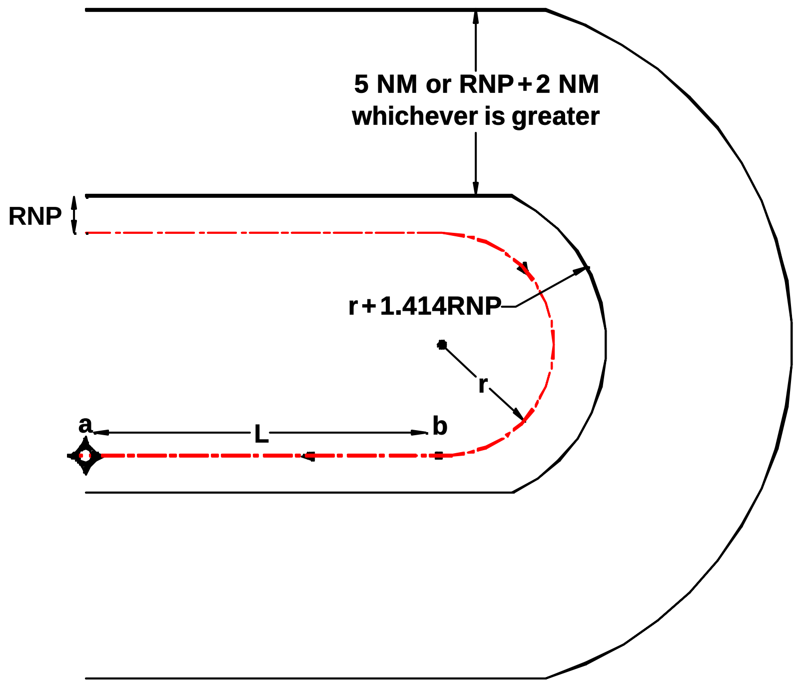

Figure 25 - RNP-RNAV Hold Phase 1

[120] If approach procedure following the hold is promulgated at a higher speed, this should be used for the hold as well.

[121] The ICAO formula of 2h+47, or national wind data may be used.

7.3.4 Locate point 'c' on the procedure axis outbound from the waypoint by a distance of 'd4'.

7.3.5 Draw an arc of 180° with radius 'r' tangential to the procedure axis at 'c'. This represents the outbound turn, taking account of a continuous tail wind throughout the turn, as well as Sector 4 entries which have high intercept angles relative to the inbound track. Draw parallel arcs of 180° with radii of 'r+1.414*RNP' and 'r+1.414*RNP+RNP+2' (or 'r+1.414*RNP+5', whichever is greater). Draw parallel lines, tangential to the three arcs, to describe the outbound track, the edge of the holding area and the edge of the buffer area Figure 26 below:

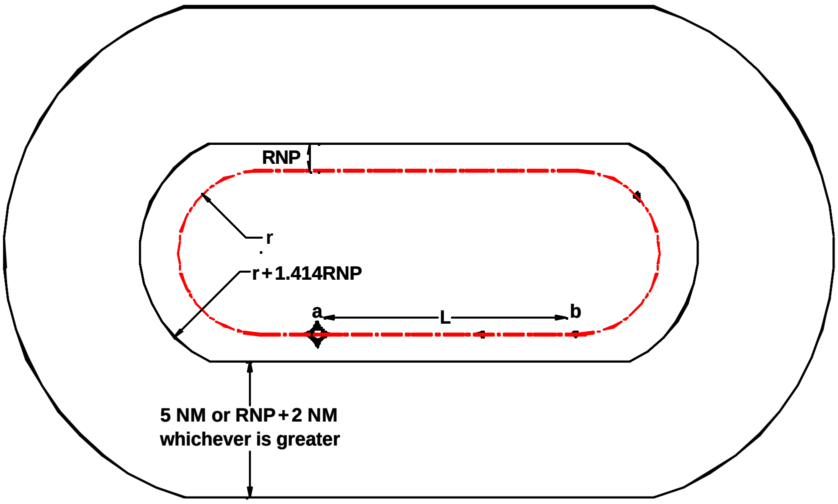

Figure 26 - RNP-RNAV Hold Phase 2

7.4 HOLDING AREA PATH TERMINATORS

7.4.1 The following path terminators may be used to define RNP-RNAV holding procedures:

a) HF - The 'holding to a fix' path leg is a holding pattern path which terminates at the first crossing of the hold waypoint, after the entry procedure has been performed. This is likely to be the path terminator most commonly used for approach procedure holds and for course reversal.

b) HM - The 'holding to a manual termination' leg is a holding pattern path where the aircraft arrives at the hold, usually with the speed and altitude set. It is manually terminated by the flight crew. This path terminator is most commonly used for the end of missed approach procedures.

c) HA - The ‘holding to an altitude’ leg is a holding pattern path which terminates at the next crossing of the hold waypoint, after an aircraft reaches or passes a specified altitude.

7.4.2 The transition from the hold to the next RNAV leg is often manually selected and it should be fly-by using the inbound course to the hold waypoint and the track to the following leg.[122]

[122] MASPS for RNP for RNAV Paragraph 3.2.4.1.3 At present, most RNAV systems apply fly-over for both joining and leaving the hold. However, if an aircraft is given a direct routing, the hold waypoint is by-passed and the aircraft is flown direct to the next waypoint from its current position in the holding pattern. The designer should, in consultation with the local ATS provider, take account of all possible routings.

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8 DEPARTURE PROCEDURES

8.1 GENERAL

8.1.1 RNAV departure procedures should provide benefits in the following areas:

a) Earlier turns can achieve earlier separation between departing traffic and, hence, provide the possibility of increasing runway capacity.

b) Optimum climb profiles help to reduce operating costs.

c) Greater control over the ground tracks of the departing aircraft means greater control of the noise footprints. Restricting traffic to specific routes will reduce the noise footprint. On the other hand, the judicious use of a number of carefully chosen departure routes may spread the noise more evenly over a wider area.

8.1.2 RNAV departure procedure designs must take account of a number of factors:

a) Departure routes should be uniquely identified in accordance with the requirements of ICAO Annex 11, Appendix 3.

b) Departure procedures should define a continuous path from take-off to the en-route structure. As a minimum, this should consist of a track to a waypoint. If the end of a departure procedure is not located on the en-route structure, it should have a logical termination which permits connectivity to that structure.

c) The departure procedure should not end before the point where the aircraft, climbing at the Procedure Design Gradient (PDG) for each leg, reaches the minimum altitude for en-route flight. The Class A GNSS-equipped aircraft change from terminal mode to en-route mode automatically at 30 NM from the ARP.

d) The initial turn should be established on the extended runway centre-line.

e) Initial turns should take account of the manoeuvre capabilities of the aircraft for which the procedure is designed.

f) Where the procedure contains an initial turn soon after take-off, this may have to be defined as a conditional transition if the earliest possible location of a fly-by waypoint is environmentally unacceptable. (A conditional transition will allow the smaller, more manoeuvrable aircraft to turn significantly earlier than the larger, heavy aircraft and can help to dilute the noise footprint.) The turn direction should always be published for conditional transitions. Conditional RNAV transitions cannot be flown by Class A GNSS-equipped aircraft.

g) Fly-over and fly-by turns must NOT exceed 120° (the angle of intersection between adjacent legs must not exceed 120°). Although it is possible to achieve turns in excess of 120° using a DF path terminator, such as in the conditional transition: FA followed by DF, turns in excess of 120° are still NOT to be used. Class A GNSS-equipped aircraft can not process turn direction flags in the navigation database. In the future, with RNP-RNAV, all turns in excess of 90° should be defined as fixed radius turns.

h) Speed limitations should only be used where it is deemed to be operationally essential. This is discussed further in paragraph 6.3.2.

i) Altitude limitations are preferable to speed limitations when used to assure obstacle clearance but must be within the capabilities of the participating aircraft.

j) Altitude limitations may be defined as altitude bands rather than specific values.

k) Initiation of course changes on passing an altitude should be avoided, where possible.

l) A departure procedure must be unambiguous and continuous and cannot include any portion which is only defined by radar vectors as this cannot be programmed into an RNAV system. This does not preclude the ATS provider from using radar vectors to re-route an aircraft off the procedure. Moreover, if the vectors are associated with published waypoints, such as tactical waypoints, then the route change can be manually input into the RNAV system.[123]

m) Heading legs should not be used for RNAV routes.[124]

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[123] One of the major benefits that can accrue from RNAV procedures is that associated with optimum climb and descent profiles. This can only be guaranteed if the profile is carefully designed and the aircraft is left to fly it automatically. Any radar vectoring is likely to reduce these benefits significantly.

[124] Heading legs cannot guarantee a repeatable ground track, however, ATC may require departures off parallel runways to follow headings rather than ground tracks if the aircraft population are not all RNAV capable..

8.2 INITIAL TURNS

8.2.1 The departure procedure starts from the DER, with the first leg ending at a waypoint on the extended centre-line, beyond the point where the PDG passes 120 m (394 ft) above the DER elevation. In a 3.3% PDG starting at 5 m (16 ft) above the DER, this equates to 1.9 NM beyond the DER. Current RNAV systems usually require a runway transition and the initial leg may be defined as FA or DF in order to start computing the necessary control inputs. Some systems require an IF, based upon the start of the take-off run, or the threshold co-ordinates at that end of the runway. This is known as the Take Off Waypoint.[125] It is included in the procedure description when a FA path terminator is used for the initial leg. The first waypoint, thereafter, defines the next transition after take-off.

8.2.2 In most circumstances, the Lateral Navigation function of the RNAV system is armed at take-off. The point at which the RNAV system is coupled to the flight director, and to the autopilot, varies according to operator specifications, aircraft type and avionics fit. Some operators are authorised to couple the autopilot to the RNAV system once the aircraft passes 120 - 150 m (400 - 500 ft), while others, which do not have P-RNAV approval should wait until the en-route phase of flight. In contrast, it is understood that certain operators require the autopilot to be coupled at take-off, although it may not accept inputs until certain pre-set parameters have been met.[126] In order to ensure that no aircraft turns below 400ft, it is strongly advised that the initial leg on every departure is coded as FA to an altitude at or above the minimum, followed by DF or CF to the next transition.

8.2.3 The obstacle limitation take-off climb surfaces, defined in ICAO Annex 14 - Aerodromes, provide protection to departing aircraft, along the extended centreline, to a height of 300m and out to a distance of up to 15060m from the DER (with a slope of between 2 and 5% depending upon the runway category). The OISs associated with the departure procedure have a gradient of 2.5% and are used to ensure that the minimum obstacle clearance (MOC) requirements are met. A degree of protection is thereby provided for contingencies, such as engine-out departures, for all aircraft categories operating from the aerodrome.[127]

125 It is the responsibility of the navigation database providers to ensure that the departure is appropriately coded for the system in question, based upon the procedure description.

126 For example, one major airline authorises FD ON for take-off, and autopilot engaged at any altitude above 100 ft AGL, for their Airbus 319/320 fleet. The A320 is currently hard-wired not to turn below 400 ft.

127 Many aircraft cannot achieve more than a 1.6% climb gradient with an engine out departure.

8.2.4 It is important to ensure that a departing aircraft does not attempt to turn until a suitable obstacle clearance margin has been achieved and, in any case, not before passing 120m (394 ft). This also applies where specific procedures are developed for aircraft with higher than average performances and an early turn is designed in order to take advantage of that performance. In such cases, the first waypoint is often brought closer to the DER or even ahead of the DER. The closer the first waypoint is to the start of the take-off run, [128] the more critical the need to ensure that the minimum altitude is reached before a turn is initiated. If necessary, the designer may prohibit the autopilot being coupled before the minimum altitude has been passed or until the first waypoint has been reached. However, a designer should not place restrictions on engaging the Lateral Navigation function unless absolutely necessary.

8.3 GRADIENTS AND CONTAINMENT AREAS

8.3.1 For DME/DME procedures, the designer should establish the navaid availability at each waypoint along the proposed departure route, based upon the height determined by the PDG and the distance from the DER. The ATT, XTT and Area Width values for each departure waypoint should then be calculated, based upon the navaid availability and the minimum altitude at each waypoint. Table 34 provides details of the relationship between height, distance from the DER, TAS for the various categories, ATT, XTT and ½AW values for a 3.3% PDG and a 10% climb gradient, ISA+15, an FTT of 0.5 NM and an ST of 0.25 NM.

8.3.2 For GNSS procedures, the ATT, XTT and Area Width values specified in Table 10 should be used for each departure waypoint.

8.3.3 The highest likely climb gradient that will be achieved by the prospective users of the procedure should then be determined - this is usually considered to be 10%. Turn calculations should be based upon the maximum waypoint altitudes using the TAS values detailed in Table 23.

8.3.4 The OIS rises from 5 m (16 ft) above the DER, splaying to the AW determined at the subsequent waypoints.

[128] Doc 8168 Vol. II Part II Paragraph 2.2 assumes that a turn at 120m (394 ft) will not be initiated sooner than 600m from the beginning of the runway. This represents a 20% climb from the start of the TORA, ie with no take off run at all.

Track Distance from DER (NM)	Height above DER (ft) (3.3%)	Cat A TAS (kt) (3.3%)	Cat B TAS (kt) (3.3%)	Cat C TAS (kt) (3.3%)	Cat D TAS (kt) (3.3%)	Cat E TAS (kt) (3.3%)	Height above DER (ft) (10%)	Cat A TAS (kt) (10%)	Cat B TAS (kt) (10%)	Cat C TAS (kt) (10%)	Cat D TAS (kt) (10%)	Cat E TAS (kt) (10%)	1/2 AW (>2DME) (NM)	ATT (>2DME) (NM)	XTT (>2DME) (NM)	1/2 AW (=2DME) (NM)	ATT (=2DME) (NM)	XTT (=2DME) (NM)
0	16	121	165	264	292	303	16	121	165	264	292	303				1.0	-	0.65
1	217	125	170	272	300	312	624	125	171	273	302	314	1.60	0.54	0.73	1.75	0.66	0.83
2	417	125	170	272	301	313	1232	126	172	276	305	316	1.69	0.62	0.79	1.88	0.77	0.92
3	618	125	171	273	302	314	1840	127	174	278	307	319	1.77	0.68	0.84	1.98	0.85	0.99
4	819	126	171	274	303	315	2448	129	176	281	311	322	1.83	0.73	0.89	2.08	0.92	1.05
5	1019	126	172	275	304	316	3056	130	177	283	314	325	1.89	0.78	0.93	2.16	0.99	1.11
6	1220	126	172	276	305	316	3664	131	179	286	316	328	1.95	0.83	0.97	2.24	1.05	1.16
7	1420	127	173	277	306	317	4272	132	180	289	319	331	2.00	0.87	1.00	2.31	1.10	1.21
8	1621	127	173	277	307	318	4880	134	182	291	322	334	2.05	0.90	1.03	2.38	1.15	1.25
9	1822	128	174	278	308	319	5488	135	184	294	325	338	2.10	0.94	1.06	2.44	1.20	1.30
10	2022	128	174	279	309	320	6096	136	186	297	328	341	2.14	0.97	1.09	2.51	1.24	1.34
11	2223	128	175	280	310	321	6704	137	187	300	332	344	2.19	1.01	1.12	2.56	1.28	1.38
12	2424	129	175	281	311	322	7312	139	189	303	335	347	2.23	1.04	1.15	2.62	1.32	1.41
13	2624	129	176	282	311	323	7920	140	191	305	338	351	2.27	1.07	1.18	2.68	1.36	1.45
14	2825	129	177	282	312	324	8528	141	193	308	341	354	2.31	1.10	1.20	2.73	1.40	1.49
15	3026	130	177	283	313	325	9136	143	195	311	344	357	2.35	1.12	1.23	2.78	1.44	1.52
16	3226	130	178	284	314	326	9744	144	196	314	348	361	2.38	1.15	1.25	2.83	1.47	1.55
17	3427	131	178	285	315	327	10352	146	198	317	351	364	2.42	1.18	1.28	2.88	1.50	1.59
18	3628	131	179	286	316	328	10960	147	200	321	355	368	2.45	1.20	1.30	2.93	1.54	1.62
19	3828	131	179	287	317	329	11568	148	202	324	358	372	2.49	1.23	1.32	2.97	1.57	1.65
20	4029	132	180	288	318	330	12176	150	204	327	362	375	2.52	1.25	1.35	3.02	1.60	1.68
21	4229	132	180	289	319	331	12784	151	206	330	365	379	2.55	1.27	1.37	3.06	1.63	1.71
22	4430	133	181	289	320	332	13392	153	208	333	369	383	2.59	1.30	1.39	3.10	1.66	1.74
23	4631	133	181	290	321	333	14000	154	210	337	372	386	2.62	1.32	1.41	3.14	1.69	1.76
24	4831	133	182	291	322	334	14608	156	213	340	376	390	2.65	1.34	1.43	3.19	1.72	1.79
25	5032	134	183	292	323	335	15216	157	215	344	380	394	2.68	1.36	1.45	3.23	1.75	1.82

Table 34 - Departure Parameters for Runways at Sea Level - Height, TAS, ½AW, ATT and XTT

1.00	-	0.65	:	Notional ½AW and XTT values for the DER or TOWP (Based upon FTT=0.1 NM, 'ST' and 'd' not considered)

8.3.5 Although not recommended, speed and/or altitude restrictions may be imposed during the departure phase. Care must be taken not to set values that are too low for the aircraft categories involved. The Category C and D aircraft performance data that is provided in Table 35 may be used to check the suitability of a procedure with respect to environmental protection areas and proposed speed restrictions. These figures are based upon a 7% climb gradient and have been derived from statistical data obtained from monitoring the climb-out of 2400 jet and propeller-driven aircraft. Designers should note that these are mean values and, were no speed or altitude restrictions are imposed, individual aircraft may be significantly faster and/or higher under certain conditions.

Distance from DER	Height above Runway (ft)	IAS (kt)
1	425	192
2	850	200
3	1275	209
4	1700	218
5	2125	229
6	2550	238
7	2976	244
8	3401	248
9	3827	252
10	4252	255
11	4677	258
12	5103	261
13	5528	263
14	5953	265
15	6379	266
16	6804	267
17	7229	269
18	7655	271
19	8080	272
20	8505	276
21	8931	278
22	9356	280
23	9781	283
24	10207	284
25	10632	286

Table 35 - Average Departure Speed for Category C & D Aircraft

8.4 OBSTACLE IDENTIFICATION SURFACE AREAS

8.4.1 The OIS areas are defined for two areas, Area 1 and Area 2. Track guidance is only considered to be available to all RNAV capable aircraft in Area 2 although, in many aircraft, the flight director or autopilot may be coupled to the RNAV system while the aircraft is transiting Area 1. Secondary areas are, therefore, specified for Area 2 only.

8.4.2 Area 1 begins at the DER with an initial width of 300m (150m either side of the runway centre-line) centred on the extended runway centre-line. It splays, at an angle of 15° on either side of the centreline, to a width determined by the PDG height and the navaid availability at the next waypoint, until:

a) The minimum distance necessary to climb to at least 120 m (394 ft) above the DER elevation, or

b) 1.9 NM from the DER[129], plus the minimum turn distance for the next waypoint, plus the ATT associated with the next waypoint, if it is a fly-by waypoint, or

c) 1.9 NM from the DER[129] plus the ATT associated with the next waypoint, if it is a fly-over waypoint.

If ATS require a climb gradient greater than the PDG, this will be charted. However, the designer should not use the ATS climb gradient as a basis to locate a turn closer to the DER than the minimum criteria detailed in paragraphs 8.4.2 and 8.4.3.

8.4.3 The height of Area 1 starts at 5 m (16 ft) above the DER and rises, in the direction of the departure, at a 2.5% gradient. Obstacle clearance is achieved through the addition of 0.8% to the OIS gradient to realise a 3.3% PDG. If obstacles penetrate the OIS, and they cannot be avoided laterally, an increased PDG must be defined to provide obstacle clearance as follows:

$$PDG = \frac{48.60896D + (H - 16)}{6072.12D}$$

Where
PDG = Climb gradient
H = Height of obstacle above DER (ft)
D = Distance of obstacle from DER (NM) measured from the DER to the earliest turning opportunity and, from there, direct to the obstacle.[130]

This is illustrated in Figure 27 and Figure 28.

[129] The 1.9 NM distance may be reduced if a PDG steeper than 3.3% is used, in accordance with Doc 8168, Vol. II Part II, Paragraph 4.2.1.

[130] $\frac{0.008D + (H - 5)}{D}$ where H is height of obstacle (metres) & D is distance from DER to obstacle (metres).

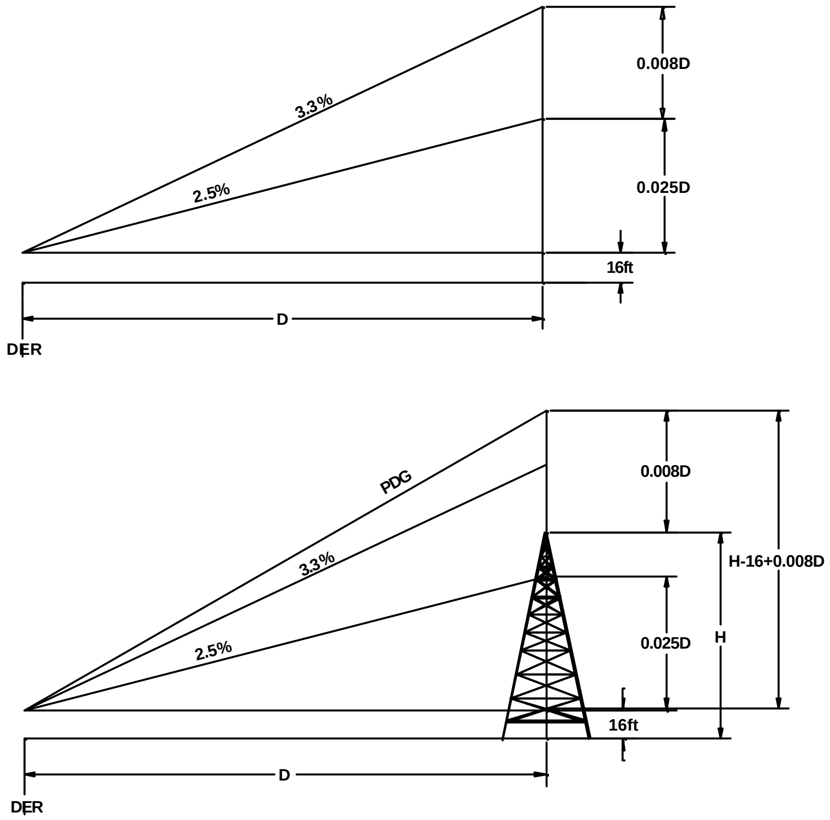
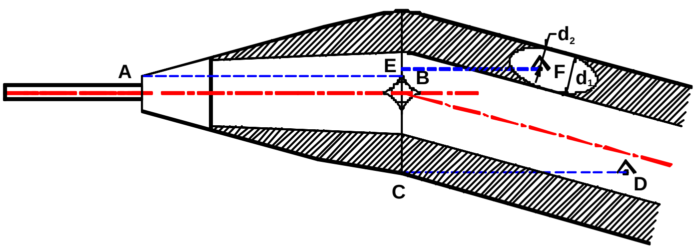


Figure 27 - PDG Calculation



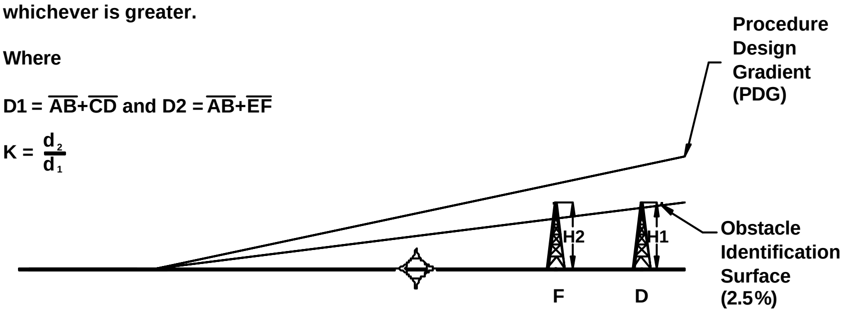
$$PDG = \frac{0.008D1+(H1-16)}{D1} \text{ or } \frac{0.008D2+K(H2-16)}{D2}$$

whichever is greater.

Where

$D1 = \overline{AB}+\overline{CD}$ and $D2 = \overline{AB}+\overline{EF}$

$K = \frac{d_2}{d_1}$



Drawing not to scale

Figure 28 - PDG Calculation (More than one obstacle)

8.4.4 Area 2 begins at the end of Area 1, with an initial width defined by the end of Area 1. It splays 15°, either side of the departure track, to a width determined by the navaid availability and the PDG height at the next waypoint together with any altitude limitations for the departure procedure. It terminates at the end of the departure procedure, where the slope, measured along the nominal flight track, reaches the minimum altitude authorised for the next phase of flight. The area width in the departure procedure may change from waypoint to waypoint with increasing altitude. The area will splay either side of the departure track, from the earliest opportunity after the previous waypoint, to reach the new area width by the next waypoint. If the en-route primary area width is different, the area will splay 30° either side of the departure track, to reach the required en-route width by the point of intersection with the en-route structure. The minimum leg length is 0.6 NM or the minimum turn distance for the transition to the next leg, or to the en-route structure, whichever is greater.

8.4.5 Once the area width has exceeded 50% of the total AW, determined by the navaid availability and the PDG, the principle of secondary areas may be applied. The secondary area follows the 2.5% gradient of the primary area and also slopes upward, perpendicularly to the leg centre-line, or the edge of the turn expansion area, as appropriate, with the obstacle clearance reducing linearly to zero at the outer edge.

8.5 STRAIGHT ROUTES

8.5.1 If the angle between the initial departure track and the extended runway centre-line is 15°, or less, the departure is considered to be straight. The semi area width for a fictious waypoint at the DER is determined by the worst case value for the allowable sensors as follows:

a) DME/DME 1.92 NM , the 500ft value for 2 DME coverage.

b) GNSS 3 NM for Class B/C and SBAS receivers or 5 NM if Class A receivers authorised for use.

c) SBAS 1 NM

8.5.2 This is illustrated in Figure 29.

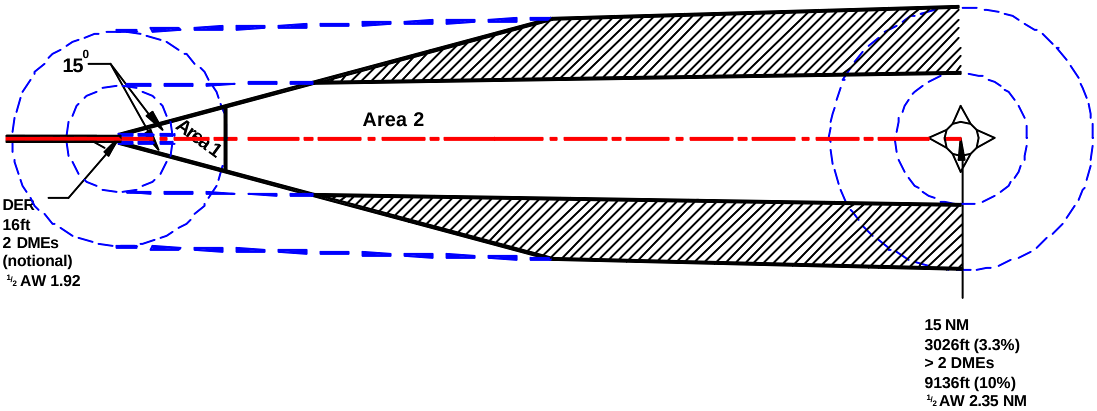


Figure 29 - Straight Departures

8.6 TURNING ROUTES

8.6.1 General

8.6.1.1 Where a turn of more than 15° is required, a turning departure must be used and a turning area must be constructed for each turn.

8.6.1.2 The size of the turning area is directly related to the aircraft category for which the procedure is designed, the distance of the waypoint from the DER, the size of track angle change and the allowable sensors.

8.6.1.3 The construction of turning areas depends upon whether the transition is conditional, fly-by, fly-over or fixed radius, and upon whether the initial splay to the specified width has been achieved before the turn commences.

8.6.2 Fly-by Splay Complete

8.6.2.1 The containment area for the fly-by splay complete turn is the same as that detailed in paragraph 6.3.7. This is illustrated in Figure 5.

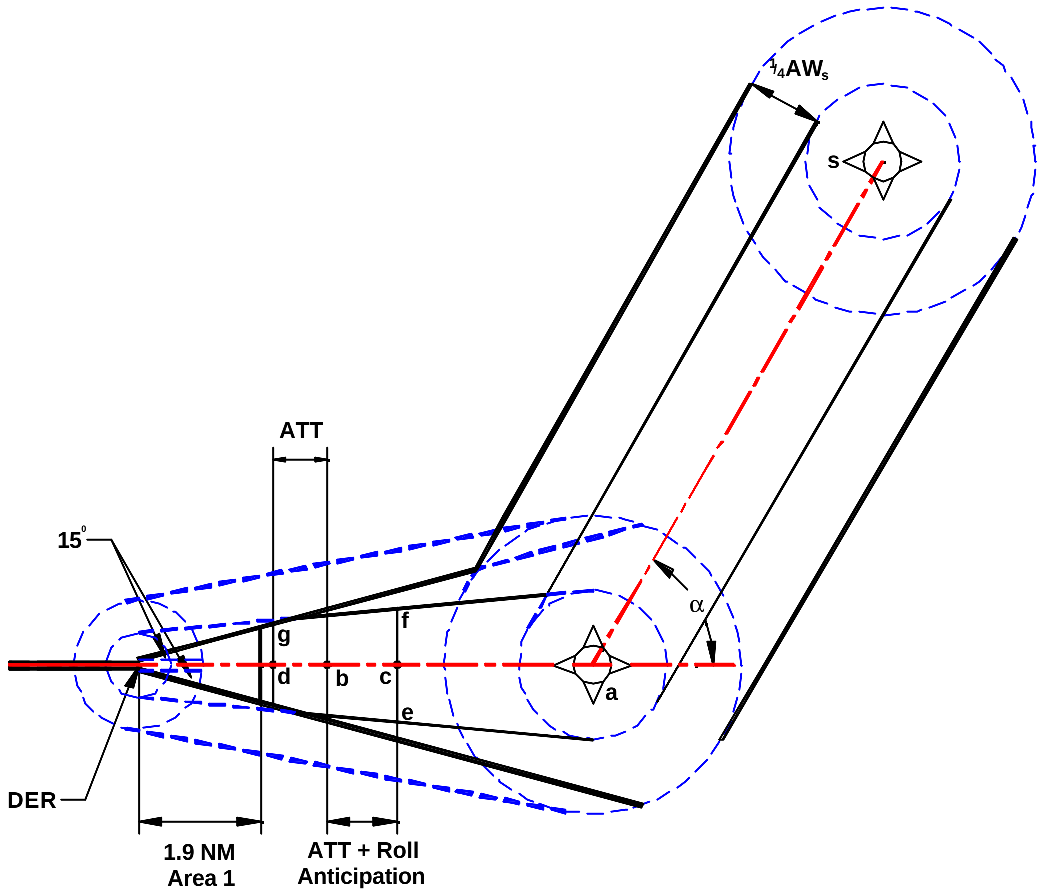


Figure 30 - Fly-by Splay Incomplete Construction - Step 1

8.6.3 Fly-by Splay Incomplete

8.6.3.1 The construction method for the OIS area for 'fly-by splay incomplete' turns is detailed in the following sub-paragraphs and is illustrated in a step-by step fashion in Figure 30, Figure 31, Figure 32 and Figure 33:

a) Draw a line representing the first leg track. Draw circles of radius ½AW $_{DER}$ and ¼AW $_{DER}$ at the centre of the DER. Locate point 'a' at the first waypoint. Draw circles of radius ½AW $_{a}$ and ¼AW $_{a}$ centred on 'a'. Draw lines tangential to the circles centred on the middle of the DER and 'a', either side of the departure track. Draw lines representing Area 1 and, if necessary, the start of Area 2. The edge of the primary area is defined by the splay from the DER, the lines tangential to the ¼AW circles and the boundary of Area 1.

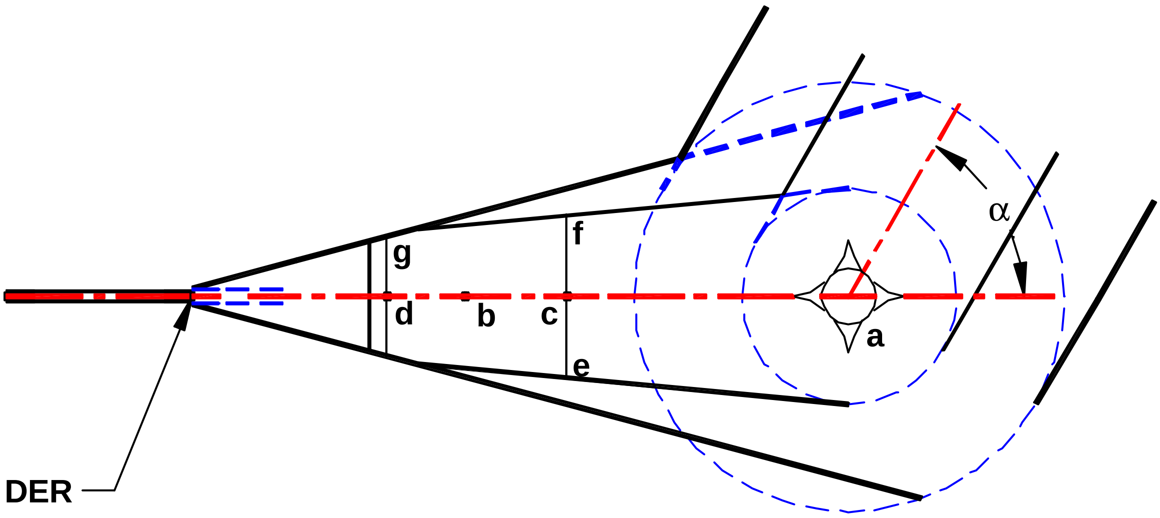


Figure 31 - Fly-by Splay Incomplete Construction - Tolerances

b) Locate points ‘b’, ‘c’ and ‘d’ at the nominal start of turn, the latest point of turn and the earliest point of turn, in accordance with paragraph 6.3.7. Draw lines perpendicular to the first leg track, through points ‘c’ and ‘d’, to intersect the primary area edges at ‘e’, ‘f’ and ‘g’.

c) Draw a line through ‘a’ to subtend an angle ‘α‘ with the first leg track, this represents the second leg track.

d) Locate the following waypoint at ‘s’, on the extended second leg track, at a distance equal to, or greater than, the minimum turn distance for the track angle changes at ‘a’ and ‘s’. Draw circles of radius ½AW_s and ¼AW_s centred on ‘s’. Draw lines tangential to the circles centred on ‘s’ and ‘a’, either side of the second leg track.

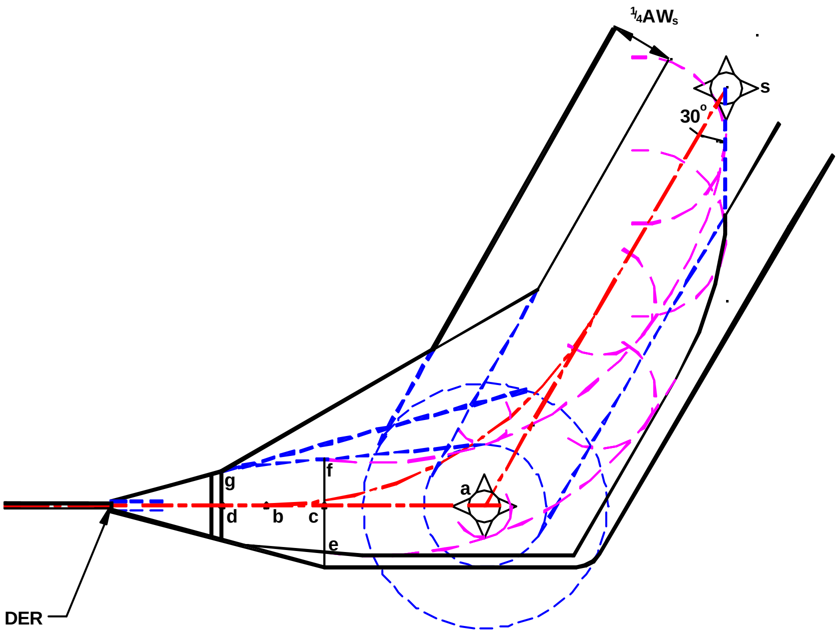


Figure 32 - Fly-by Splay Incomplete Construction - Step 2

e) Draw wind spirals from 'e' and 'f', based upon the height and speed at 'a', associated with the maximum climb gradient.

f) Draw a line tangential to the wind spiral from point 'e' or point 'f', whichever is furthest from the second leg track, at an angle of 30° to the subsequent leg track, to intersect the '¼AW' line between 'a' and 's'. Draw a line tangential to the spiral from 'e', and parallel to the subsequent leg track, to intersect the extended outer primary area edge from the initial leg.

g) If there is no outer secondary area in the first leg, it should commence from the point where the outer ¼AW line on the second leg intersects the 30° line drawn tangential to the wind spiral from 'e' or 'f'. If there is an outer secondary area in the first leg, the inner edge of the secondary area should continue past the intersection of the extension of the 'f-e' line to meet a line drawn parallel to the nominal track on the first leg and tangential to the windspiral from 'e'. The outer edge of the secondary area on the first leg should be a line parallel to the inner edge starting from the point of intersection with the line 'f-e'. The inner edge of the secondary area on the subsequent leg should be parallel to the nominal track on the subsequent leg and tangential to the outer wind spiral. At the end of the wind spiral rejoin the primary area edge at ana angle of 30°. The outer edge should continue to splay at 15° to the nominal track until a width of ¼Aw_a is achieved. This width should be maintained parallel to the outer primary area edge.

h) Draw the nominal transition track in accordance with paragraph 6.3.7.

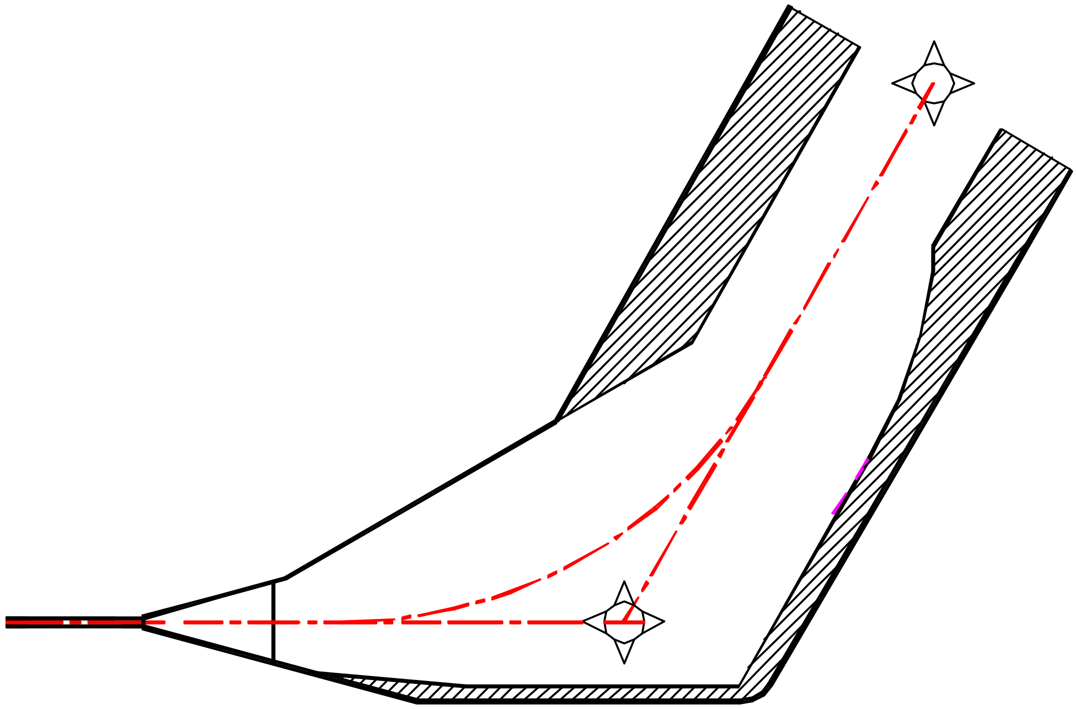


Figure 33 - Fly-by Splay Incomplete Construction - Step 3

i) Draw a $\alpha/2$ cut-off on the inside of the turn from 'g' to intersect the inner primary area edge.

j) The inner secondary area is that area formed by the straight line cut-off from 'g' and the inner ½AW and ¼AW lines on the second leg.

k) This is illustrated in Figure 30 to Figure 33 above.

8.6.4 Fly-over Splay Complete

8.6.4.1 The primary area for 'fly-over splay complete' is the same as the containment area detailed in paragraph 6.3.7.7.

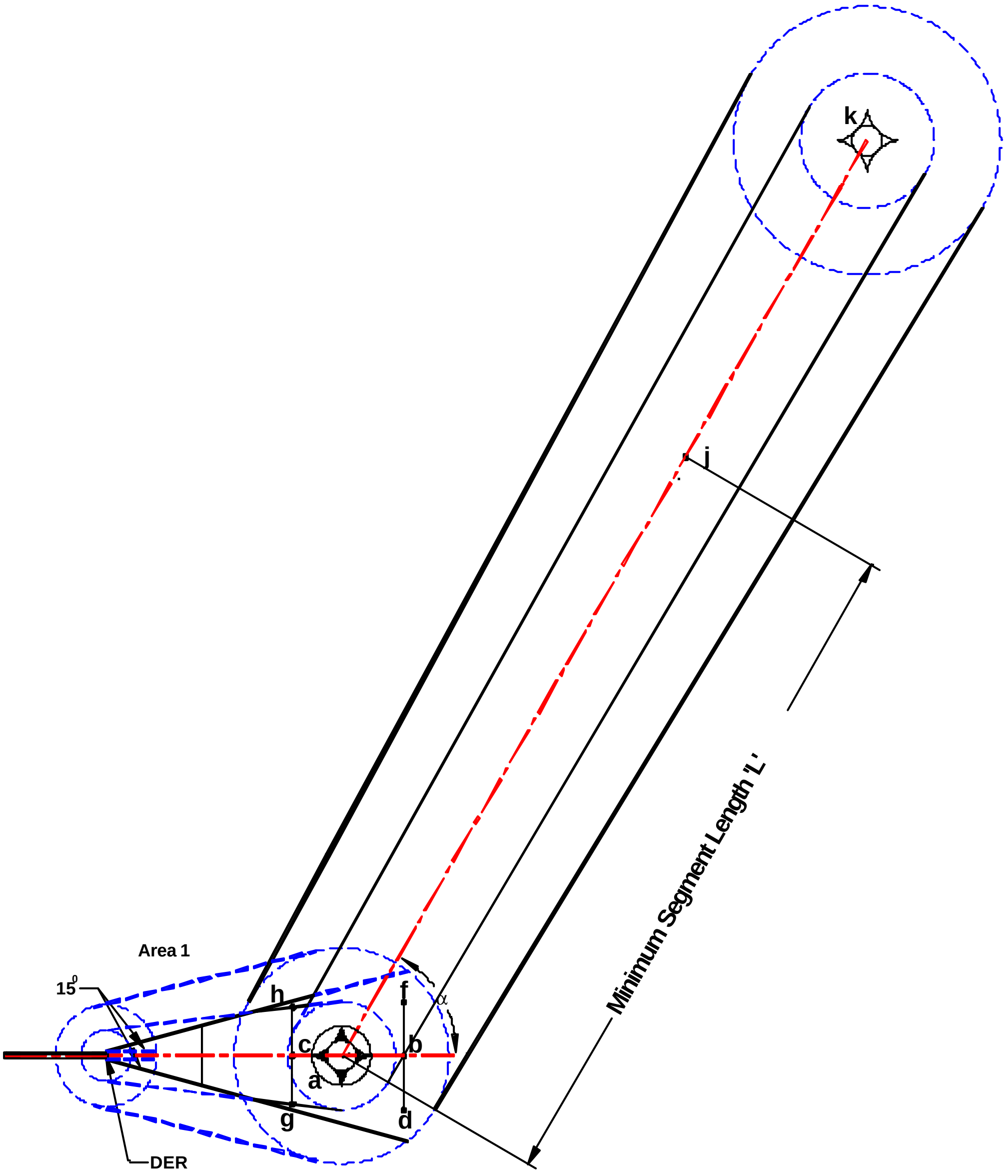


Figure 34 - Fly-over Splay Incomplete Construction - Step 1

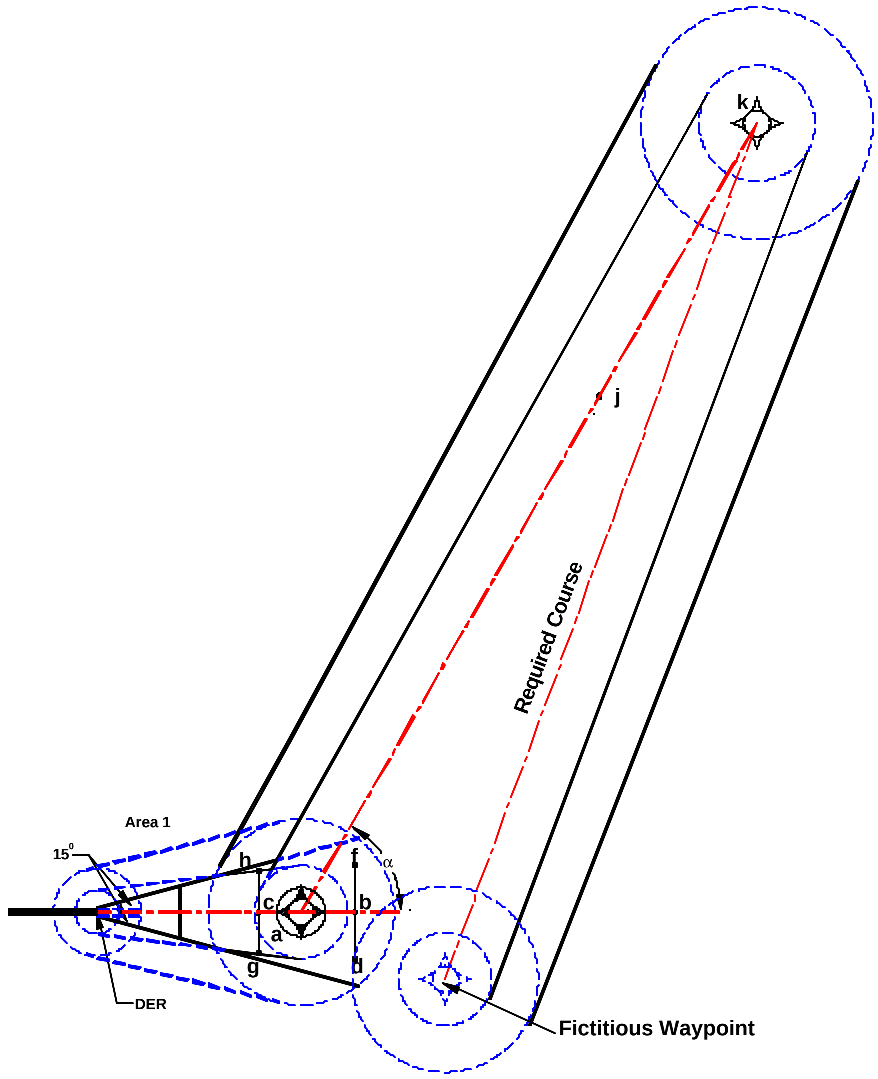


Figure 35 - Fly-over Splay Incomplete Construction (CF) - Step 1

8.6.5 Fly-over Splay Incomplete

8.6.5.1 The construction method for the OIS area for 'fly-over splay incomplete' turns is detailed in the following sub-paragraphs and is illustrated in a step-by step fashion in Figure 34, Figure 36, Figure 37 and Figure 39:

a) Draw a line representing the first leg track. Draw circles of radius ½AW $_{DER}$ and ¼AW $_{DER}$ at the centre of the DER. Locate point 'a' at the first waypoint. Draw circles of radius ½AW $_{a}$ and ¼AW $_{a}$ centred on 'a'. Draw lines tangential to the circles centred on the middle of the DER and 'a', either side of the departure track. Draw lines representing Area 1 and, if necessary, the start of Area 2. The edge of the primary area is defined by the splay from the DER, the lines tangential to the ¼AW circles and the boundary of Area 1.

b) Draw a line through 'a' to subtend an angle 'α' with the first leg track, to represent the second leg track.

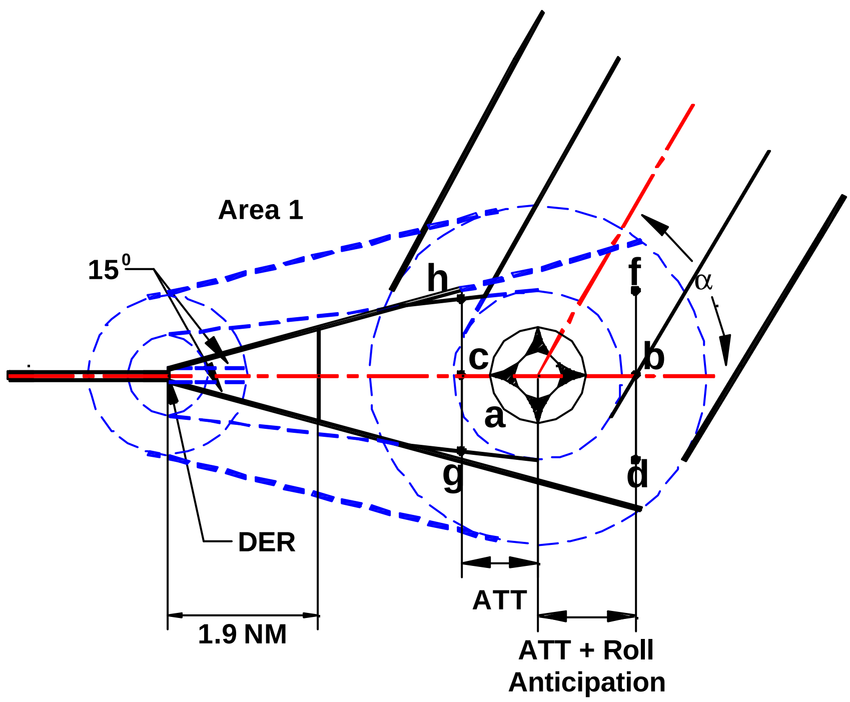


Figure 36 - Fly-over Splay Incomplete Construction - Tolerances

c) Locate point 'b' beyond point 'a', on the extended track of the first leg, at a distance corresponding to the ATT plus the distance associated with roll anticipation and pilot reaction time.

d) Locate point 'c' before point 'a' on the preceding leg, at a distance corresponding to the ATT. Draw line 'dbf', equal in width to ½AW_a, perpendicular to the first leg, through 'b'. Draw a line through 'c', perpendicular to the first leg, to intersect the primary area edges at 'g' and 'h'.

e) Locate a point 'j', on the subsequent leg track, a distance 'L' from 'a', equal to the minimum segment length for the fly-over track angle change at 'a', in accordance with paragraph 6.3.7.7.

f) The next waypoint, 'k', may be located at any point from 'j' onwards.

g) Draw circles of radius ½AW_k and ¼AW_k centred on 'k'. Draw lines tangential to the circles centred on 'k' and 'a', either side of the second leg track.

h) If a CF path terminator is to be used on the subsequent leg, draw a line through 'k' on the required course. Locate a fictitious waypoint on the line at a distance from 'k' equal to 'a-k'. Draw circles of radius ½AW_a and ¼AW_a centred on the fictitious waypoint.. Draw lines tangential to the circles centred on ‘k’ and the fictitious waypoint on the outside of the second leg track.

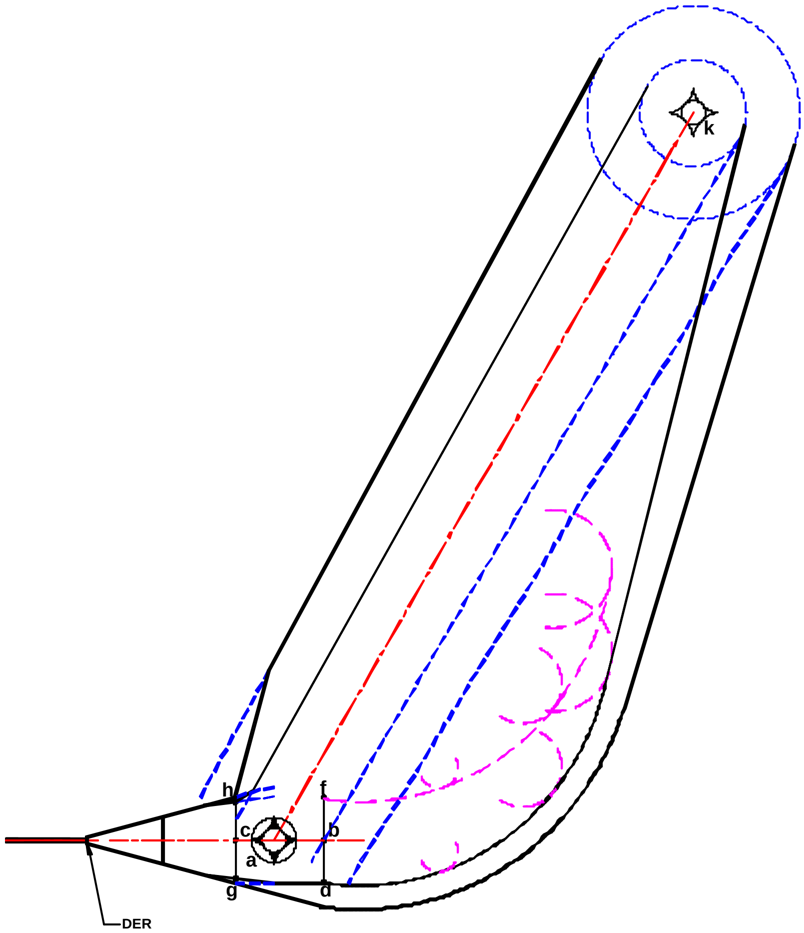


Figure 37 - Fly-over Splay Incomplete Construction (DF)- Step 2

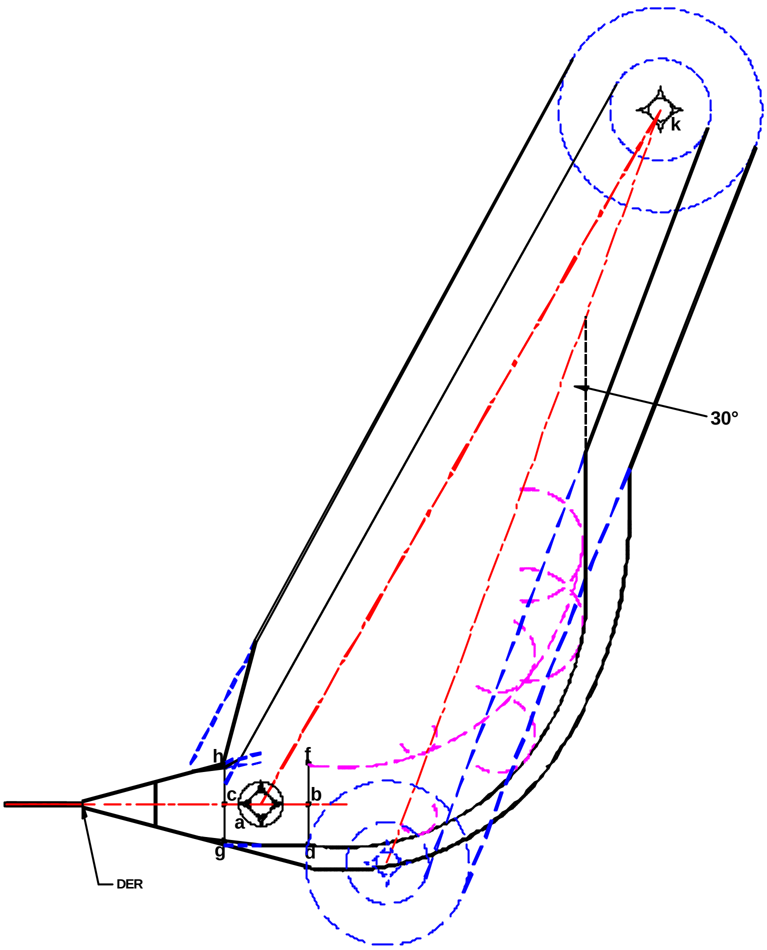


Figure 38 - Fly-over Splay Incomplete Construction (CF) - Step 2

i) Draw wind spirals from points 'd' and 'f' up to the points where the tangents become parallel to a line drawn at an angle of 30° to the subsequent leg track.

j) On the inside of the turn, continue the 15° splay from the point where the line 'gch', extended if necessary, intersects the inner edge of the initial leg, until the splay intersects the inner ½AW line on the second leg. Draw a line from 'h' at an angle of $\alpha/2$ to the first leg track to intersect the inner ¼AW line on the second leg. (If the secondary area starts on the first leg, draw the line from the point of intersection between the inner primary area edge and the line 'gch'.) This represents the inner edge of the primary area at the transition.

k) The leg after the fly-over waypoint is usually designated as a DF leg as it allows a smoother turn and results in a slightly shorter track distance. The edge of the outer primary area on a DF leg is defined by a line drawn tangentially to the ¼AW_k circle and the wind spirals from 'd' and/or 'f'. The outer primary area edge, around the rest of the turn, is defined by the wind spirals and joining tangential lines, where necessary.

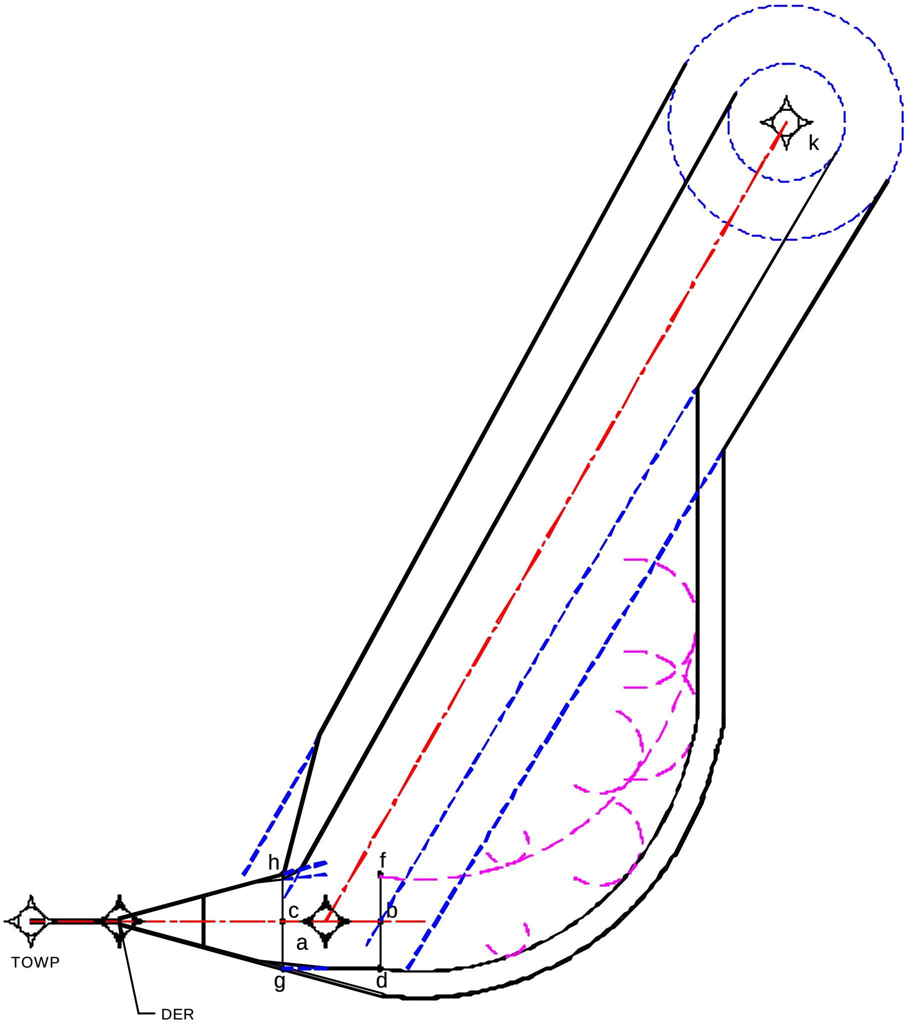


Figure 39 - Fly-over Splay Incomplete Construction (TF) - Step 2

l) If airspace is critical, the CF path terminator may be used, although only when absolutely necessary. The edge of the outer primary area on a CF leg is defined by a line drawn at an angle of 30° to the required course and tangential to the wind spirals from ‘d’ and/or ‘f’.

m) The outside edge of the outer secondary area, in both cases, is defined by a line drawn as follows:

i) For the initial turn, the line is drawn parallel to the outer primary area edge, offset by the distance between ‘d’ and the outer splay, measured perpendicular to the initial leg track.

ii) For the remainder of the recovery - the line is drawn tangentially to the offset curve defined by wind spiral, as defined in paragraph i) above, and the ½Aw$_k$ circle.

n) This is illustrated in Figure 34 to Figure 41.

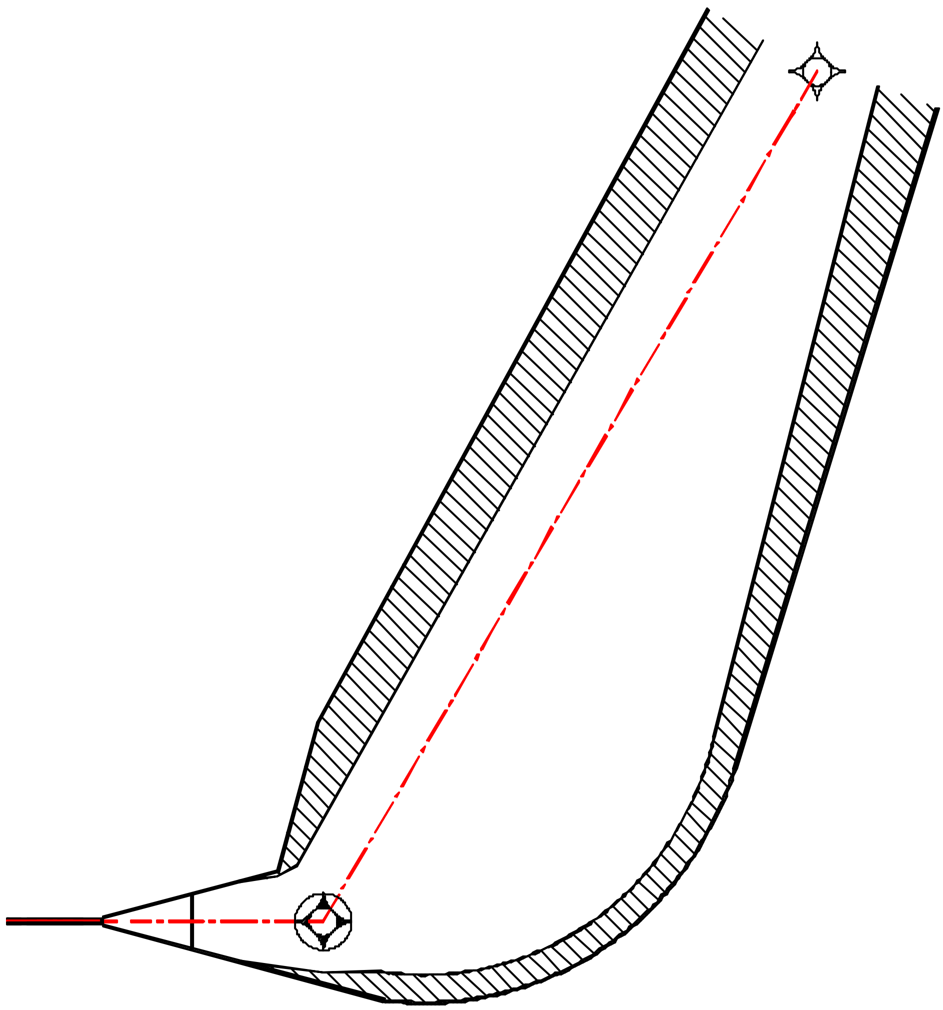


Figure 40 - Fly-over Splay Incomplete Construction- Step 3 (DF)

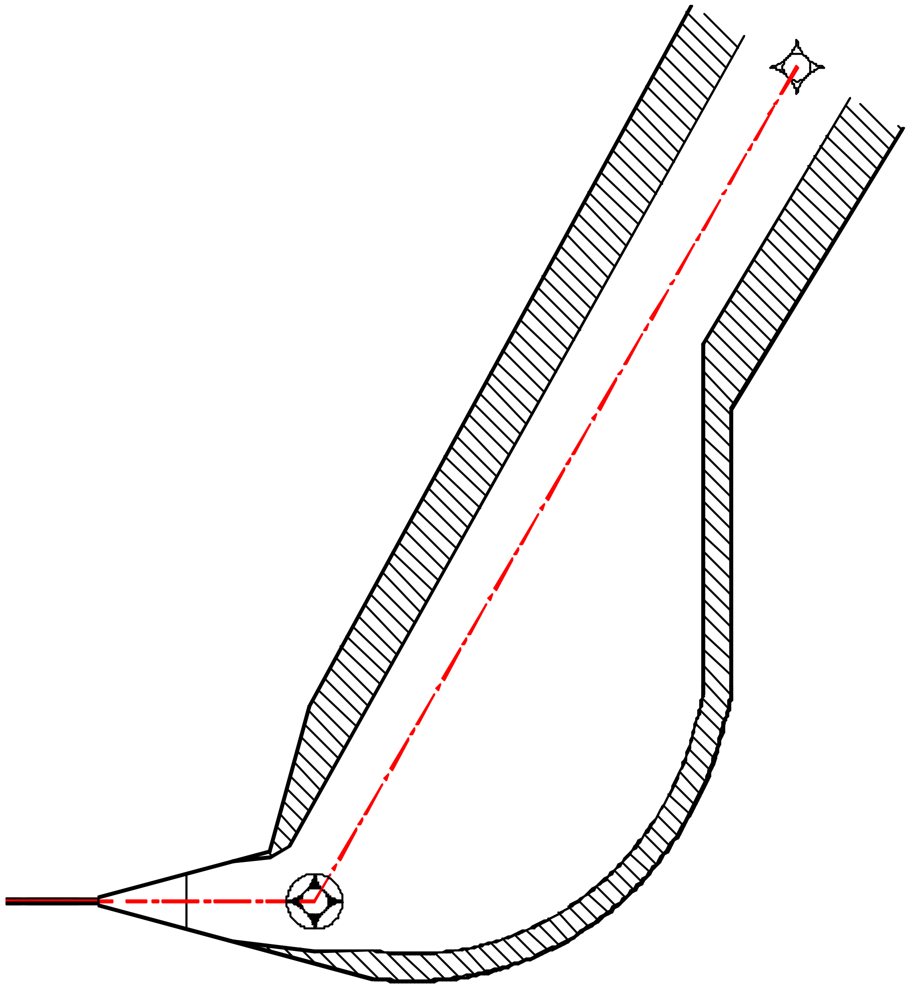


Figure 41 - Fly-over Splay Incomplete Construction - Step 3 (TF)

8.6.6 Conditional Transitions

8.6.6.1 Where a turn at altitude is prescribed, with the first leg defined by an FA path terminator, the nominal track cannot be defined in such a way that it is either predictable or repeatable. The procedure designer should calculate an earliest turning point, based upon the maximum anticipated climb gradient and the distance from the beginning of the runway, and a latest turning point, based upon the PDG and the distance from the DER.

8.6.6.2 The greatest track angle change will occur at the latest turning point and may exceed 120° in certain circumstances. In such cases, it may be necessary to specify the direction of turn if adequate protection cannot be given for turns in both directions. The higher the turn height, the further apart the earliest and latest turning points will be and the larger the required protected area. The earliest turning point must not be closer to the preceding waypoint than the minimum turn distance associated with that waypoint, or 600m, if the 'preceding waypoint' is the beginning of the runway. The following waypoint should not be placed closer than the minimum turn distance for the latest turning point.

8.6.6.3 The protected area will depend upon the path terminator used for the subsequent leg and should be constructed as follows:

a) The primary and secondary area edges on the inside of the turn should be based upon a fly-over transition at the earliest turning point, as detailed in paragraphs 8.6.4 and 0, with the ATT value set to zero. Note that, although the climb gradient used to define the earliest turning point is considerably greater than the PDG, the OIS gradient after the turn (defined as the line between the earliest turning point and the latest point) should continue at 2.5% from the required altitude at the turning point.

b) The primary and secondary area edges on the outside of the turn should be based upon a fly-over transition for the appropriate path terminator at the latest turning point, as detailed in paragraphs 8.6.4 and 0, with the ATT value set to zero.

c) Where the protected areas of the two fly-over transitions overlap, the primary and secondary areas associated with the fly-over transition at the latest turning point take precedence.

8.6.6.4 The DF path terminator is usually used for conditional transitions. However, if airspace is limited and a CF leg is specified, it is important that flyability checks are carried out for the earliest, nominal and latest turning points for all the aircraft types that are expected to use the procedure. Two examples of conditional transitions are illustrated in Figure 42 and Figure 43. A TF path terminator is not allowed after a FA leg.

8.6.6.5 Note that Class A GNSS receiver systems are not capable of performing conditional transitions.

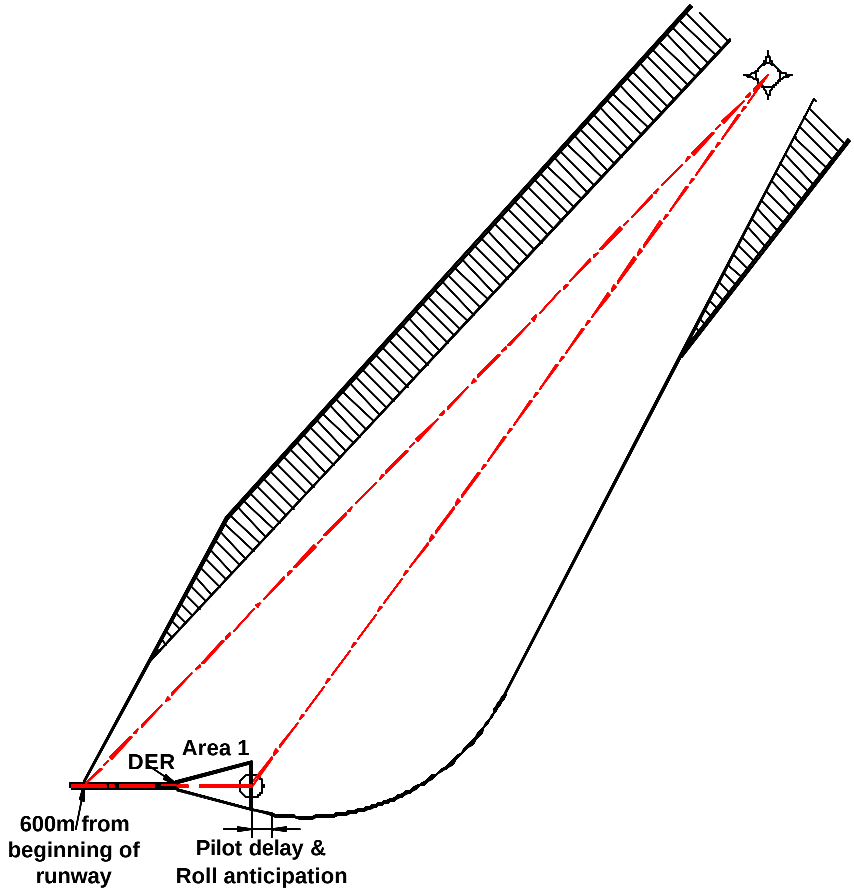


Figure 42 - Conditional Transition - Turn after passing 400'

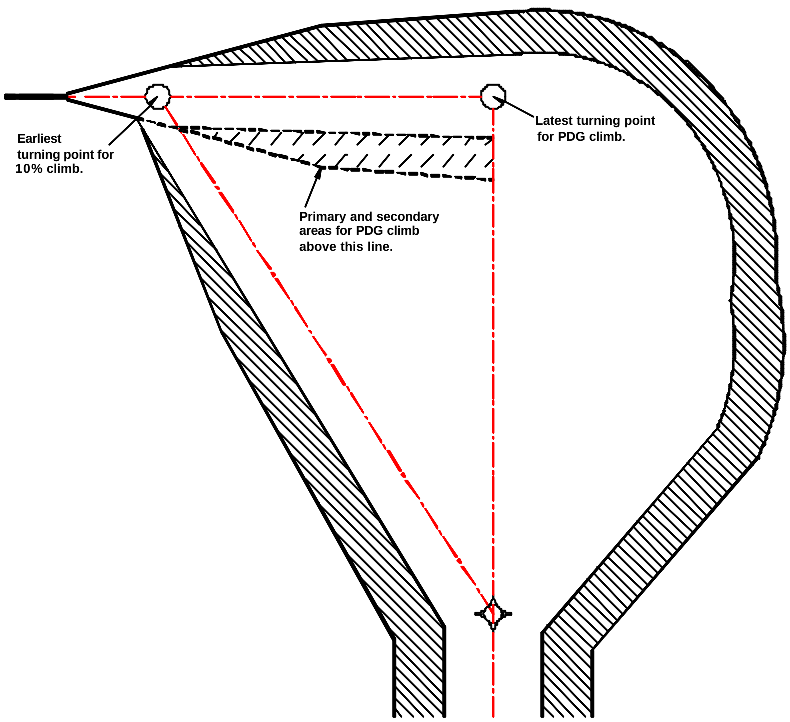


Figure 43 - Conditional Transition - Turn after passing 3000'

9 CONTINGENCY PROCEDURES

9.1 It is the responsibility of the operator to develop contingency procedures to cover the case of engine failure, or an emergency in flight, which occurs after V_1. Where terrain and obstacles permit, these procedures should follow the normal departure route and the appropriate Take Off Performance Limits (TOPL) should be set to ensure that this is the case. If the operator can demonstrate that a separate engine out procedure is feasible, a reduction in TOPL may be allowed. In either event, an unplanned turn before the aircraft reaches the minimum sector altitude means that the TOPL calculations lose validity and the aircraft may not be adequately protected in the event of a subsequent emergency.

9.2 When it is necessary to develop turning procedures to avoid an obstacle which would have become limiting, the point for the start of the turn must be readily identifiable, by the pilot, when flying under instrument conditions.

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10 ARRIVAL/APPROACH PROCEDURES

10.1 INTRODUCTION

10.1.1 A conventional approach procedure may consist of up to 5 separate segments: arrival, initial approach, intermediate approach, final approach and missed approach.

a) The arrival segment starts at the point of departure from the en-route structure and terminates at the Initial Approach Fix (IAF).

b) The initial approach segment starts at the IAF and terminates at the Intermediate Fix (IF).

c) The intermediate approach segment starts at the IF and terminates at the Final Approach Fix (FAF).

d) The final approach segment starts at the FAF and terminates at the Missed Approach Point (MAPt).

e) The missed approach segment starts at the MAPt and terminates at a point at which a new approach, holding or return to en-route flight can be initiated.

Under certain circumstances, the IAF, or even the IF, may be located at the point of departure from the en-route structure, in which case the preceding segments are not used.

10.1.2 Similar conventions may be used when designing an RNAV arrival/approach, with the significant exception that the start/termination points for each segment are defined by waypoints. The IAF, IF, FAF and MAPt retain their existing nomenclature.

10.2 GENERAL

10.2.1 It is imperative that the procedure designer works closely with the ATC organisations that will use the new procedures. Mixed mode operations with RNAV and non-RNAV aircraft may be expected for some time to come, but designers must guard against developing overlay procedures which offer little benefit to the RNAV-equipped aircraft. Where a radar service is provided, it should be possible to identify a route structure that can accommodate both RNAV and non-RNAV aircraft from an analysis of the routes/flight patterns currently used when aircraft are receiving radar vectors.

10.2.2 The use of off-set waypoints and route extensions or short cuts, as illustrated in Figure 46 and Figure 47, should assist the radar controller to provide adequate separation and appropriate sequencing for RNAV aircraft while enjoying a significantly reduced R/T workload. In a non-radar environment, RNAV routes should offer the simplest and quickest arrival and approach solutions rather than replicate existing procedures. Later, as the free routing concept matures, fixed route structures for RNAV and non-RNAV traffic may have to be integrated with free route airspace. The main disadvantage of RNAV procedures is that they reduce the flexibility that radar vectoring affords the controller and experience has shown that, without the help of a very advanced arrival manager, controllers tend to revert to radar vectoring during the peak periods.

10.2.3 RNAV arrival procedures should provide benefits in the following areas:

a) Optimum descent profiles will help operators to reduce costs significantly. The greatest cost savings are likely to be achieved by providing engine-idle descents from cruising altitude direct to final approach. This is not easy to achieve, particularly under medium to heavy traffic loads where automated ATM support tools may be necessary, but it should remain one of the designer's long term goals.

b) Optimised engine-idle descents have the least environmental impact.

c) R/T traffic, as well as controller and flight deck workloads, should be reduced if aircraft separation and sequencing can be maintained using the tactical waypoints and radar monitoring, instead of continuous discrete radar vectoring.

10.2.4 Procedure designers must also take account of the following general factors:

a) RNAV arrival procedures should define a continuous path from leaving the en-route structure to the MAPt, and from the MAPt to the HWP, or another designated waypoint, at which a new approach or return to en-route flight can be initiated. This should be the goal of the designer although ATC may insist on the application of 'Open STARs' in certain circumstances. (See paragraph 10.3.2)

b) Arrival and approach routes must be uniquely identified in accordance with the requirements of ICAO Annex 11, Appendix 3.

c) Arrivals starting from different waypoints must have different identifiers.

d) Arrivals starting from the same waypoint but following different routes must have different identifiers.

e) Where arrival routes overlap, the tracks, distances and altitude restrictions should be common.

f) Fly-over transitions should only be used for the MAPt and the Hold.

g) Fly-by or fixed radius[131] transitions should be used, wherever possible, but may NOT be used for the MAPt.

h) Speed limitations should only be used where it is deemed to be operationally essential. Note that some aircraft systems will not process the speed constraint unless there is an altitude constraint for the same waypoint.

i) Altitude limitations are preferable to speed limitations when used to assure obstacle clearance.

j) Altitude limitations should be defined as altitude bands rather than specific values, except in the RNAV/Baro VNAV approach.

k) As a rule of thumb, where a turn in excess of 90° is required, a fixed radius turn [131] should be defined. The turn radius must take account of the manoeuvre capabilities of the aircraft and turns must not exceed 120°.

l) Heading legs should NOT be used for RNAV routes although a STAR terminating on the downwind leg will result in the aircraft flying a heading after the last waypoint. This may be a preferred solution from an ATC perspective, particularly in a mixed mode environment.

10.2.5 The IAS values, used in the transition calculations, must reflect the performance of the aircraft types for which the procedure is being designed and must be based upon the values detailed in Table 23. Where airspace requirements are critical for a specific category of aircraft, and a lower speed category has been used in the calculations, the procedure must either be restricted to the lower categories or limited to a specific IAS for the affected segments. The procedure designer must publish the IAS values used in the procedure calculations.

[131] Only available in RNP-RNAV systems and, hence, of little value in the near term.

10.2.6 Many RNAV systems include a VNAV function. If VNAV is engaged during the arrival and approach phases, the aircraft will descend using the optimum profile possible, based upon published descent gradients as well as altitude and speed restrictions, both published and imposed by the ATS on the day.[132] The OCP has developed a new set of procedure criteria known as the RNAV/Baro VNAV approach procedures. These take advantage of VNAV capabilities to reduce the volume of protected airspace associated with the final approach segment and are described in more detail in paragraph 10.7.3.

10.2.7 Many in the aviation community consider that stabilized approaches on conventional NPAs using the VNAV element of an RNAV system are significantly safer than descending to minimums and then maintaining a level course to the MAPt. However, this can also be achieved without relying on VNAV and there are related issues including crew training that must be addressed. The JAA is in the process of issuing a revision to JARs addressing the application of Constant Angle Non Precision Approaches (CANPA).

10.2.8 Procedure designers should be aware that, to support CANPA operations, database providers have anticipated the application of VNAV and do not code MDA/H. They generally use the runway threshold as the final waypoint on the approach leg and calculate a glide slope from a point 50 ft above the threshold back to the FAF, taking account of any step down limitations. The glide slope angle is calculated by the database supplier, if it is not provided by the state. It is the responsibility of the pilot to ensure that a missed approach is executed, if he is not visual with the aerodrome or if the aircraft is not in a position to make a stabilized landing, by the time that the MDA/H is reached.

10.2.9 The use of VNAV systems on conventional approaches is not supported throughout Europe. Indeed the prevalent view amongst many EUROCONTROL States is that NPAs should be replaced with appropriately designed RNAV and RNAV/Baro VNAV approaches and RNAV overlay operations on conventional NPAs should be actively discouraged.

132 An FMS usually 'builds' a profile backwards from a point 50 ft above the runway threshold to the initial constraint (usually an altitude restriction at the FAF), from the FAF back to the deceleration point (DECEL) and from there back to the Top of Descent. The final approach segment is a geometric profile using the published descent gradient, if available, while the other segments may be calculated as geometric profiles and as deceleration/idle speed profiles. The geometric profiles often use the same descent gradient as that used for the final approach and will include level legs, if an altitude constraint is reached before the next waypoint. The deceleration/idle speed profile is based on the geometric profiles, ie takes account of speed and altitude constraints, but is intended to provide an optimum descent and, hence, level segments should be kept to a minimum. The pilot usually has the capability to select either the geometric profile or the optimum descent profile provided that the deceleration point has been sequenced, the profile is being achieved, the Lateral Navigation function is engaged and the XTT<1.5 NM. However, some FMSs only calculate the geometric profile.

10.3 ARRIVALS

10.3.1 Terminal Arrival Areas

10.3.1.1 The FAA developed a concept, known as the Terminal Area Approach (TAA) concept, to allow straight-in RNAV approaches, without necessarily having to take account of any ground-based navaid. [133] The concept is based upon an approach procedure laid out in the shape of a 'Y', or a 'T', with the 'arms' of the 'Y' comprising two initial approach segments off-set between 45°[134] and 90° from the intermediate segment. If the off-set is between 70° and 90°, it should be possible to enter the procedure from any direction without having to use a reversal procedure. The intermediate segment lies on the extended runway centre-line, together with the final approach segment and the first part of the missed approach segment. The IF is also the IAF for aircraft arriving in the 'Straight-in Area', although a third IAF may be defined beyond the IF on the extended runway centre-line.[135] This is illustrated in Figure 44.

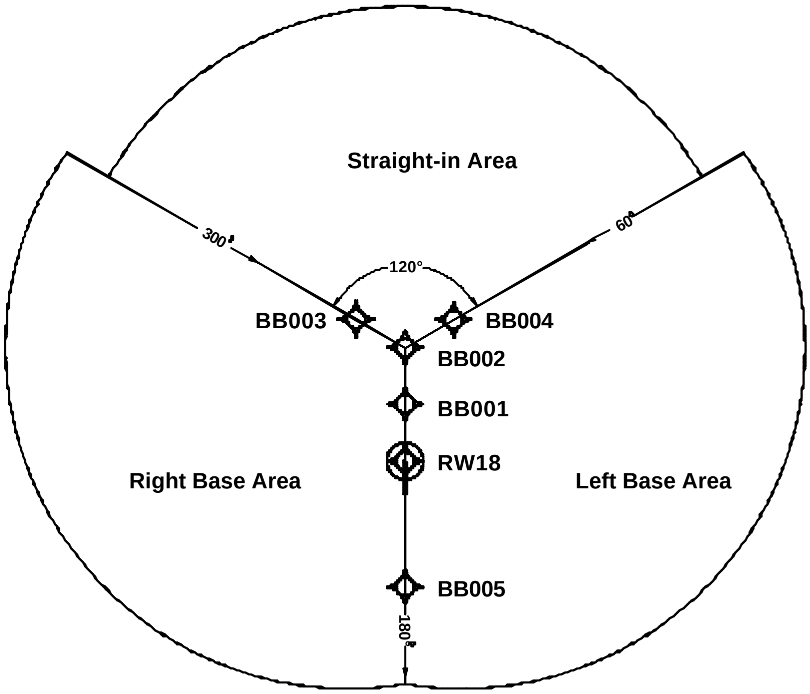

Figure 44 - The 'Y' Concept

[133] This concept was first introduced in DOC 8168 specifically in relation to procedures for basic GNSS receivers.

[134] If a designer is trying to keep the intermediate segment as short as possible, without applying speed restrictions, and/or accommodate an ILS final approach, the turn at the IF may have to be restricted to as little as 45° in order to provide an acceptable straight component of between 1 NM and 1.5 NM, depending upon aircraft category, after completion of the turn.

[135] This is recommended for basic GNSS approaches in DOC 8168 Vol 2 Part III, Appendix to Chapter 33.

10.3.1.2 The OCP is introducing the concept of Terminal Arrival Altitudes for use with RNAV approaches. This is the lowest altitude which may be used which will provide a minimum clearance of 300m (984ft) above all objects located in an area contained within a sector of a circle of 46km (25NM) radius of the IAF of an RNAV approach, with an additional 5NM buffer area on all sides of the sector. See Figure Figure 45.

10.3.1.3 The TAA is usually divided into three sectors - straight-in, left base and right base. These may be sub-divided by step-down arcs[136], with associated buffer areas, where this is necessary. Additional sectorisation is not permissible in the base sectors although the straight in sector may be divided radially into sub-sectors[137] or may be merged with the left and/or right base sectors if no approach can be designed for either, or both of the bases.

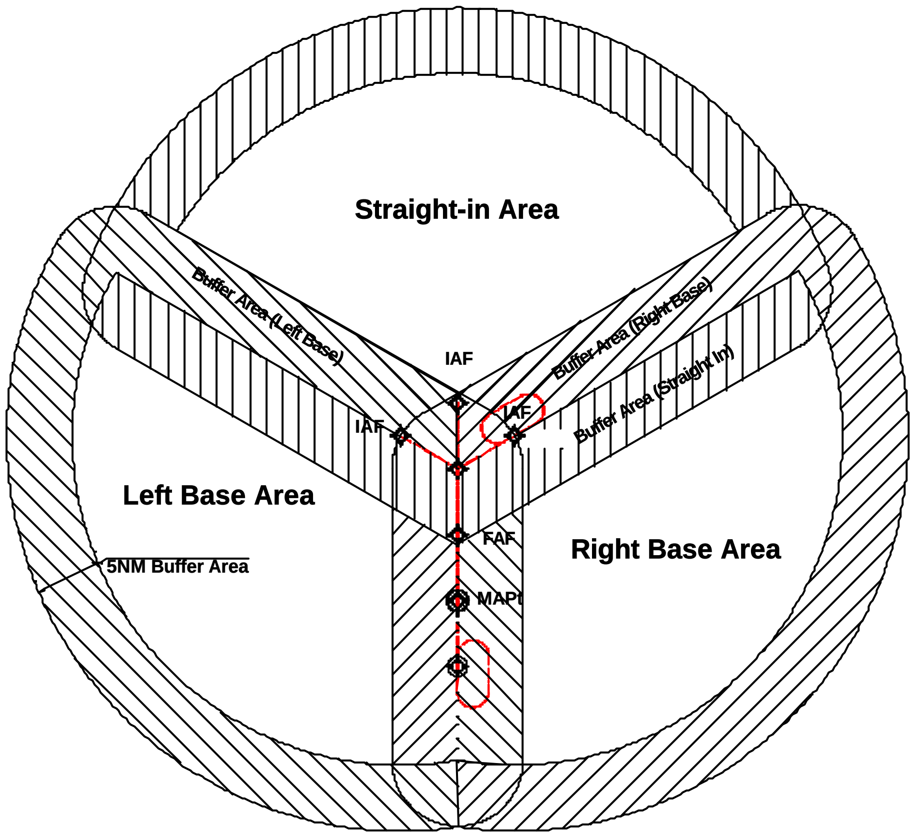

Figure 45 - Omni-directional Terminal Arrival Areas

136 Step-down arcs no closer than 10NM from the IAF and at least 10NM from the TAA boundary.

137 Sub-sectors no smaller than 30° of arc or, if a step-down arc is used, no smaller than 45°.

10.3.1.4 En-route obstacle clearance criteria apply. The MOC is 300 m (984 ft) above the highest obstacle[138], in the except in mountainous areas where it may be increased to 600 m (1969 ft), or more, above the highest obstacle.[139]

10.3.2 Open and Closed RNAV STARs

10.3.2.1 The TAA concept can be applied in any airspace and is being adopted by ICAO for all RNAV approaches. The 'Y' structure may also be adapted for use in a radar environment, with additional tactical waypoints defined for traffic management purposes. This is illustrated in Figure 46 and Figure 47. This integration of the TAA concept with RNAV STARs and radar vectors can be achieved in one of three ways:

a) Closed RNAV STARs which terminate at the IF. This STAR is characterised by the publication of an uninterrupted RNAV nominal track to the final approach segment of the relevant instrument approach.

b) Open RNAV STARs which terminate in a heading segment on the downwind leg, abeam the FAF. The aircraft are subsequently turned onto final approach using radar vectors.

10.3.2.2 Closed RNAV STARs allow the RNAV system to fly the most efficient profile, thereby minimising fuel burn, noise and emissions. However, closed RNAV STARs from either or both left and right-bases increase the risk of an aircraft turning to final without separation from another aircraft on the extended final approach or the opposite base leg. As a result, closed RNAV STARs can be used most effectively in low to medium traffic densities.

10.3.2.3 It may be possible to use closed RNAV STARs in high traffic density in conjunction with a sophisticated sequencing assistance tool. However in the near term, there is an option to use the Open RNAV STAR in order to ensure consistent aircraft-to-aircraft separation. STARs to parallel approaches for independent parallel runways must be designed as open RNAV STARs in order to comply with current ICAO provisions[140].

10.3.2.4 Figure 46 shows an example of an open RNAV STAR. In this example, the published procedures that are called up in the flight plan route via the IAFs JUREN, BULFA, TWIGG and HOLGA respectively. ALBAR is the FAF and RW27C is the MAPt. The arrival from TWIGG is an open STAR which ends at SD424. Thereafter aircraft are usually radar vectored onto final approach although ATC may clear the aircraft to continue via ALBAR if traffic conditions permit.

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138 This includes the buffer areas in the same way as is done with conventional MSAs.

139 The increase in the MOC should take account of the effects of the mountainous area, including the statistical wind and the propensity for mountain waves.

140 Dec 2002

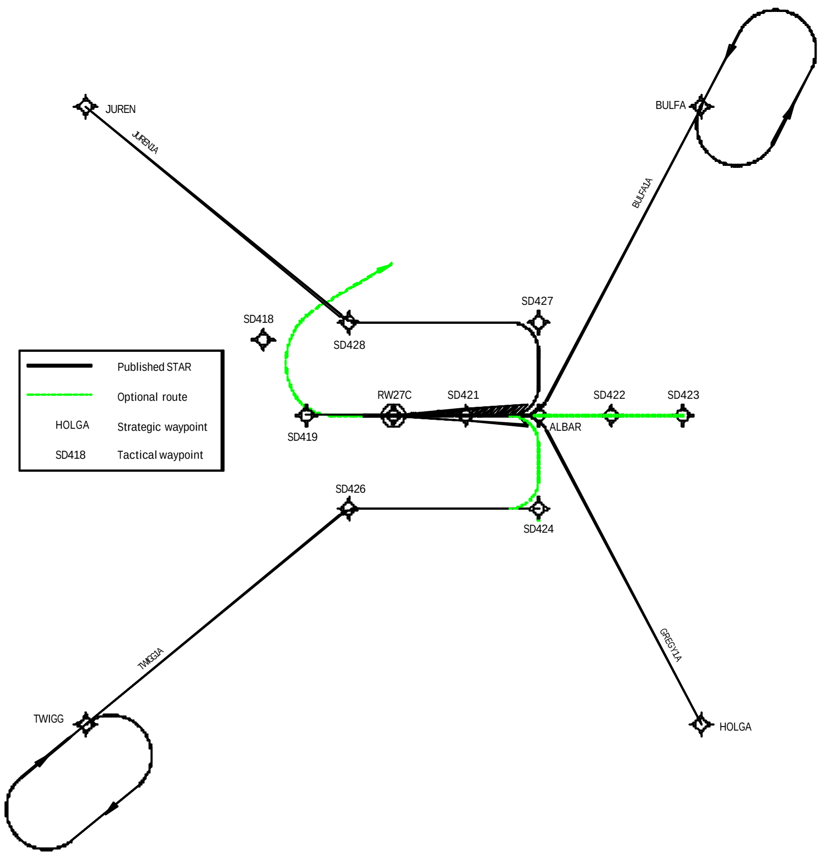

Figure 46 - Open STAR

10.3.2.5 Figure 47 shows an example of a closed RNAV STAR. In this case the STAR follows the longest route and incorporates all the tactical waypoints used for ATM[141]. An altitude restriction at a waypoint at the start of the downwind leg can be used to ensure that aircraft are at a suitable altitude for early turns to final. An example is shown in Figure 47. Note that, when traffic permits, ATC can short cut the STAR by issuing 'Direct to' clearances to TERRY, KLAUS, SD025, MARTN, BODOR and SD026; and further to SD022 or SD023. This design may also allow a Comm Fail procedure to be published which mirrors the complete STAR. Airspace restrictions may limit the use of such STAR designs. In any event, the procedure designer must work closely with the airspace designer and the affected ATC unit to ensure that the design is operationally efficient.

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141 In itself, this route-extension technique cannot be considered to provide sufficient mitigation against the risks described in paragraph. 10.3.2.

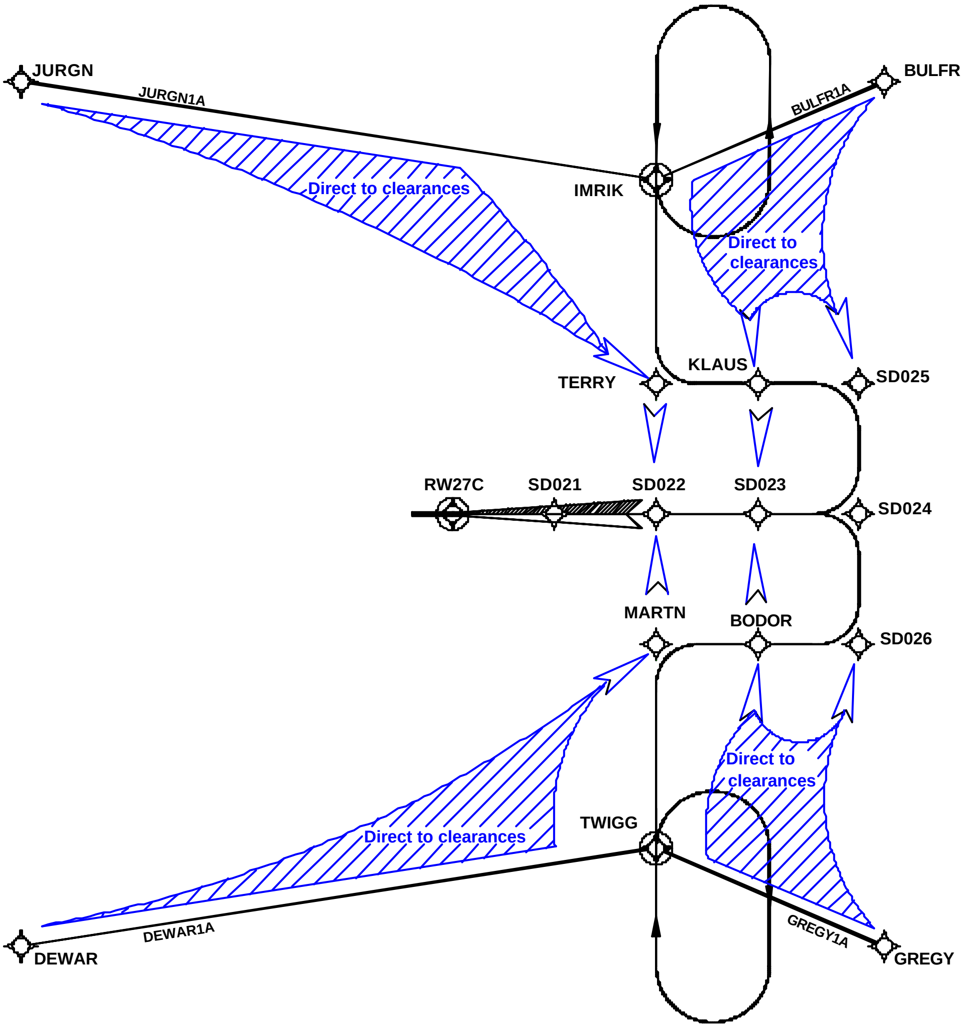

Figure 47 - Closed STAR

10.4 ARRIVAL SEGMENT

10.4.1 There is no limit to the number of legs used for an arrival segment. Turn transitions should be fly-by. Where the track angle exceeds 15°, turn expansion areas must be defined, as detailed in Chapter 6. An area width equal to the en-route width must be used when more than 25 NM along track from the IAF for DME/DME and, for Basic GNSS criteria, when more than 30 NM range from the ARP. For multi-sensor procedures, the more constraining of both criteria apply. Initial approach criteria apply within 25 NM of the IAF and 30 NM of the ARP provided that the next waypoint is the IAF. This is illustrated in Figure 48.

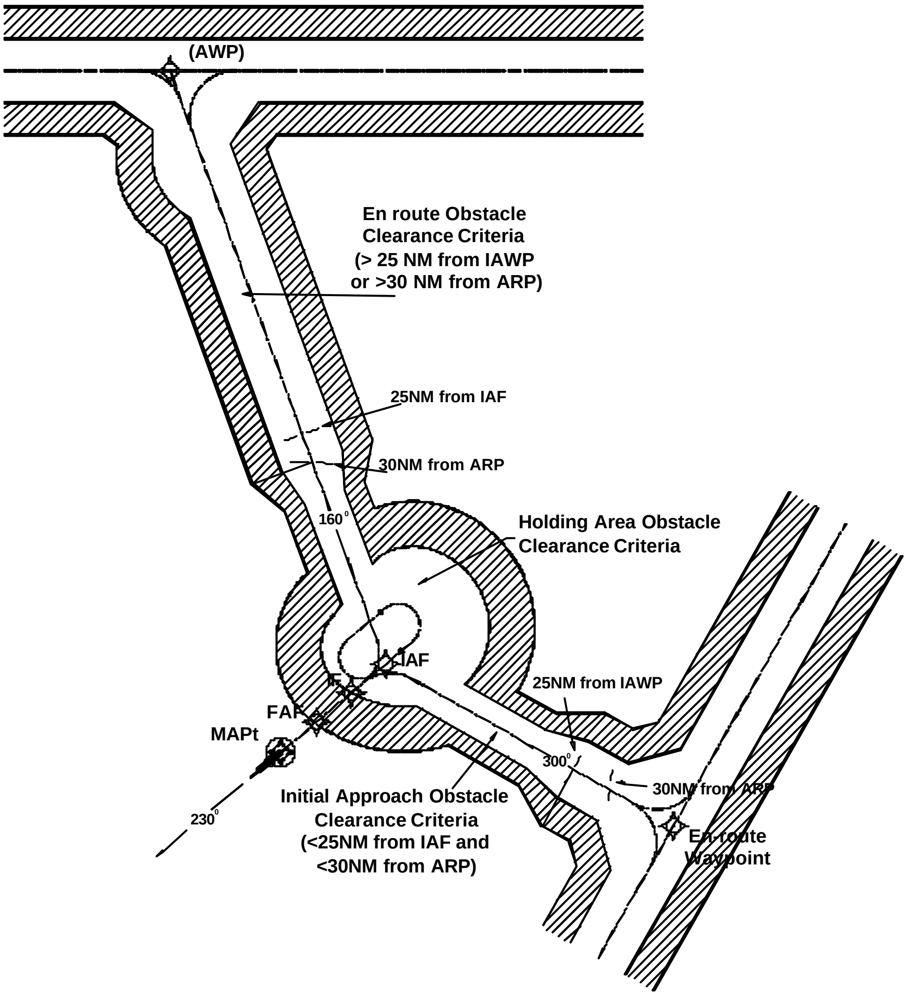

Figure 48 - Arrival Routing

10.5 INITIAL APPROACH SEGMENT

10.5.1 General

10.5.1.1 The initial approach segment begins at the IAF and ends at the IF.

10.5.1.2 The optimum length of the initial approach segment is 5 NM.[142] The optimum descent gradient is 4.0%.[143] The maximum permissible descent gradient is 8.0%.

[142] DOC 8168 Vol 2 Part III Chapter 33 Paragraph 33.4.2 states that, for GNSS approaches, the minimum length for an initial approach segment that follows an arrival route is 6 NM, to allow for blending.

[143] DOC 8168 Vol 2 Part III Appendix to Chapter 33 Paragraph 3.5 states that optimum gradient for basic GNSS receivers is 5%.

10.5.1.3 The minimum length must be determined in accordance with the required descent gradient and the formulae detailed in paragraphs 6.4.2 and 6.6, using the speeds detailed in Table 23. The length may also be varied to accommodate the largest or smallest aircraft expected to use the approach, in order to allow the required altitude changes to be made in the optimum distance.

10.5.1.4 Obstacle clearance requirements are as follows:

a) Primary Area - the MOC is 300 m (984 ft) above the highest obstacle.

b) Secondary Area - the obstacle plane starts at the edge of the primary area at 300 m (984 ft) below the MOC altitude and tapers uniformly to zero feet at the outer edge. The minimum obstacle clearance, at any point, may be determined by $\frac{984 \times d_2}{d_1}$ where d_1 is the width of the secondary area and d_2 is the distance from the obstacle to the outer edge of the secondary area.

10.5.2 RNAV Approaches

10.5.2.1 In a conventional design, the initial approach may consist of up to 4 straight line legs, each defined by a fly-by waypoint at each end. The total length must be sufficient to allow the required altitude changes to be made.

10.5.2.2 Within 25 NM of the IAF and 30 NM of the ARP (if BGNSS criteria are being applied) the obstacle assessment area must taper inward, 30° relative to the centre-line, from the en-route width to the width determined by the navaid availability and any altitude limitations of the approach procedure. Where the taper is not complete before the end of the first leg of the initial approach segment, the turning areas must be constructed in a similar fashion to that described in paragraph 8.6.3. Secondary areas must be used. This is illustrated in Figure 49.

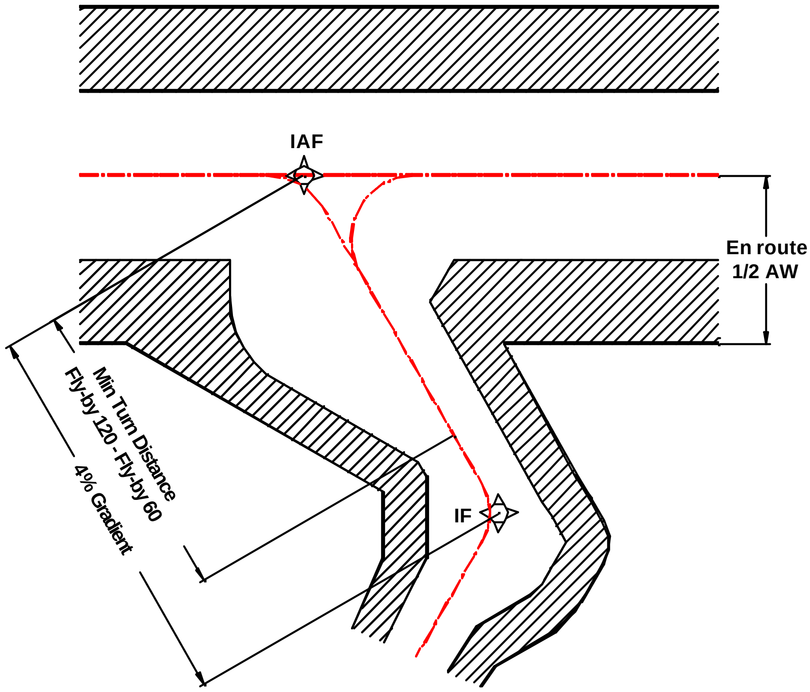

Figure 49 - Initial Approach Segment

10.5.2.3 In a 'Y' design, the initial approach is aligned between 60° and 90° to the intermediate segment and is nominally 5 NM in length (Consistent with the track angle changes at the IF and the IAF and the maximum IAS). If reversal procedures are required, a racetrack pattern should be established at the appropriate IAF, aligned to the initial approach segment. To avoid congestion, only one holding pattern should be established for each procedure. The normal location for a holding pattern would be at one of the IAFs. The initial approach segment may have to be extended up to 10 NM in order that the holding area does not overlap or infringe the IF.

10.5.2.4 Aircraft approaching in the ‘straight-in area’ may arrive directly at the IF and enter the intermediate approach segment.

10.6 INTERMEDIATE APPROACH SEGMENT

10.6.1 The intermediate approach segment begins at the IF and ends at the FAF. In RNAV/Baro VNAV procedures the intermediate segment ends at the Final Approach Point (FAP), which is located at the intersection of the Vertical Path and the minimum height specified for the intermediate segment.

10.6.2 This segment should have a minimum length of 2 NM plus the associated turn initiation distances and an optimum length of 5 NM[144]. Greater distances should not be used unless justified by an operational requirement. The descent gradient should be flat. If a descent is necessary, the maximum permissible gradient is 5.0% and a horizontal leg of at least 1.5 NM (Cat C and D), or 1.0 NM (Cat A and B), should be included to allow the aircraft to prepare its speed and configuration for entry into the final approach segment.

10.6.3 Obstacle clearance requirements are as follows:

a) Primary Area - the MOC is 150 m (492 ft) above the highest obstacle.

b) Secondary Area - the obstacle plane starts at the edge of the primary area at 150 m (492 ft) below the MOC altitude and tapers uniformly to zero feet at the outer edge. The minimum obstacle clearance, at any point, may be determined by $\frac{984 \times d_2}{d_1}$ where d_1 is the width of the secondary area and d_2 is the distance from the obstacle to the outer edge of the secondary area.

10.6.4 If the descent gradient and the navaid availability allows, or if the final approach is a precision approach, the area width may change during the intermediate phase. This is shown in Figure 50. If the final approach is a specific precision approach using ILS or MLS, the existing requirements for that instrument approach will take precedence throughout the precision segment.

144 A Final Approach Course Fix (FACF) is coded in the navigation databases at a distance of between 2 and 8NM from the FAF on the final approach track. If the intermediate segment is longer than 8NM then this FACF will be calculated by the database provider. It is therefore recommended that segments longer than 8NM are not used.

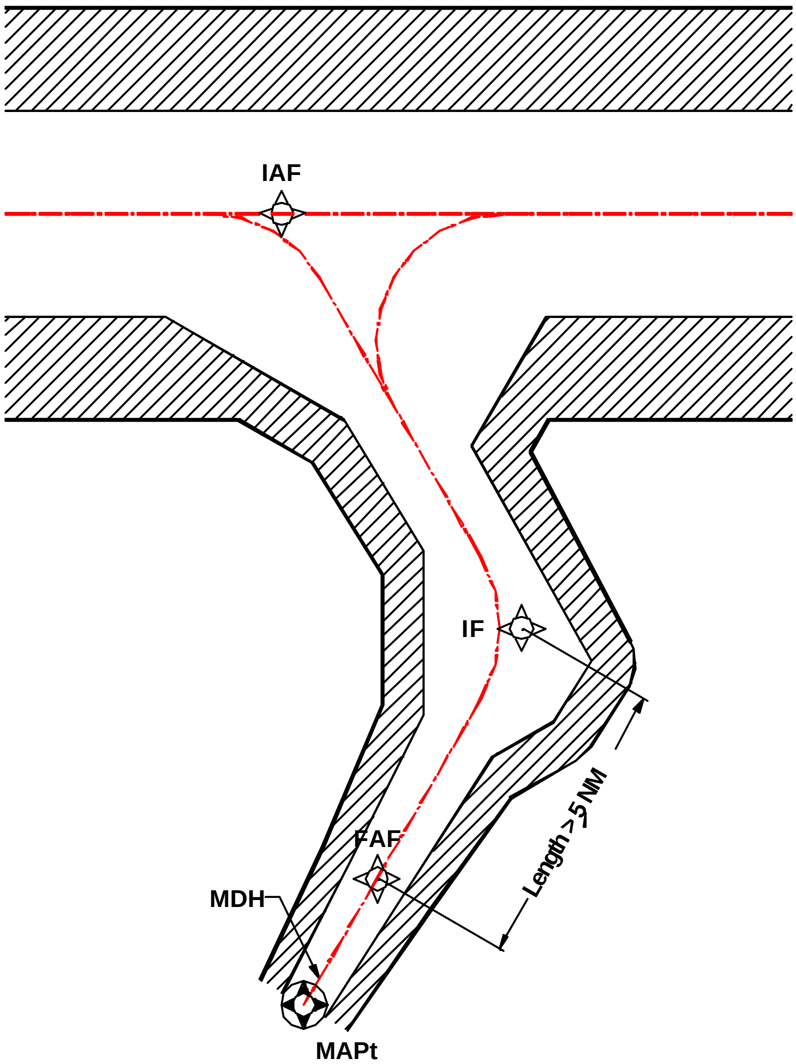

Figure 50 - Intermediate Approach Segment

10.6.5 The intermediate approach should be aligned to the final approach track. Where this is not practical, the maximum track change at the FAF shall not exceed 30°.

10.7 FINAL APPROACH SEGMENT

10.7.1 General

10.7.1.1 The final approach segment begins at the FAF and ends at the MAPt. If the final approach has no vertical guidance element, it is termed a Non Precision Approach (NPA). An NPA may be straight-in or circling. If vertical guidance is provided which does not meet the requirements for precision approach and landing, (e.g. based upon a path calculated by the RNAV system) it is termed an 'Approach Procedure with Vertical Guidance' (APV). An APV may be based upon RNAV/Baro VNAV or RNAV/Geometric-VNAV[145]. Precision approach and landing operations use precision azimuth and glide path guidance with minima as determined by the category of operation.

10.7.1.2 Descent gradient is calculated as $\frac{\Delta h}{\Delta l}$

Where

Δh The vertical distance between the altitude at the FAF and a point 15 m (50 ft) above the threshold (or the circling OCA for circling approaches).

Δl The horizontal distance from the FAF to the threshold (or the first usable portion of the landing surface for circling approaches).

10.7.1.3 The optimum descent gradient is 3° or 5.24%. The minimum descent gradient is 2.5° or 4.37%.

10.7.1.4 The maximum descent gradients are as follows:

a) RNAV and NPA: 3.77°, or 6.5%, for Cat A and B aircraft and 3.5°, or 6.11%, for Cat C and D aircraft.

b) RNAV/Baro VNAV and Cat I Precision Approach: 3.5° or 6.11%.

c) Cat II and III Precision Approach: 3° or 5.24%.

10.7.1.5 The descent angle, descent gradient, the minimum IFR altitude at the FAF and the vertical path altitude at the FAF should be published for all RNAV approaches and NPAs. The vertical path, Reference Datum & Height (RDH) and the altitude at the FAP should be published for all RNAV/Baro VNAV approaches. The GP, RDH and the glide path altitude at the FAP should be published for all Precision Approaches [146]

[145] No criteria have yet been developed for RNAV/Geometric-VNAV. The APV I and APV II operations for SBAS and GBAS will be RNAV/Geometric VNAV.

[146] Presented as glide path angle for precision approaches, vertical path angle for APVs and descent gradient (descent angle) for NPAs. Gradients should be specified in feet per NM; angles should be published to hundredths of a degree.

10.7.2 RNAV Approaches

10.7.2.1 The optimum length for the final approach segment is 5 NM and it should not normally exceed 10 NM.[147] The minimum length must provide adequate distance for an aircraft to meet the required descent rate and to regain course alignment when a turn is required over the FAF.

10.7.2.2 The primary area is centred on the Final Approach Course (FAC). It tapers from the width specified for the intermediate segment, at the FAF, to the width specified by the navaid availability, the descent gradient and the OCA, at the MAPt.

10.7.2.3 In a conventional design, the optimum straight-in FAC should be coincident with the extended runway centre-line. In any event, it must not exceed 30° from the extended runway centre-line, for Category A and B, or 15°, for Category C and D. If the track angle change is ≤5°, the FAC must be contained within 150m of a point on the extended centre-line, located 1400m prior to the threshold.

10.7.2.4 The final approach segment terminates at the MAPt for non-precision approaches. The MAPt is located at the intersection of the FAC and the extended runway centre-line, except where the FAC is aligned to the Landing Threshold Point (LTP). In such a case, the MAPt may be located at any point along the FAC up to, and including, the LTP.[148]

10.7.2.5 All other RNAV final approaches are considered to be circling approaches with prescribed tracks. These are aligned to a designated point from which a visual manoeuvre can be conducted to bring an aircraft into position for landing. The nominal ground track from the designated point to the threshold of the landing runway is provided, and may be coded in the database, but the MAPt may only be located at, or prior to, the designated point.

10.7.2.6 Obstacle clearance requirements for straight-in approaches where the track angle change is ≤5° are as follows:

a) Primary Area - the MOC is 75 m (246 ft).

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147 If the length is in excess of 6 NM, the obstacle clearance requirements detailed in Doc 8168 Vol 2 Part III Paragraph 6.3.6.b apply.

148 DOC 8168 Vol 2 Part III Appendix to Chapter 33 Paragraph 6.1 requires the MAPt to be located at the threshold for approaches aligned with the runway, and on the FAC abeam the threshold when the approach is not aligned to the runway. Where the MAPt has to be moved to effect obstacle clearance, it may be relocated towards the FAF up to, but not beyond, the point where the OCH intersects a nominal 5% descent gradient to the runway.

b) Secondary Area - the obstacle plane starts at the edge of the primary area, 75 m (246 ft) above the highest obstacle, and tapers uniformly to zero feet at the outer edge. The MOC, at any point, may be determined by $\frac{246 \times d_2}{d_1}$ where d_1 is the width of the secondary area and d_2 is the distance from the obstacle to the outer edge of the secondary area.

10.7.2.7 If the track angle change is >5°, the lowest obstacle clearance heights that may be applied in the primary area are those detailed in Table 36 below:

Aircraft Category	Obstacle Clearance Heights
A	115 m (377 ft)
B	140 m (460 ft)
C	165 m (540 ft)
D	165 m (540 ft)
E	180 m (590 ft)

Table 36 - RNAV Final Turns>5° (Minimum Obstacle Clearance Heights)

10.7.2.8 The obstacle clearance heights in the circling area are detailed in Table 37. The circling approach area does not have a secondary area.

Aircraft Category	Obstacle Clearance Heights
A & B	90 m (295 ft)
C & D	120 m (394 ft)
E	150 m (492 ft)

Table 37 - Circling Approaches (Minimum Obstacle Clearance Heights)

10.7.3 RNAV/Baro VNAV Approaches[149]

10.7.3.1 General

RNAV/Baro VNAV approach criteria are only applicable to the final approach and missed approach phases of flight. They may only be used in conjunction with RNAV procedures and overlay the final segment of an RNAV procedure, if it is aligned with the runway centreline. The conventional obstacle clearance areas associated with the RNAV FAF and MAPt are used to define the lateral limits of the RNAV/Baro VNAV obstacle clearance areas but the actual RNAV/Baro VNAV final approach segment is defined using an FAP and a DA/H. RNAV/Baro VNAV operations may only be flown using a current local altimeter setting source.

[149] Commonly known as VNAV approaches although this is a misnomer as VNAV may be used in arrivals and NPAs as described in paragraph 10.2.6.

Note: An approach flown using the LLZ and VNAV is NOT equivalent to an RNAV/Baro VNAV approach

10.7.3.2 Cold Temperature Corrections

RNAV/Baro VNAV approach criteria take account of the minimum promulgated operating temperature for the aerodrome and the associated corrections as detailed in Table 38[150]. These values should be added to the minimum safe altitudes as appropriate. The minimum promulgated temperature[151] is determined by rounding down the minimum probable temperature to the next lower 5°C increment.

Minimum Promulgated	**Height above the Elevation of the Altimeter Setting Source (ft)**													
Temperature °C	200	300	400	500	600	700	800	900	1000	1500	2000	3000	4000	5000
0	11	17	22	28	33	39	44	50	55	83	111	167	223	280
-10	19	29	38	48	57	67	76	86	95	143	192	288	386	484
-15	23	35	47	58	70	82	93	105	117	175	234	353	472	593
-20	28	42	55	69	83	97	111	125	139	209	279	420	562	706
-30	37	56	74	93	111	130	149	167	186	279	373	562	753	945
-40	47	71	95	118	142	166	189	213	237	356	476	717	961	1206
-50	58	88	117	146	175	205	234	263	293	440	588	886	1187	1490

Table 38 - Cold Temperature Corrections (ft)

Unless temperature corrections are applied in the aircraft, the VPA will vary according to the temperature on the day. The values in the table below show the variation for an aerodrome at sea level where the 3.00° VPA has been designed for a nominal aerodrome temperature of +15°C.

A/D Temp	**VPA**
+30°C	3.15°
+15°C	3.00°
0°C	2.83°
-15°C	2.65°
-30°C	2.44°

Table 39 - VPA Deviations

10.7.3.3 System Requirements

RNAV/Baro VNAV approaches may only be flown with appropriately certified aircraft. The RNAV/Baro VNAV criteria were developed on the assumption that the following minimum capabilities would be available:

150 They are calculated for an aerodrome at sea-level and are conservative when applied to higher aerodromes. A formula to calculate more precise corrections is provided in Doc 8168 PANS-OPS Vol I Part VI Chapter 3, paragraph 3.3.3.

151 Based upon the mean low temperature, at aerodrome elevation, for the coldest month of the year, collated over a period of at least a 5 years.

a) A lateral navigation system, certified for approach operations:

   i) To RNP-RNAV ≤0.3, or

   ii) Having a 95% total system performance equal to, or less than 0.3NM, and using:

      - GNSS sensors, or

      - DME/DME sensors and IRUs (using inputs only from DME stations that meet post 1989 Annex 10 requirements)

b) A vertical navigation system, certified for approach operations, with an accurate source of barometric or geometric altitude and an ability to switchover from approach to missed approach guidance.

c) A navigation database containing all the waypoints and associated data (including RDH and GP) for the procedure and the missed approach that is automatically loaded when selected by the flightcrew.

The JAA is producing a TGL for RNAV approach operations which will also address RNAV/Baro VNAV applications and which will provide the basis for certification and operational approval for RNAV/Baro VNAV operations in Europe.

10.7.3.4 Aerodrome Requirements

RNAV/Baro VNAV procedures require that no obstacles with a height of 5 m or more above the threshold penetrate the visual protection surface for the runway.

The Visual Protection Surface has the lateral dimensions of the First and Second Sections of the Approach Surface for a Precision Approach Runway Code No 3,4 as defined in Annex 14, as well as that portion of the runway strip from the threshold to 60m before the threshold. The sloping surface starts 60m before the threshold with a slope of 3.33% and ends $\left[\frac{(OCH - RDH)}{\tan GP} + ATT\right]$m before the threshold.

All obstacle heights must be referenced to threshold elevation.

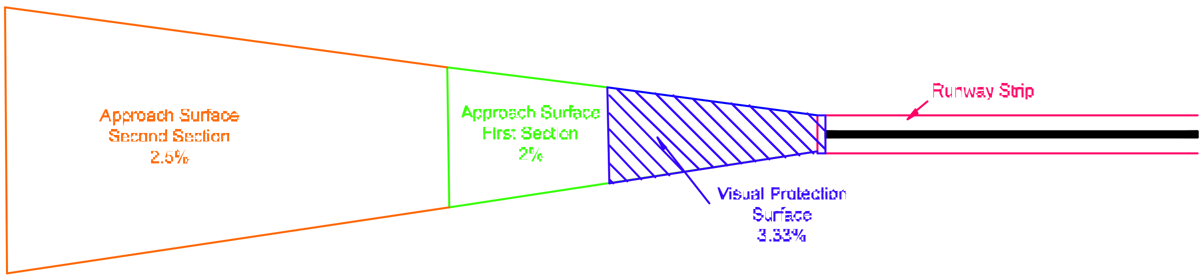


Figure 51 - Visual Protection Surface

10.7.3.5 Design Criteria

An RNAV/Baro VNAV approach must be aligned to the runway centreline. It is defined by an RDH, a GP and an FAP as follows:

a) The RDH is a point located 50 ft above the runway threshold (the Threshold Crossing Height (TCH)). It is defined by latitude/longitude (to $^1/_{100}$ second) and height above the threshold (to 1 ft).

b) The GP is a vertical angle between 2.5° and 3.5° (to $^1/_{100}$ degree). The optimum value is 3°.

c) The FAP is normally located within 10NM of the threshold at the point where the GP intersects the minimum height specified for the preceding segment.

This is illustrated in Figure 52.

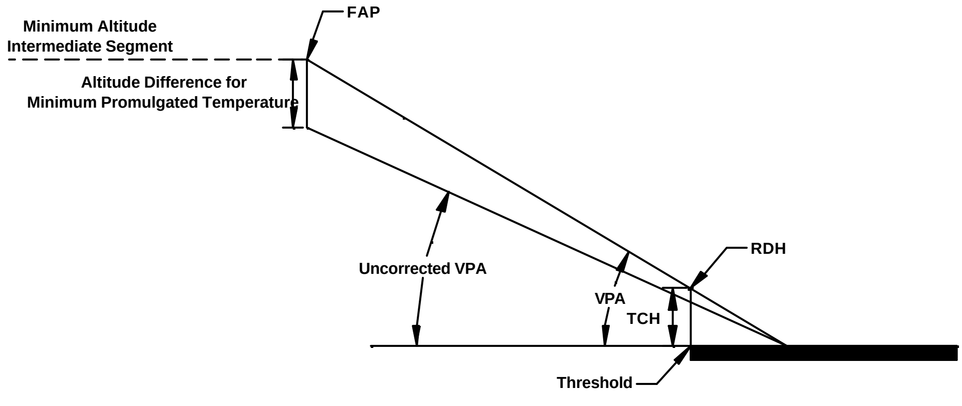


Figure 52 - RNAV/Baro VNAV RDH, GP and FAP

The APV Segment Obstacle Assessment Surface starts at the FAP and ends at the MATP or MAHF, whichever is first. If a turn is specified at the RNAV MAPt, then the APV segment terminates at the MAPt. The APV OAS has the following surfaces, each of which has associated side surfaces:

a) Final Approach Surface (FAS)

b) Horizontal Plane

c) Intermediate and final missed approach surfaces (Zi and Zf)

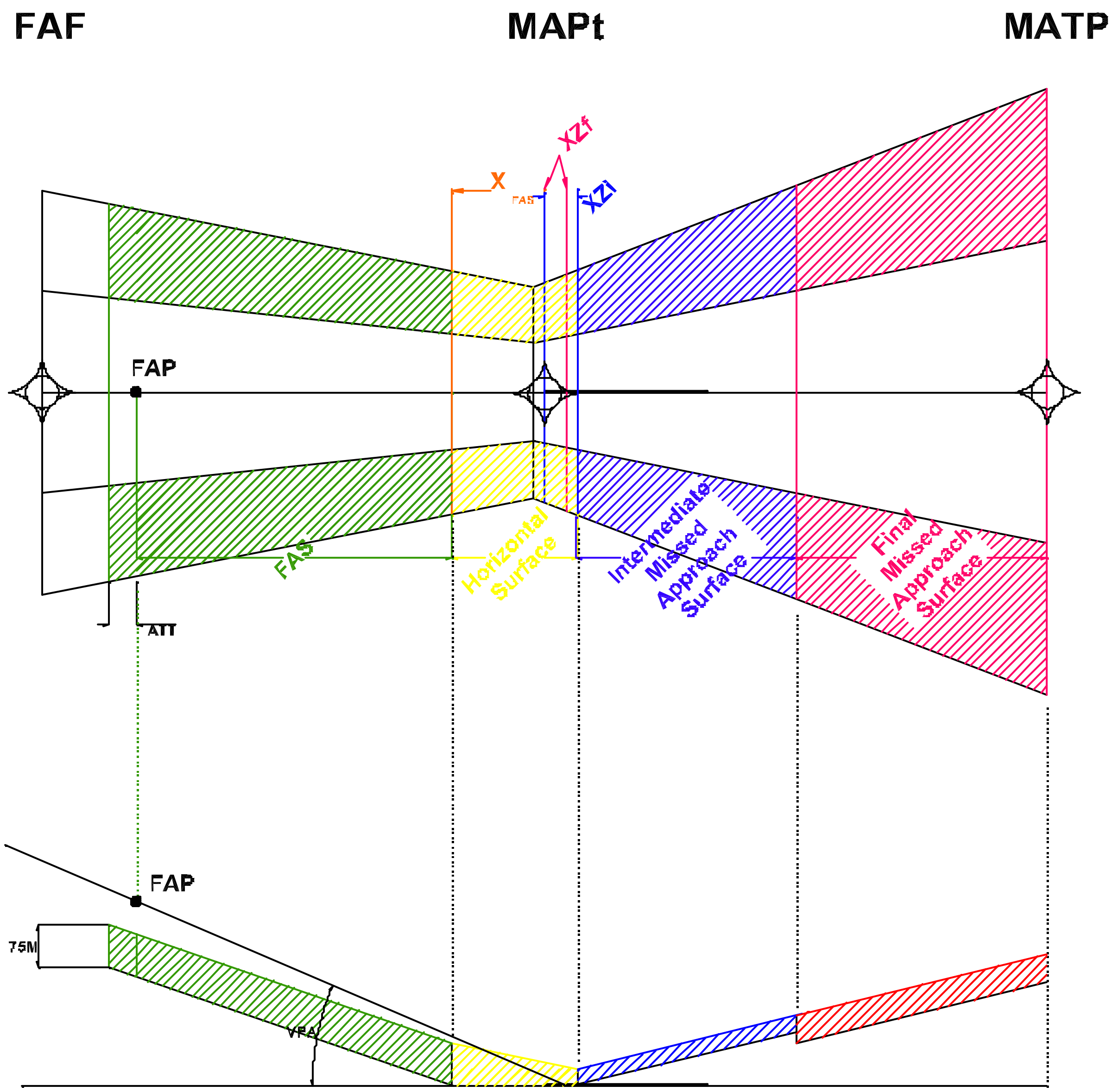
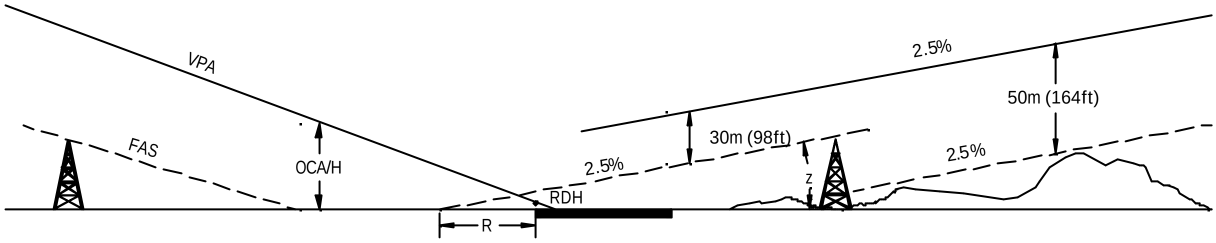


Figure 53 - APV OAS



The FAS originates at threshold level,

$$X_{FAS} = \frac{(MOC_{app} - RDH)}{\tan VP} + ATT$$ m before the threshold

and ends ATT before the FAP. The angle of the FAS is determined by:

$$\tan \alpha_{FAS} = \frac{(Height_{FAP} - MOC_{app} - TempCorrn) * \tan VP}{(Height_{FAP} - MOC_{app})} .$$

The FAS has the lateral dimensions equivalent to the related RNAV OCS primary area. Its side surfaces are defined by the edge of the RNAV primary area at the FAS elevation and the outer edge of the RNAV secondary area 75M above the FAS elevation.

The horizontal plane is a surface at threshold level with lateral dimensions equivalent to the related RNAV OCS. It lies between the FAS and the intermediate missed approach surface. Its side surfaces are defined by the edge of the RNAV primary area, at the threshold elevation, and the outer edge of the RNAV secondary area, 75M above the threshold elevation at the FAS origin and 30M above the threshold elevation at the Zi origin.

The intermediate missed approach surface (Zi) starts at threshold level, at a distance Xzi after the threshold.

$$XZi = \frac{(MOC_{app} - RDH)}{\tan VP} - ATT - d - X + \frac{(MOC_{app} - 30)}{\tan Z}$$

Where:
MOC_{app} is the MOC for the approach
d is the distance corresponding to a 3 second delay for pilot reaction time
X is the transitional tolerance
Z is the angle of the missed approach surface (Tan Z is usually 2.5%)
30 is the MOC for the intermediate missed approach

Zi has a nominal gradient of 2.5% and it ends at the first point at which 50m MOC is obtained and maintained. It has the lateral dimensions of the related RNAV OCS primary area. Its side surfaces are defined by the edge of the RNAV primary area at the Zi elevation and the outer edge of the RNAV secondary area 30M above the Zi elevation.

The final missed approach surface starts at the end of the intermediate missed approach surface. At that point and after that point it is defined by a surface, Zf, which originates at threshold level, at a distance Xzf after the threshold. Its side surfaces are defined by the edge of the RNAV primary area at the Zf elevation, the inner edge of the RNAV secondary area at the Zf elevation and the outer edge of the RNAV secondary area 50M above the Zf elevation.

$$XZf = \frac{(MOC_{app} - RDH)}{\tan VP} - ATT - d - X + \frac{(MOC_{app} - 50)}{\tan Z}$$

Where:
50 is the MOC for the final missed approach

Zf has a nominal gradient of 2.5% and it ends at the MATF or MAHF, whichever is earliest. If a turn is specified at the RNAV MAPt, then the APV segment terminates at the MAPt. This is illustrated in Figure 53.

10.7.3.6 Minimum Obstacle Clearance

The OCA/H calculation is very similar to that applied for ILS OAS assessments with the exception that the principle of secondary areas is applied throughout.

The MOC value is based upon the status of the Annex 14 surfaces and, where appropriate, the effect of any mountainous terrain or excessively long final approaches.

The MOC in the final approach area is governed by the status of the Annex 14 inner approach, inner transitional and baulked landing surfaces together with the maximum lateral tolerance of the RNAV system:

a) If the Annex 14 surfaces have been assessed and have not been penetrated, the MOC is 75 m (246 ft)

b) If the Annex 14 surfaces have been penetrated or have not been assessed, the MOC is 90 m (295 ft)

If the APV-OAS is not penetrated then the OCH is defined by the MOC.

Accountable approach obstacles penetrate the FAS or the horizontal plane.

The secondary areas of the horizontal plane are complicated by the fact that the inner edge is at the threshold elevation while the outer edge descends from 75m above threshold elevation to 30m above threshold elevation. The height of a point on the surface is established by first determining the height of the outer edge abeam the point:

$$Z_{abm} = 75 + (30 - 75)\left(\frac{X_{pt}}{X + X_{zi}}\right)$$

Where:
Z_{abm} is the height of the outer edge abeam the point
X_{pt} is the distance from the FAS origin to the point

and then determining the height of the point:

$$Z_{pt} = Z_{abm}\left(1 - \frac{Y_{pt}}{Y_{abm}}\right)$$

Where:
Z_{pt} is the height of the point
Y_{pt} is the distance from the inner edge to the point
Y_{abm} is the distance from the inner edge

Accountable missed approach obstacles penetrate the missed approach surfaces.

The equivalent height of a missed approach obstacle is determined by: $h_a = \frac{h_{ma} \cot z + (XZ + x)}{\cot z + \cot VP}$

Where:
h_a is the equivalent approach obstacle height
h_{ma} is the height of the missed approach obstacle
z is the angle of the z surface
VP is the vertical path angle
XZ is the distance from the threshold to the start of the Xzi or XZf surface, as appropriate
X is the distance from the threshold to the obstacle (negative after the threshold)

The OCH is the sum of the height of the highest accountable obstacle and the MOC.

10.7.4 ILS And MLS Approaches

In a precision approach, the precision elements of the final approach and missed approach segments must be designed in accordance with the existing requirements for the approach aid in question.[152]

[152] All arrival and approach legs should be coded TF although some older RNAV systems require a CF leg to the threshold for the ILS interception.

10.8 MISSED APPROACH SEGMENT

10.8.1 General

10.8.1.1 The missed approach segment begins at the MAPt and ends at a point where the aircraft, climbing at the minimum prescribed climb gradient, reaches the minimum altitude for a new approach, en-route flight or holding, whichever is appropriate.

10.8.1.2 The missed approach procedure for a Non Precision Approach comprises three distinct phases: initial, intermediate and final.

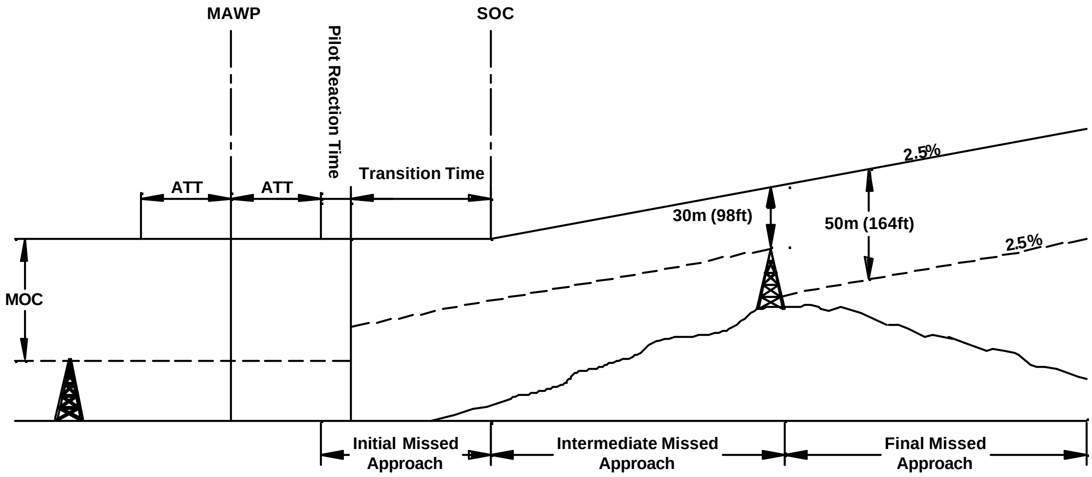


Figure 54 - Missed Approach Phases

10.8.1.3 The initial phase begins at the MAPt and ends at the start of climb (SOC) point. It includes the longitudinal tolerance applied for the navigation system (ATT), the effect of a tail wind of 10 kt, a timing tolerance associated with the manually initiated transition from approach to missed approach climb (3 seconds) and the transitional tolerance allowed for aircraft configuration and flight path changes (15 seconds). This is detailed in Table 40. Minimum obstacle clearance must be the same as for the last leg of the final approach segment, except where the extension of the missed approach surface towards the MAPt requires less clearance. No turn may be defined for this phase, nor may any turn anticipation commence during this phase.

Aircraft Category/ Speeds (Including 10 kt tailwind)	A 110 kt	B 140 kt	C 170 kt	D 195 kt	E 240 kt
ATT (at 500 ft) (2 DME / >2 DME)	0.81/0.64	0.81/0.64	0.81/0.64	0.81/0.64	0.81/0.64
Pilot Reaction Time (3 sec)	0.09	0.12	0.14	0.16	0.20
Transition Time (15 sec)	0.46	0.58	0.71	0.81	1.00
Distance from MAPt to latest MAPt	0.90/0.73	0.93/0.76	0.95/0.78	0.97/0.80	1.01/0.84
Distance from MAPt to SOC	1.36/1.19	1.51/1.34	1.66/1.49	1.78/1.61	2.01/1.84

Table 40 - Missed Approach Tolerances - DME/DME (Calculated at 500 ft)

10.8.1.4 The intermediate phase begins at the SOC and continues until 50 m (164 ft) obstacle clearance is obtained and can be maintained. Track changes of up to a maximum of 15° are permissible. Minimum obstacle clearance is 30 m (98 ft).

10.8.1.5 The final phase begins at the point where 50 m (164 ft) obstacle clearance is first obtained, and can be maintained, and extends to the point at which the aircraft, climbing at the minimum prescribed climb gradient, reaches the minimum altitude for a new approach, en-route flight or holding, whichever is appropriate. The angle of intersection between adjacent segments should not exceed 120°.

10.8.1.6 The initial and intermediate phases of a missed approach procedure, associated with a precision approach using a specific ground aid, should be calculated in accordance with the existing requirements. The precision segment terminates once the obstacle assessment surface reaches a height of 300 m (984 ft) above the threshold, or at a designated turning point or altitude. It is from this point that the obstacle assessment for the RNAV missed approach procedure can commence.

10.8.1.7 The MAPt shall be a fly-over transition for an RNAV procedure. Subsequent transitions should be fly-by, wherever possible. The minimum leg distance for the first leg must be that detailed in Table 40, plus the minimum segment length, as detailed in Table 27, plus the ATT, as detailed in Chapter 8. The minimum leg distance for subsequent legs must be the minimum turn distance or 0.6 NM, whichever is greater. This is shown in Figure 55. The first leg may end in a conditional transition if this provides operational benefits.

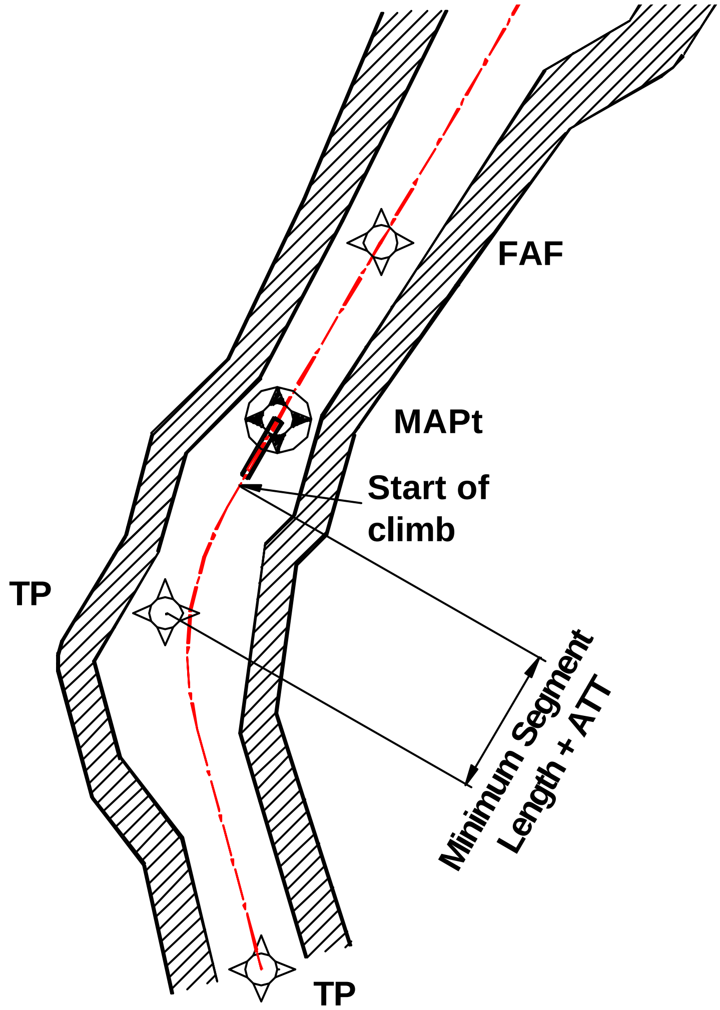


Figure 55 - Missed Approach Segment

10.8.1.8 Obstacle clearance is determined by identifying those obstacles that penetrate the OIS/missed approach surface and increasing the Obstacle Clearance Altitude/Height (OCA/H), or moving the MAPt, or specifying a climb gradient that will provide the required obstacle clearance. The nominal climb gradient is 2.5%, although 2% may be used if the necessary survey and safeguarding can be provided, and 3 to 5% may be used for aircraft whose climb performance permits an operational advantage to be obtained.[153] The principles upon which the departure calculations are based, detailed in Chapter 8, also apply to missed approaches. The determination of navaid availability, maximum angle of bank, XTT, ATT and Area Width should be based upon the minimum climb gradient authorised for the procedure.

[153] Doc 8168 Vol 2 Part III Paragraphs 7.1.6 and 7.1.7 (Draft 8260.40A says a 40:1 missed approach surface with a 200 ft/NM (3.3%) climb gradient)

10.8.2 RNAV Approaches

10.8.2.1 The missed approach area begins at the 'earliest MAPt', a distance equal to the ATT before the MAPt, with the same width as the preceding final approach segment leg. The primary and secondary areas are splayed at 15° to the track centreline from the earliest MAPt until track guidance is regained.

a) For procedures used by RNAV systems capable of guided missed approaches, this is assumed to have been achieved by the end of the initial missed approach segment (SOC). Thereafter the width is increased in accordance with the navaid availability and the Minimum Climb Gradient (MCG), using the values detailed in Table 34, or calculated according to the appropriate formulae. If the required width at the SOC is less than that achieved by the outward splay, the area should be splayed inward again at 15° until the appropriate width is attained. Secondary areas are applicable throughout.

b) For procedures used by RNAV systems that are not capable of guided missed approaches, the criteria specified for conventional missed approaches in Chapter 7 of Doc 8168 should be applied.

10.8.2.2 If the procedure joins a structure with a wider obstacle assessment area, the splay at 15° to the track centre-line shall be continued until the greater width is reached.

10.8.3 RNAV/Baro VNAV Approaches

10.8.3.1 The specific missed approach criteria for the APV segments are covered in paragraph 10.7.3. Connections to the rest of the missed approach procedure are detailed in the following paragraph.

10.8.4 APV and Precision Approaches

10.8.4.1 The RNAV missed approach procedures, defined in this document, start at the end of the precision segment with the same width as the preceding segment 'Z' surface. This width is then splayed at 15° to the track until the area width, appropriate to the navaid availability and the MCG, is achieved. The width is increased, as necessary, according to the navaid availability and minimum usable altitude at each waypoint. If the procedure joins a structure with a wider obstacle assessment area, the area will be splayed at 30° to the track centre-line in the final leg, in order that the width of the subsequent area is reached at the point of intersection. Secondary areas are applicable throughout the RNAV elements of the route.

11 PROCEDURE DESCRIPTIONS

11.1 GENERAL REQUIREMENTS

11.1.1 The chart users' requirements can differ significantly:

a) A navigation database provider requires unambiguous descriptions and depictions of all the procedures in sufficient detail to allow them to be accurately coded for the RNAV systems. All relevant information must be available either on the chart or in supporting text and tables.

b) A pilot needs a chart to be clear and easy to read in the cramped and dimly lit conditions on the flight deck. The chart should only contain that information which is necessary for the conduct of the flight.

11.1.2 Although most pilots use charts provided by commercial charting organisations, in certain States a significant number of pilots rely on the charts provided in the AIPs. For this reason, the AIP provider must ensure that the charts provided are designed to meet the requirements of all anticipated user types.

11.1.3 An accurate graphical depiction of the required tracks is essential for the pilot and the coder, both of whom compare the chart to the map display generated by the RNAV system. Wherever possible, the chart and the EFIS display, which is to scale, should match. However, while it is highly desirable, it is not essential for RNAV charts to be drawn to scale and it is preferable to provide a concise summary of long range SIDs and STARs rather than a scaled representation of the routes. See paragraph 11.1.13

11.1.4 The primary function of all RNAV charts is to:

a) Provide pilots with a clear description of the required procedure and sufficient data to monitor the performance of the RNAV system.

b) Provide database suppliers with an unambiguous representation of the procedure in order to check the database coding generated from the procedure descriptions.

11.1.5 In complex terminal areas it may be beneficial to the database coders to provide additional schematic diagrams to clarify and complement the conventional charts.

11.1.6 Waypoint and navaid co-ordinates should be published in one location in an AIP. Co-ordinates specifically associated with an aerodrome should be published in the appropriate aerodrome entry. Although the RNAV system databases hold co-ordinate data to a resolution appropriate to the calculations that have to be made, the data displayed to the pilot is usually limited to a resolution of 0.1 minutes. Where co-ordinate data is provided on the charts used by pilots, it should be to a resolution that is compatible with the RNAV system displays. It is recommended that the Annex 15 requirements are met by the publication of all waypoint and navaid co-ordinates in tabular form and the charting requirements for pilots are met by the publication, on the charts or on associated pages of the chart manual, of appropriate co-ordinates to a resolution of 0.1 minutes.

11.1.7 When operationally required, separate charts can be published for different sensors/navigation infrastructures, or combinations thereof, or for different aircraft categories, where appropriate.

11.1.8 Where part of a SID or STAR is designated as appropriate for RNP-RNAV, B-RNAV or P-RNAV approved aircraft, it must be annotated on the chart itself. Furthermore, each RNAV chart shall be identified as follows:

a) **RNAV** denotes that the procedure design is predicated on DME/DME, Basic GNSS and VOR/DME. In ECAC it is not recommended for use as P-RNAV systems require DME/DME or GNSS as primary sensors.

b) **RNAV$_{\textbf{(DME/DME or GNSS)}}$** denotes that the procedure design is predicated on DME/DME and GNSS. It may be flown using DME/DME or GNSS.

c) **RNAV$_{\textbf{(DME/DME)}}$** denotes that the procedure design is predicated on DME/DME only.

d) **RNAV$_{\textbf{(GNSS)}}$** denotes that the procedure design is predicated on GNSS[154].

e) **RNAV$_{\textbf{(DME/DME or GNSS except Class A)}}$** denotes that the procedure design is predicated on DME/DME and Class B and C GNSS.

RNP-RNAV approaches should be clearly identified by publishing the RNP value in the minimum box.

11.1.9 Each terminal procedure shall be described in the following forms:

a) Textual description

[154] In the future, when Galileo and the Space Based Augmentation Services are available, it is anticipated that the generic terms ABAS and SBAS will be used instead.

b) Tabular description

c) Graphical representation

11.1.10 Charts for pilots' use must include:

a) Distances (to nearest tenth of a NM) between waypoints.

b) Bearing (to nearest degree) and horizontal distance (to nearest tenth of a NM) from specified navaids to specific waypoints to allow navigation accuracy checks to be performed, when required.

c) All waypoints associated with the procedure/route, including names.

d) All navaids associated with the procedure, together with frequencies and identifications.

e) When required, altitude/flight level (in units of 100ft or less as appropriate)and speed constraints (in units of 10 kts).

11.1.11 The altitude constraints shall be depicted on charts as follows:

- An altitude/flight level window has a line above and below the appropriate levels:

$$\overline{\text{FL220}}$$
$$\underline{\text{10,000}}$$

- An "at or above" altitude/flight level has a line below the appropriate level:

$$\underline{\text{7000}}$$

- A "hard" altitude/flight level has a line above and below the appropriate level:

$$\underline{\overline{\text{3000}}}$$

- A "at or below" altitude/flight level has a line above the appropriate level:

$$\overline{\text{5000}}$$

- A "recommended" altitude/flight level has no lines associated with it:

5000

- An altitude/flight level to which clearance may be expected is preceded by the text "Expect":

Expect 5000

11.1.12 Any speed constraints below the appropriate ICAO values, detailed in Table 23, must be charted.

11.1.13 It is recommended that both scale-bars and parallel/meridian graduations are shown on charts that have been drawn to scale. A NOT TO SCALE annotation is required for any sections on charts that are not drawn to scale.

11.1.14 It is recommended that States publish path terminator details for RNAV procedures. However, where a procedure designer requires a particular track to be flown (TF path terminator), or a particular course to be flown (CF path terminator), or a track direct to the next waypoint (DF path terminator) or a fixed radius turn (RF path terminator), this must be clear to the coders. This can be achieved by use of a formal textual description and an abbreviated procedure description, as detailed Table 41 and Table 42; or by including path terminator details in the tabular description as illustrated in Table 43. The abbreviated procedure description is intended to be used by those States where publication of path terminators is currently not permitted. The use of the abbreviated description on charts is optional - some pilots have indicated that it is a useful quick reference but there is insufficient evidence as yet to justify requiring inclusion on all charts.

Textual Description in AIP	Abbreviated Description in AIP	Expected Path Terminator Coding	Fly-Over Required
Climb on track 047°M, at or above 800 ft turn right.	[A800+; M047; R]	FA	
Direct to ARDAG at 3000ft	→ARDAG[A3000]	DF	
To PF035 at or below 2000ft, turn left.	PF035[A2000-; L]	TF	Y
To OTR on course 090°M at 210 kts	OTR[M090; K210]	CF	
To DF006 at 2000 ft minimum, 4000 ft maximum, minimum speed 210 kts	DF006[A2000+; A4000-; K210+]	TF	Y
To PD750 at 250 kts, turn right with 3.7 NM radius to PD751	PD750[K250]-PD751[R, 3.7, 0543451.2N 0021234.7E]	RF	
From STO at or above FL100, turn left direct to WW039 at or above FL070, to WW038 at or above 5000ft	STO[F100+; L]→WW039[F070+]-WW038[A5000+]	IF TF DF TF	Y

Table 41 - Example Coding for Abbreviated Procedure Description

An RNAV procedure is defined by one or a number of waypoints, each defined by a waypoint name and a set of constraints.

Waypoint Name

Constraints

Waypoint Name (underlined) denotes 'fly-over'.

Waypoint Name (not underlined) denotes 'fly-by'.

'To' Waypoint Name denotes TF leg coding.

'Direct to' Waypoint Name denotes DF leg coding.

'To' Waypoint Name 'on course XXX° ' denotes CF leg coding.

'Çlimb on track XXX° ' denotes FA coding

'From' Waypoint Name 'to' Altitude/Flight Level 'on track XXX°' denotes FA coding

Waypoint Name followed by {R, NN.N, LatLong} denotes the waypoint at the end of the turn, the radius and the centre point of a fixed radius turn.

Waypoint Name followed by {H, Turn Direction, Inbound Track, Leg Distance/Time, Terminating Altitude} denotes a holding procedure.

[Speed, track and altitude constraints are contained within square brackets.]

If [A Set of Constraints] is not preceded by a waypoint name, the last calculated track must be flown until the constraint is reached.

Each constraint is coded in the format UNNNNNCD where:

U may be one of the following letters:

A for altitude in feet AMSL

F for Flight Level

K for Indicated Air Speed in knots

M for degrees magnetic

T for degrees true

NNNNN is a number from 000 to 99999

C may be one of the following:

+ for 'at or above'

- for 'at or below'

a blank space for 'at'

D is used to indicate turn direction in conditional and fly-over transitions:

L for 'Turn left'

R- for 'Turn right

Multiple constraints should be separated by a semi-colon (;).

Individual waypoints in a procedure, together with their associated constraints, should be separated by a hyphen (-), except when the subsequent leg is coded as DF when an arrow (→) should be used.

Table 42 - Examples of Procedure Descriptions

Path Terminator	Fix Identifier (Waypoint Name)	Fly Over	Course ° M (° T) [155]	Turn Direction	Altitude	Speed Limit	Recommended Navaid	Bearing/ Range to Navaid	Vertical Angle	Navigation Performance
FA	RW20	-	201 (203.3)	-	400	-	LUM	-	-	P-RNAV
DF	FOKSI	-	-	R	-	-	-	-	-	P-RNAV
TF	PF213	Y	345 (346.8)	-	+5000	-	-	OKE 330/30	-	P-RNAV
CF	TARTO	-	254 (256.1)	-	+FL100	250	OKE	-	-	B-RNAV

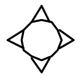
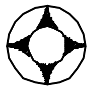
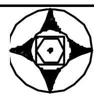
Table 43 - Example of a Tabulated Description of a SID

Path Terminator	Fix Identifier (Waypoint Name)	Fly Over	Course ° M (° T) [155]	Turn Direction	Altitude	Speed Limit	Recommended Navaid	Bearing/ Range to Navaid	Vertical Angle/ Threshold Crossing Height	Navigation Performance
IF	SUSER	-	-	-	+5000	250	-	LOM 262/29	-	RNP 1
TF	CV023	-	258 (256.0)	-	4000	-	-	-	-	RNP 0.3
TF	CV024	-	348 (345.8)	-	2680	150	-	-	-	RNP 0.3
TF	RW35L	Y	348 (345.8)	-	370	-	-	-	-3.0/50	RNP 0.3
FA	RW35L	-	348 (345.8)	-	+770	-	LOM	-	-	RNP 0.3
DF	SUSER	Y	-	L	+5000	-	-	-	-	RNP 1

Table 44 - Example of a Tabulated Approach and Missed Approach

[155] Required for CF and FA legs, recommended for other legs.

11.1.15 Charts should only use the symbols detailed in ICAO Annex 4. The waypoint symbol was designed to accommodate other symbols such as navaid or significant point symbols within the inner circle, as illustrated below:[156]

Fly-by Waypoint	
Fly-over Waypoint	
Fly-by Waypoint coincident with Significant Point (Compulsory Reporting Point)	
Fly-over Waypoint coincident with VOR/DME	
Fly-by Waypoint coincident with NDB	

11.2 SID CHARTS

11.2.1 An RNAV SID chart should be clearly identified as described in paragraph 11.1.8.

11.2.2 The graphic portrayal of the departure route should include the following:

a) The SID route(s) by arrowed continuous line(s) indicating direction of flight.

b) Plain language designator (route designator).

c) All waypoints defining the route together with their name codes.

d) Any reporting points associated with the route.

e) Track:

f) For flight crew use: Magnetic to the nearest degree along each segment of the route.

[156] The current method can be difficult to read on charts, particularly where an RNAV waypoint coincides with a navaid and a compulsory reporting point. The FAA are proposing that a new method for displaying RNAV symbols on charts be adopted, whereby each waypoint is shown on the chart using either a navaid symbol, an RNAV waypoint symbol or a 'fix' symbol (the current reporting point symbol). All fly-over waypoints are surrounded by a circle. All compulsory reporting points are 'filled-in'. This 'Symbol Hierarchy' is being considered by the OCP at present and may well be adopted by ICAO in the future.

g) For database coder use: True to the nearest tenth of a degree along each segment of the route.

h) Distances to the nearest tenth of a nautical mile between waypoints.

i) Initial cleared level, when required.

j) Altitude/flight level constraints, as required, expressed in units of 100 ft/flight level.

k) Speed constraints, as required, expressed in units of 10 kts.

l) All navaids associated with the route including:

   i) Navaid name

   ii) Navaid identifier

   iii) Navaid frequency/channel

   iv) Elevation (to the nearest foot) (for DMEs only)

   v) Navaid criticality, if appropriate

m) Where appropriate, the bearing (to the nearest degree for flight crew use and to the nearest tenth of a degree for database coders) and distance (to the nearest tenth of a nautical mile) of the waypoint from the reference navaid.

n) Applicable holding patterns

o) The RNP value associated with each segment of the route, if appropriate. If a part of the route depends upon the serviceability of specific navaids, it must be clearly identified, together with the navaids. If the initial part of the SID is conventional and it subsequently changes to RNAV, the point of changeover must be clearly identified.

p) Minimum Terrain Altitudes

q) The highest obstacle in the departure area, significant obstacles that penetrate the OIS and significant obstacles outside the departure area that dictate the design of the procedure.

r) The point at which a departure gradient greater than 3.3% is no longer used.[157]

[157] See PANS-OPS Vol II Part II Chapter 5 for more details on the requirements for published SID information.

s) Tabular data including:

   i) Transition altitude.

   ii) Magnetic variation.

   iii) Radio communication frequencies, including callsigns, required for the execution of the procedures.

   iv) Where appropriate, communication failure procedures.

11.2.3 The waypoint sequence for each route depicted on the chart should be detailed in a table in the AIP. The co-ordinates of the waypoints and navaids associated with the procedure should only be published in one location in the AIP.

11.2.4 An RNAV SID chart should be laid out as shown in the following figures. The first shows a P-RNAV application and the second shows a B-RNAV application.

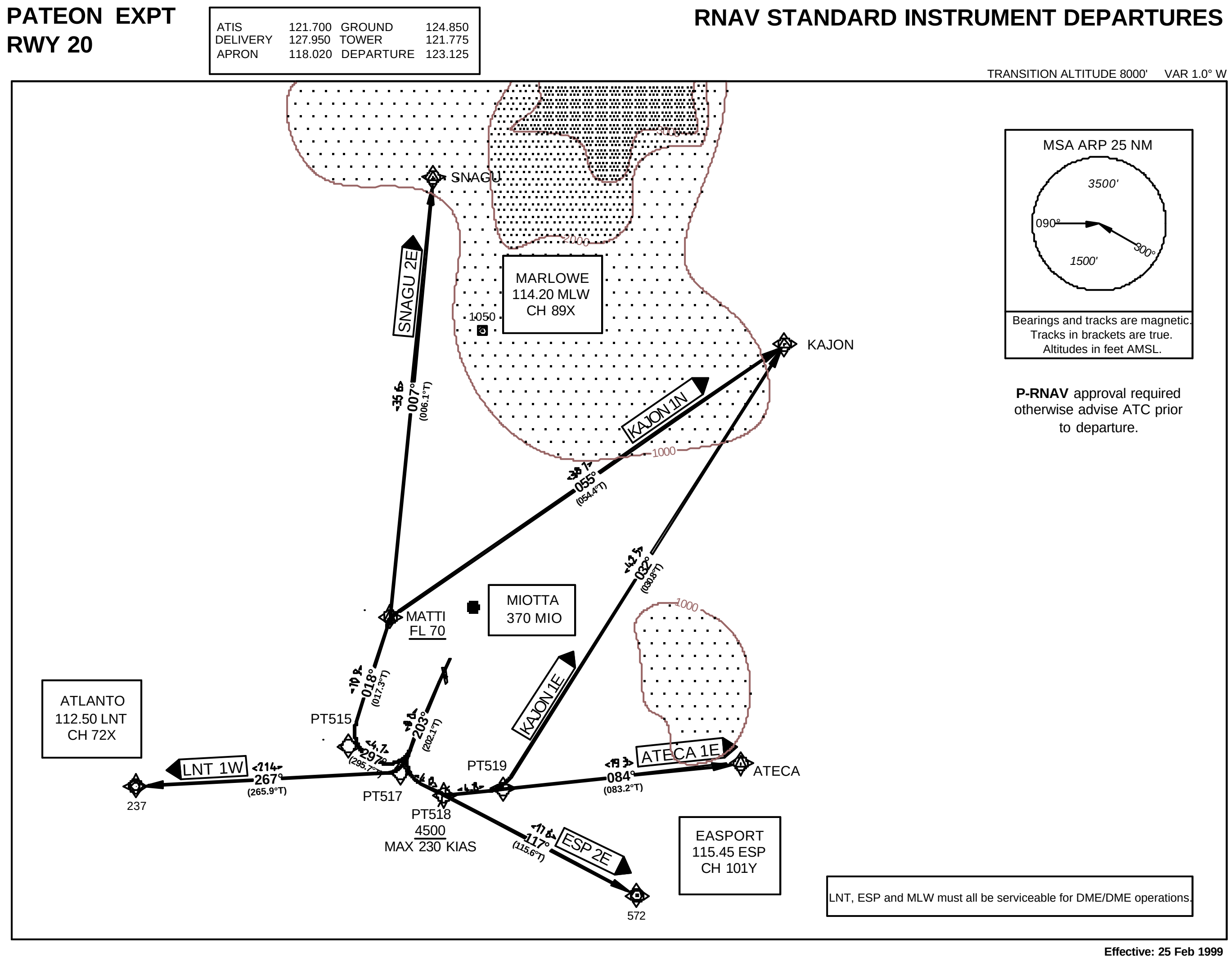


Figure 56 - RNAV SIDs Chart (P-RNAV Approval Required)

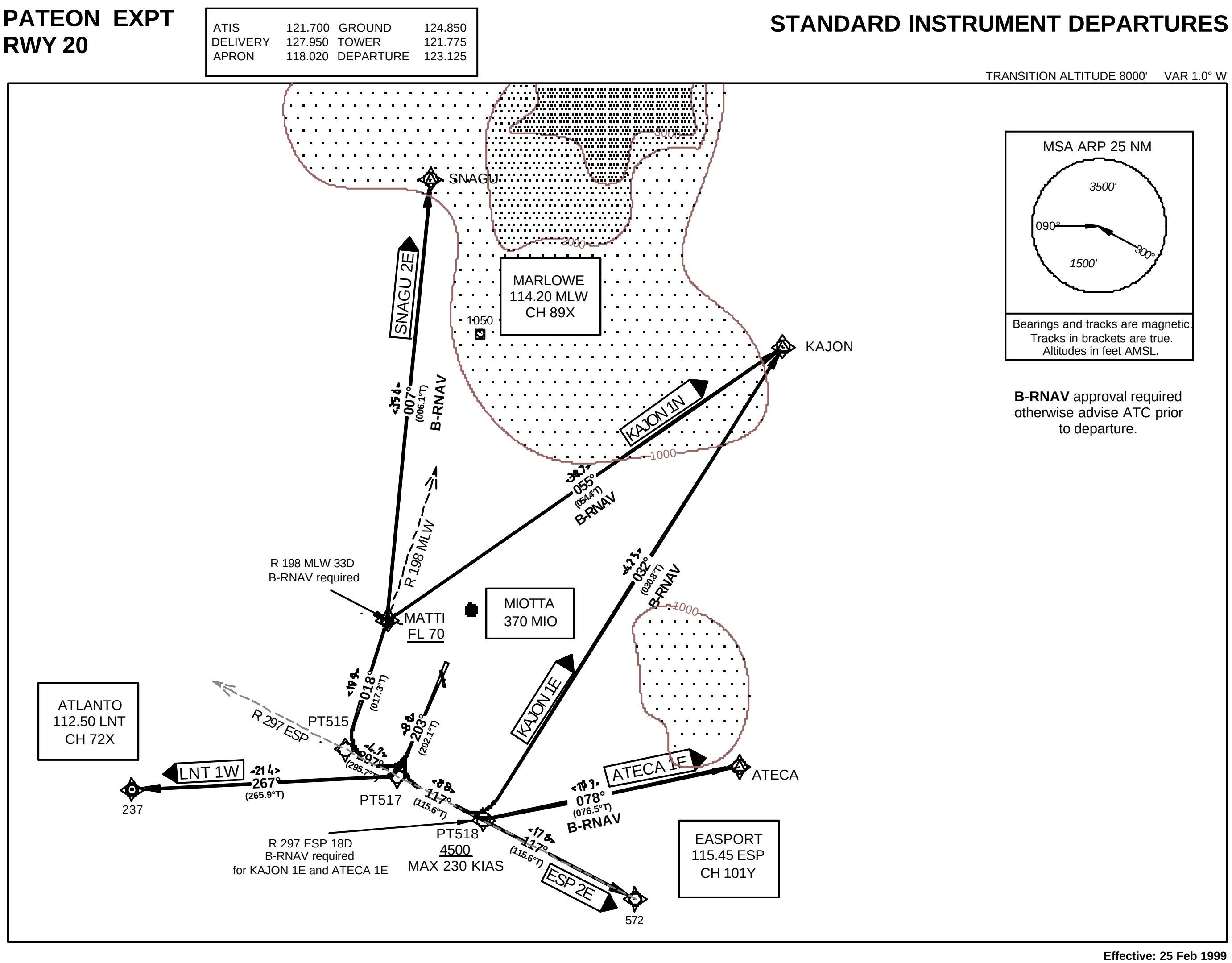


Figure 57- RNAV SIDs Chart (B-RNAV Approval Required)

11.3 STAR CHARTS

11.3.1 A STAR is a designated IFR arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced[158]. In practice, STARs are usually common arrival routes that are used to deliver traffic to the point from which individual approaches are made to specific runways. In some cases STARs may be designed to serve specific runways, ending at the FAF/FAP rather than the IAF.

11.3.2 RNAV provides the possibility to transit smoothly from the en-route structure, via a STAR to an RNAV or XLS approach using the most direct route possible. The route from the end of the STAR to the FAF/FAP is identified as an Approach Transition in the navigation database using a 5 character alphanumeric identifier[159]. Additional waypoints may be used to provide route extensions or short cuts and thereby facilitate the traffic sequencing. Not all these applications are currently recognised as approved ICAO concepts. Furthermore, they cannot be adequately depicted on either the existing STAR chart or the Instrument Approach Chart.

11.3.3 Where STARs finish at the FAF/FAP, the full routing can be shown on a STAR chart. Where STARs finish at the IAF, and there are a number of alternate RNAV approaches available, it is proposed that a supplemental chart is introduced to show the RNAV Initial Approaches. The illustration shown in this section is entitled RNAV Initial Approach but is very similar to that required for RNAV STARS that terminate at the IF for an ILS/RNAV approach. In the latter case no IAF is designated. Note that the designation of individual RNAV Initial Approaches is not currently addressed in ICAO documentation.

11.3.4 RNAV STARS that terminate at the IF are termed 'Closed STARs'. In order to ensure standardised operation, States publishing Closed STARs should include the following text in their AIPs:

Lateral Track Guidance to Final Approach Segment provided by **RNAV**

The STAR is characterised by the publication of an uninterrupted RNAV nominal track to the final approach segment of the relevant instrument approach.

Unless otherwise instructed by ATC, aircraft cleared to fly such a STAR are expected to fly the STAR as published so as to intercept the final approach segment, for the relevant instrument approach, descending in accordance with the cleared level.

ATC will issue a separate and explicit clearance for a straight-in approach to the relevant runway.

Similar text should be included on the charts.

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158 Definitions – Doc 8168-OPS/611 PANS-OPS

159 It is not technically possible to have two consecutive STARs defined for an RNAV procedure.

11.3.5 RNAV STARs may also terminate in a heading segment on the downwind leg abeam the FAF, with aircraft turned to final by radar vectors. Such STAR are termed 'Open STARs'. In order to ensure standardised operation, States publishing Open STARs should include the following text in their AIPs:

Lateral Track Guidance to Final Approach Segment provided by **Radar Vectors**:

The STAR is characterised by the publication of an RNAV nominal track up to a waypoint abeam the FAF of the relevant instrument approach, followed by a published heading to be flown.

Unless otherwise instructed by ATC, aircraft cleared to fly such a STAR are expected to fly the STAR as published up to the waypoint which defines the end of the STAR, and thereafter to fly the published heading, in accordance with the cleared level.

Further lateral track guidance to the final approach segment of the relevant instrument approach, will be provided by ATC in the form of radar vectors.

ATC will issue a separate and explicit clearance for a straight-in approach to the runway in question.

Note: This method of lateral track guidance to a final approach segment may be published selectively for those P-RNAV STARs which contain a downwind segment.

Similar text should be included on the charts.

11.3.6 RNAV STAR charts and RNAV Initial Approach charts should be clearly identified as described in paragraph 11.1.8.

11.3.7 The graphic portrayal of the arrival or transition route should include the following:

a) The STARs and initial approach and intermediate approach route(s) by arrowed continuous line(s) indicating direction of flight.

b) Plain language designator.

c) All waypoints defining the route together with their name codes.

d) Any reporting points associated with the route

e) Track:

f) For flight crew use: magnetic to the nearest degree along each segment of the route. (In higher latitudes true is used instead of magnetic)

g) For database coders use: true to the nearest tenth of a degree along each segment of the route.

h) Distances to the nearest tenth of a nautical mile between waypoints.

i) Altitude constraints, as required, expressed in units of 100 ft/flight level.

j) Speed constraints, as required, to the expressed in units of 10 kts.

k) All navaids associated with the route including:

  i) Navaid name.

  ii) Navaid identifier.

  iii) Navaid frequency/channel.

  iv) Elevation (for DMEs only)

l) Where appropriate, the bearing (to the nearest degree for flight crew use and to the nearest tenth of a degree for database coders) and distance (to the nearest tenth of a nautical mile) of the waypoint from the reference navaid.

m) Applicable holding patterns

n) The RNP value associated with each segment of the route, if appropriate. If a part of the route depends upon the serviceability of specific navaids, it must be clearly identified, together with the navaids. If the initial part of the STAR is RNAV and it subsequently changes to a conventional STAR, the point of changeover must be clearly identified.

o) Tabular data including:

  i) Transition altitude.

  ii) Magnetic variation.

  iii) Radio communication frequencies, including callsigns, required for the execution of the procedures.

  iv) Where appropriate, communication failure procedures.

11.3.8 The waypoint sequence for each route depicted on the chart should be detailed in a table in the AIP. The co-ordinates of the waypoints and navaids associated with the procedure should only be published in one location in the AIP.

11.3.9 An RNAV STAR chart and an RNAV Initial Approach chart (or RNAV STAR to Final Approach chart) should be laid out as shown in the following figures:

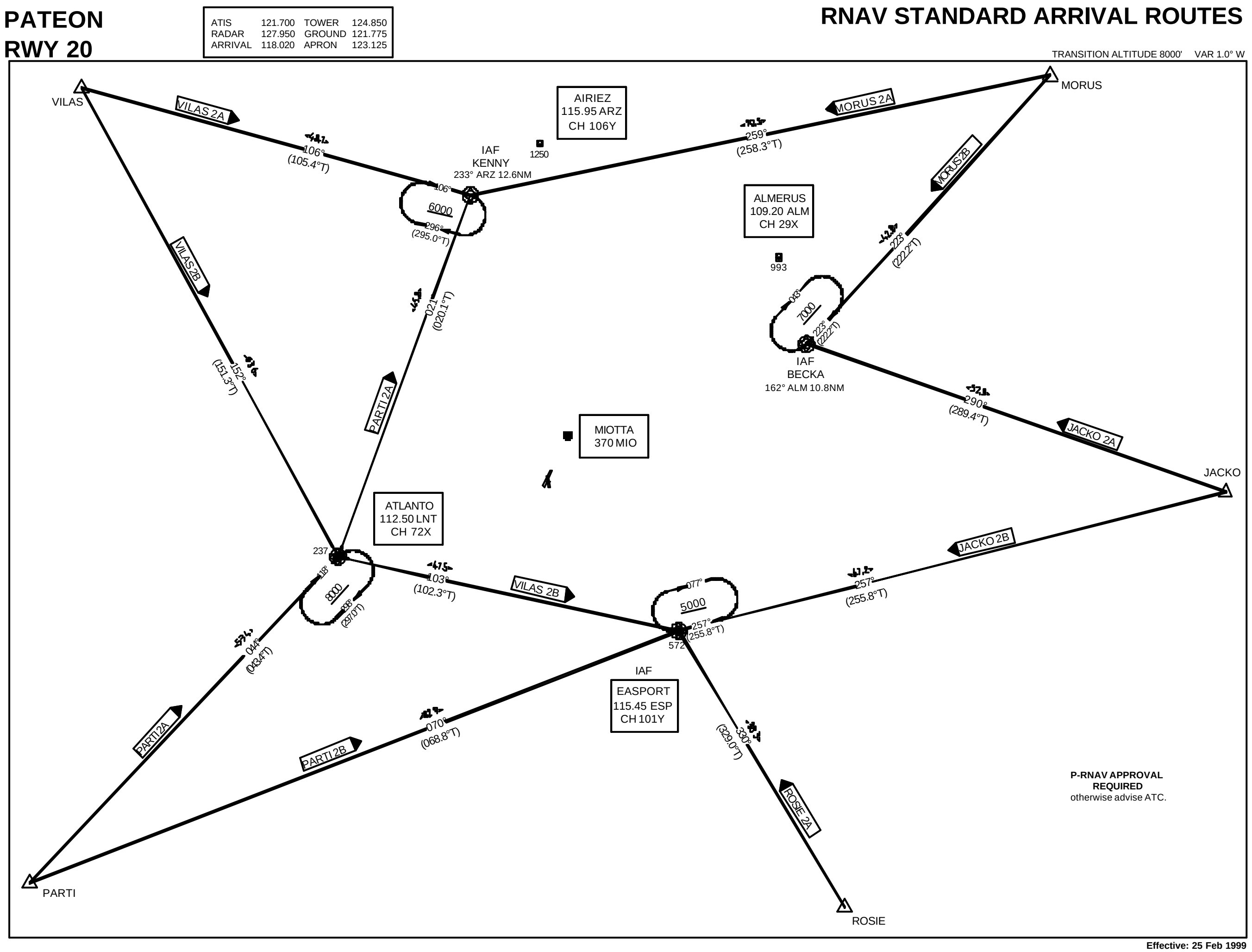


Figure 58 - RNAV STARs Chart

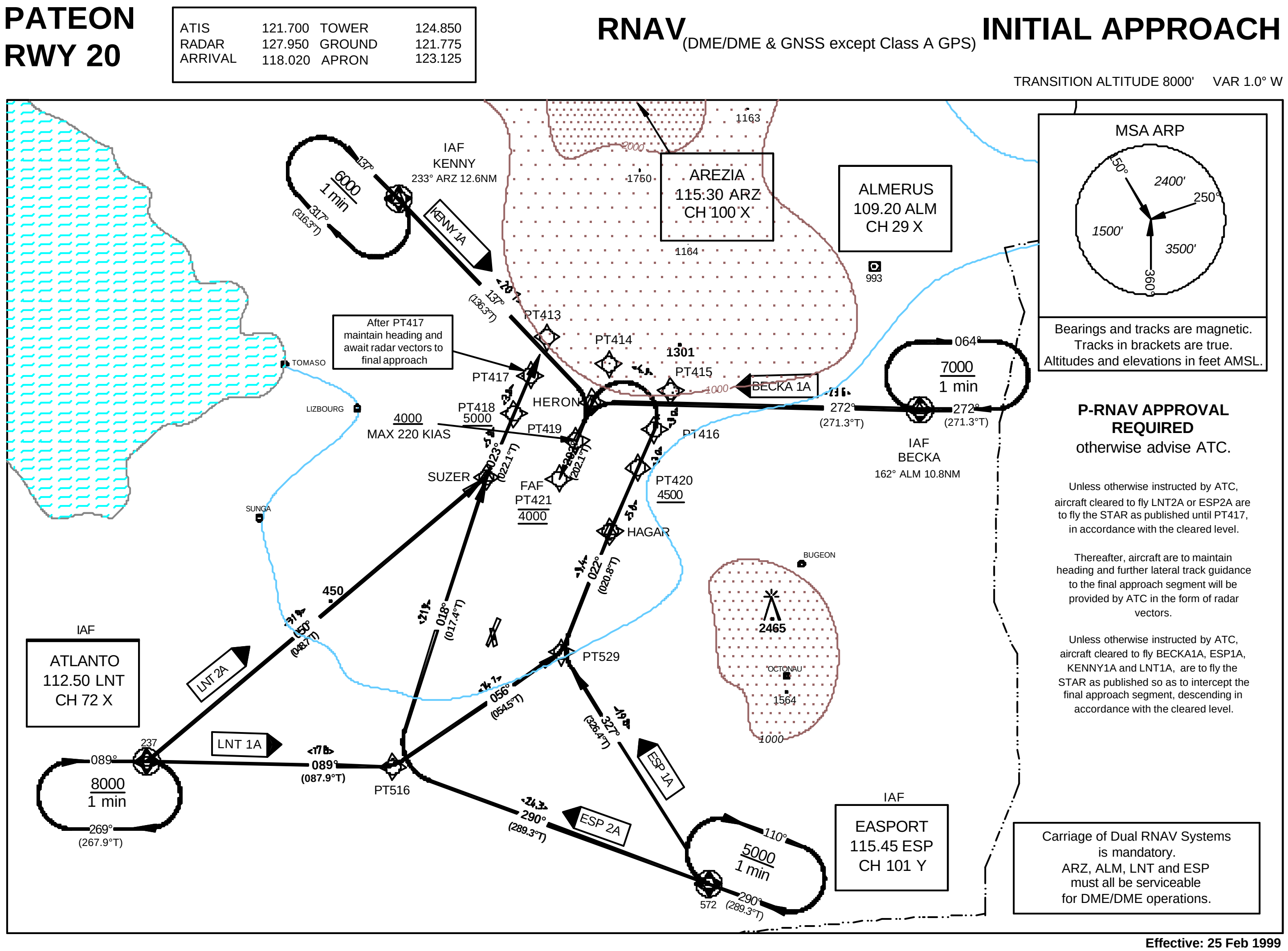


Figure 59 - RNAV STAR/Initial Approach Chart

11.4 APPROACH CHARTS

11.4.1 An RNAV Approach chart should be clearly identified as described in paragraph 11.1.8.

11.4.2 The graphic portrayal of the approach should include the following:

a) Plan View

i) The primary approach track(s) by arrowed continuous line indicating direction of flight.

ii) The missed approach track by arrowed broken line.

iii) Any alternate approach track(s) by arrowed dotted line(s).

iv) All waypoints defining the approach together with their name codes. The Initial Approach Waypoint (denoted IAF), the Final Approach Waypoint (denoted FAF), the Missed Approach Waypoint (denoted MAPt) and the Runway Threshold (where the MAPt is not coincident with the threshold) should also be identified.[160] .

v) Any Reporting Points associated with the approach.

vi) Track along each segment of the primary approach track and the missed approach track:

vii) For flight crew use: magnetic to the nearest degree along each segment of the route.

viii) For database coders use: true to the nearest tenth of a degree along each segment of the route.

ix) Distances to the nearest tenth of a nautical mile between waypoints along each segment of the primary approach track and the missed approach track.

x) Altitude constraints, as required, expressed in units of 100 ft/flight level.

xi) Speed constraints, as required, expressed in units of 10 kts.

xii) Any holding pattern(s) (including minimum holding altitude/height and outbound times) associated with the approach and missed approach.

[160] In the ICAO AIS/MAP Divisional Meeting in 1999, it was decided that the terms IAF, IF, FAF and MAPt would continue to be used for RNAV procedures in place of the terms IAF, IF, FAF and MAPt. The term MAHWP would not be used on charts.

xiii) All navaids specifically required by the approach including:

- Navaid name.
- Navaid identifier.
- Navaid frequency/channel.

xiv) Where appropriate, the bearing (to the nearest degree and to the nearest tenth of a degree for database coders) and distance (to the nearest tenth of a nautical mile) of the IAF and the FAF from the reference navaid.

xv) The RNP value associated with each segment of the approach, if appropriate. If a part of the approach depends upon the serviceability of specific navaids, it must be clearly identified, together with the navaids. If the initial part of the approach is RNAV and it subsequently changes to conventional, such as ILS, the point of changeover must be clearly identified. (This may be achieved by appropriate text in the Chart Title)

xvi) The boundaries of any sector in which visual manoeuvring is prohibited.

b) Profile View

i) Aerodrome by a solid block at aerodrome elevation.

ii) The approach track by arrowed continuous line indicating direction of flight.

iii) The missed approach track by arrowed broken line.

iv) Waypoints defining the approach together with their name codes, including, as a minimum, the Final Approach Waypoint (FAF) and the Missed Approach Waypoint (MAPt). (Note: Wherever possible the procedure designer should ensure that the FAF/FAP for a NPA or an ILS PA is coincident with the FAF/FAP of a RNAV procedure to the same runway – this will allow a smooth transition from the RNAV STAR to the approach.)

v) Track (magnetic) to the nearest degree along each segment of the primary approach track and the missed approach track.

vi) Distances to the nearest tenth of a nautical mile between waypoints along each segment of the primary approach track and the missed approach track.

vii) Altitude constraints, where applicable.

viii) Speed constraints, where applicable, to the nearest 10 kts.

ix) The RNP value associated with each segment of the approach, if appropriate. If the initial part of the approach is RNAV and it subsequently changes to conventional, such as ILS, the point of changeover must be clearly identified.

x) The vertical path angle (to the nearest hundredth of a degree for database coders and the nearest tenth of a degree for charts) for the Final Approach segment(s) .

xi) Threshold crossing height[161].

c) Tabular data including:

i) City/Town and Aerodrome Names.

ii) RNAV procedure identification as detailed in paragraph 11.1.8.

iii) Runway Identifier.

iv) Radio communication frequencies, including callsigns, required for the execution of the procedure.

v) Minimum required navaid serviceability.

vi) The aerodrome OCA/OCH or vertical operating minima[162] for LNAV and LNAV/VNAV, as appropriate, together with the systems authorised for use for the different aircraft categories.

vii) Minimum aerodrome temperature (where appropriate)

11.4.3 RNAV procedures based upon the T or Y concept shall have Terminal Arrival Altitudes (TAA) established for each approach arc: straight in, left base and right base, as appropriate. The TAA is the lowest altitude which may be used which will provide a minimum clearance of 300m (984ft) above all objects located in an area contained within a sector of a circle of 25NM radius of the IAF.

11.4.4 RNAV/Baro VNAV procedures must include details of the RDH, VPA and the minimum aerodrome temperature for which Baro VNAV operations are allowed. Consideration should also be given to including a table showing the VPA deviation that will occur in systems that do not compensate for temperature at different actual temperatures. For example:

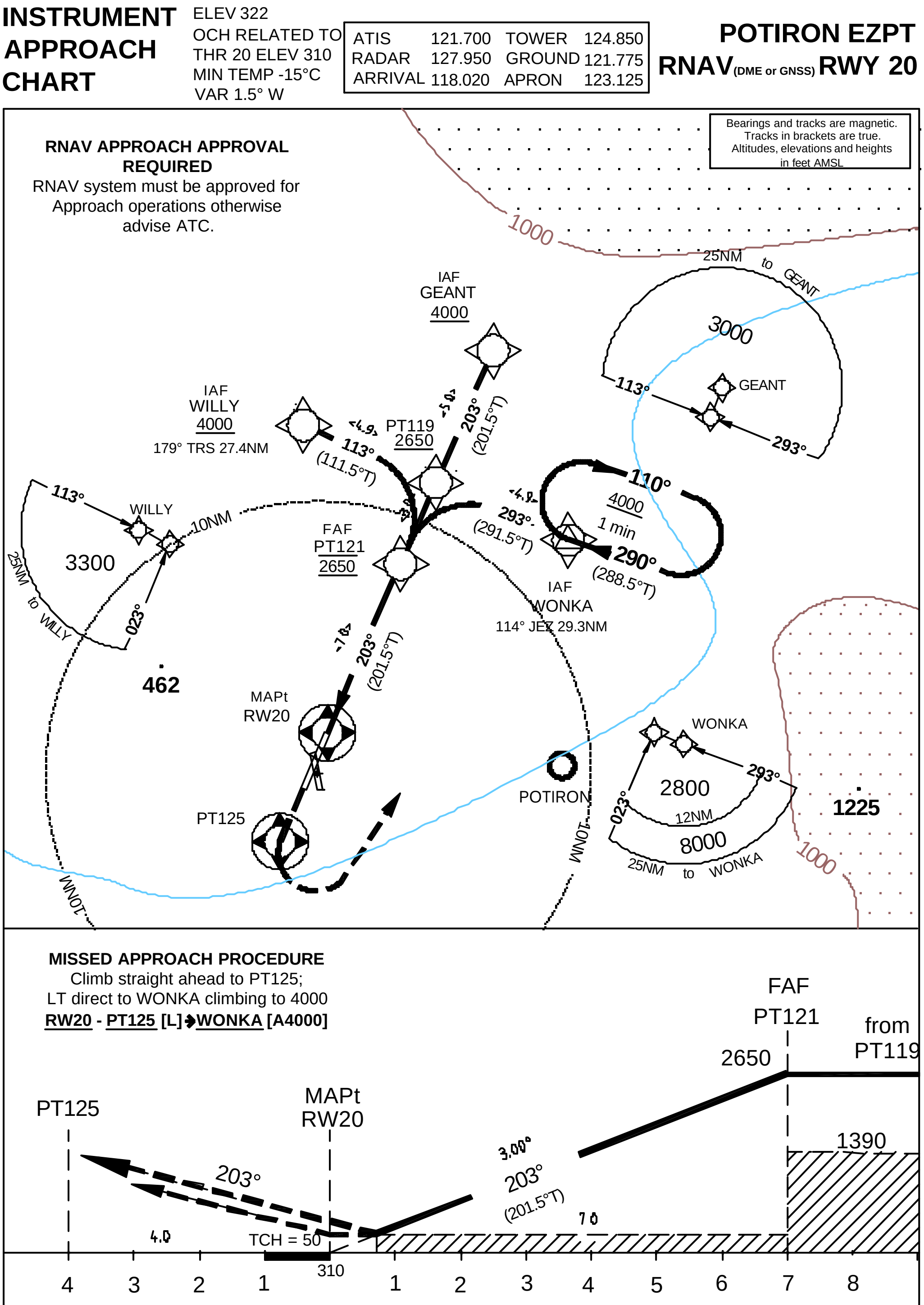
[161] The TCH for RNAV approaches should be 15 m (49 ft) although 50 ft is usually used as a default value by the database coders. Where a RDH is published for an ILS approach to the same threshold, the TCH for an RNAV approach should be the same as the RDH.

[162] Normally States publish OCA/OCH and the operator determines the vertical operating minima.

VPA Deviations for Non-compensated Systems	
A/D Temp	**VPA**
+30°C	3.20°
+15°C	3.00°
0°C	2.80°
-15°C	2.68°
-31°C	2.50°

The LNAV FAF and MAPt are also required for database coding purposes. If LNAV minima are shown on the same chart then the FAF and MAPt must also be charted.

11.4.5 An RNAV Approach chart should be laid out as shown in the following figure. Where an RNAV procedure has been designed to mirror a conventional procedure, these two procedures should be depicted on separate charts.



OCA (OCH)	A	B	C	D
LNAV/ VNAV	610 (300)	610 (300)	610 (300)	610 (300)
LNAV	810 (500)	810 (500)	810 (500)	810 (500)

DIST THR	7	6	5	4	3	2	1
ALTITUDE	2651	2332	2014	1696	1377	1059	740

Timing is not permitted

Effective: 19 Apr 2001

Figure 60 - RNAV Approach Chart

LIST OF ILLUSTRATIONS

LIST OF TABLES

ANNEX A - GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ANNEX B - ARINC 424 PATH TERMINATORS

ENDNOTE - FLY-OVER TRANSITION FORMULAE

It is possible to calculate the minimum segment length, ‘L’, for a fly-over transition using one of the following formulae:

ICAO FORMULA

$$L = r_1 \sin a + r_1 \cos a \tan 30 + r_1\left(\frac{1}{\sin 30} - \frac{2\cos a}{\sin 60}\right) + r_2 \tan 15 + \frac{10V}{3600}$$

Where

$r_1 = (V+W)^2 \times (\mathrm{Tan} f_1)^{-1} \times 1.458 \times 10^{-5}$ is the initial turn radius.

$f_1 = \min\left(\frac{a}{2}, 25^\circ, 20^\circ \, or \, 15^\circ\right)$ is the bank angle for the initial turn.

$r_{21} = (V+W)^2 \times (\mathrm{Tan} f_2)^{-1} \times 1.458 \times 10^{-5}$ is the recovery turn radius.

$f_2 = 15^\circ$ is the bank angle for the recovery turn.

This is illustrated in the figure below. Note that the total pilot delays are assumed to be 10 seconds.

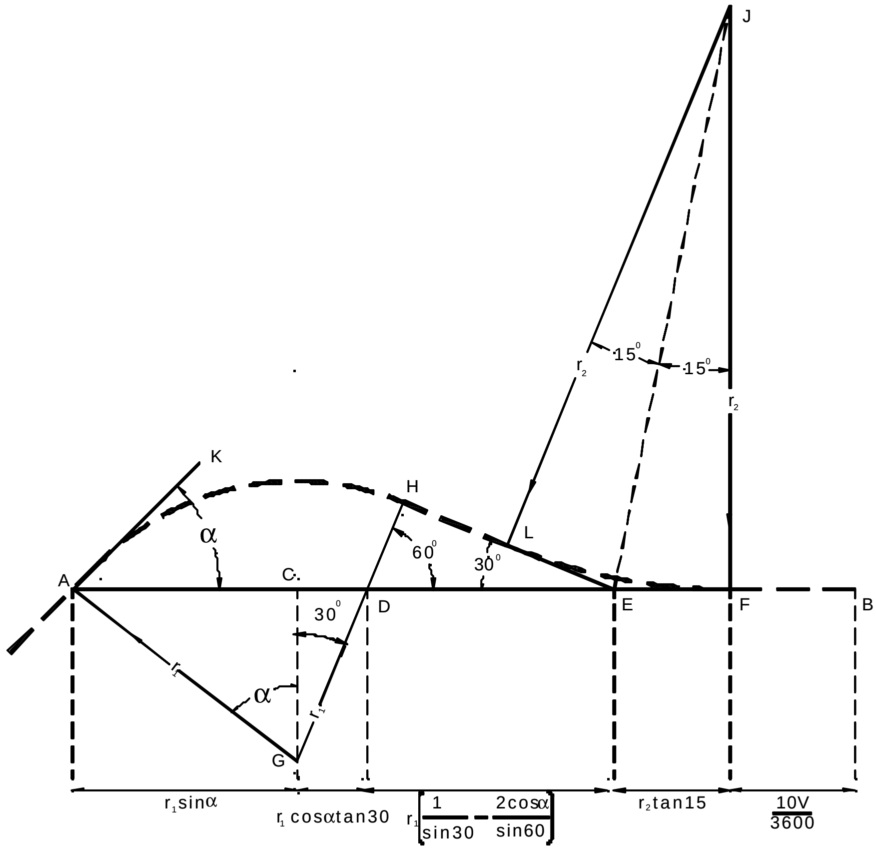


Figure 61 - Fly-over Transition - ICAO Formula

PROPOSED GENERAL PURPOSE FORMULA

$$L = r_1 \sin a + r_1 \cos a \tan b + r_1 \left(\frac{1 - \cos a / \cos b}{\sin b} \right) + r_2 \tan\left(\frac{b}{2}\right) + a_1 + a_2$$

Where

$a_1 = \frac{(V+W)}{3600} \times (\frac{f_1}{5} + 10 or 6 or 3)$ is the roll anticipation distance for the initial turn.

$r_1 = (V+W)^2 \times (\mathrm{Tan} f_1)^{-1} \times 1.458 \times 10^{-5}$ is the initial turn radius.

$f_1 = \min\left(\frac{a}{2}, 15^\circ, 20^\circ or 25^\circ\right)$ is the bank angle for the initial turn (RNP MASPS limits the bank angle to 23° to allow a reserve for high cross wind components.)

$a_2 = \frac{(V+W)}{3600} \times (\frac{f_2}{5} + 10 or 6 or 3)$ is the roll anticipation distance for the recovery turn.

$f_2 = \min\left(\frac{b}{2}, 15^\circ, 20^\circ or 25^\circ\right)$ is the bank angle for the recovery turn.

This is illustrated in the figure below. Note that a_1 and a_2 refer to the pilot delay and roll anticipation for the initial and recovery turns respectively.

This formula has still to be fully validated. It is based upon the ICAO formula but is intended to provide greater flexibility with respect to roll anticipation, AOB and recovery turn. It can be applied to any track angle change up to 120° and produces similar values to the ICAO and the RNP MASPS formulae when the appropriate wind, AOB and recovery turn parameters are used.

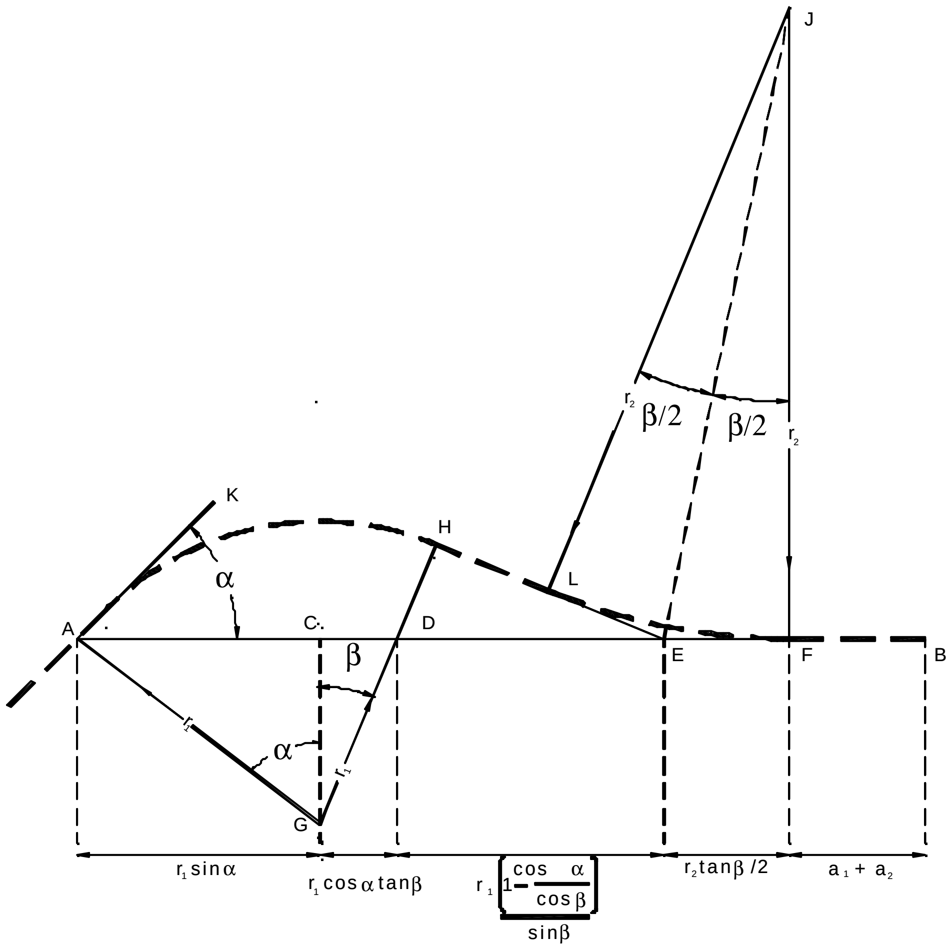


Figure 62 - Fly-over Transition - Proposed General Purpose Formula

ANNEX A - GLOSSARY OF ACRONYMS AND ABBREVIATIONS

5LNC	Five Letter Name Code
AAIM	Aircraft-based Autonomous Integrity Monitoring
ABAS	Aircraft-based Augmentation Systems
AF	DME Arc to a Fix (ARINC 424 Path Terminator)
AIC	Aeronautical Information Circular
AIP	Aeronautical Information Publication
AOB	Angle of Bank
ARINC	Aeronautical Radio Incorporated
ARP	Aerodrome (Airport) Reference Point
ATC	Air Traffic Control
ATS	Air Traffic Services
ATT	Along Track Tolerance
AW	Area Width
AWOP	All Weather Operations Panel (ICAO)
B-RNAV	Basic Area Navigation
CA	Course to an Altitude (ARINC 424 Path Terminator)
CAT I/II/III	Category of Approach
CD	Course to a DME Distance (ARINC 424 Path Terminator)
CDI	Course Deviation Indicator
CF	Course to a Fix (ARINC 424 Path Terminator)
CI	Course to Intercept (ARINC 424 Path Terminator)
CR	Course to a VOR Radial (ARINC 424 Path Terminator)
CRC	Cyclic Redundancy Check
CRM	Collision Risk Model
DA/H	Decision Altitude/Height
DER	Departure End of the Runway
DF	Direct to a Fix (ARINC 424 Path Terminator)
DME	Distance Measuring Equipment
DOC	Designated Operational Coverage
DoD	Department of Defence
EANPG	European Air Navigation Planning Group[
ECAC	European Civil Aviation Conference
EGNOS	European Global Navigation Overlay Service
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organization for the Safety of Air Navigation
FA	Course from a Fix to an Altitude (ARINC 424 Path Terminator)
FAA	Federal Aviation Administration (United States of America)
FAC	Final Approach Course
FACF	Final Approach Course Fix
FAF	Final Approach Fix
FAF	Final Approach Waypoint
FAP	Final Approach Point
FC	Course from a Fix to a Distance (ARINC 424 Path Terminator)
FD	Course from a Fix to a DME Distance (ARINC 424 Path Terminator)
FDE	Fault Detection and Exclusion
FL	Flight Level
FM	Course from a Fix to a Manual Termination (ARINC 424 Path Terminator)
FMS	Flight Management Systems
FTE	Flight Technical Error
FTT	Flight Technical Tolerance
ft	Feet
GBAS	Ground Based Augmentation System
GEO	Geostationary Satellites
GLONASS	Global Navigation Satellite System (Russia)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System (United States of America)
HA	Holding to an Altitude (ARINC 424 Path Terminator)
HF	Holding to a Fix (ARINC 424 Path Terminator)

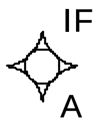
HM	Holding to a Manual Termination (ARINC 424 Path Terminator)
IAF	Initial Approach Fix
IAS	Indicated Air Speed
iaw	in accordance with
IAF	Initial Approach Waypoint
ICAO	International Civil Aviation Organization
IF	Intermediate Fix
IF	Initial Fix (ARINC 424 Path Terminator)
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMAL	Integrity Monitoring Alarm limit
INS	Inertial Navigation System
IRS	Inertial Reference System
ITRF	International Terrestrial Reference Frame
JAA	Joint Aviation Authority
kt	knots
LAAS	Local Area Augmentation System
LNAV	Lateral Navigation
LTP	Landing Threshold Point
MAHF	Missed Approach Holding Fix
MAPt	Missed Approach Point
MASPS	Minimum Aviation System Performance Standards
MAPt	Missed Approach Waypoint
MCC	Master Control Centres
MCG	Minimum Climb Gradient
MDA/H	Minimum Descent Altitude/Height
MLS	Microwave Landing System
MRVA	Minimum Radar Vectoring Altitude
MSA	Minimum Sector Altitude
MSAS	Multi-functional Transport Satellite Space-based Augmentation System
MSL	Mean Sea Level
MOC	Minimum Obstacle Clearance
NANU	Notice Advisory to NAVSTAR/Navigation Users
Navaid	Navigation aid
NLES	Navigation Land Earth Stations
NM	Nautical mile
NOTAM	Notice to Airmen
NPA	Non Precision Approach
nte	not to exceed
OCA/H	Obstacle Clearance Altitude/Height
OCP	Obstacle Clearance Panel (ICAO)
OIS	Obstacle Identification Surface
PANS	Procedures for Air Navigation Services
PANS-OPS	Procedures for Air Navigation Services - Aircraft Operations
PDG	Procedure Design Gradient
PDOP	Position Dilution of Precision
PI	Procedure Turn to Intercept (ARINC 424 Path Terminator)
PVT	Position Velocity Time
P-RNAV	Precision Area Navigation
RIMS	Ranging and Integrity Monitoring Stations
RF	Radius to a Fix (ARINC 424 Path Terminator)
RAIM	Receiver Autonomous Integrity Monitoring
RGCSP	Review of the General Concept of Separation Panel (ICAO)
RNAV	Area Navigation
RNP	Required Navigation Performance
R/T	Radio Telephony
RTCA	Radio Technical Commission for Aeronautics
RSS	Root Sum Squared
SARPS	Standards and Recommended Practices
SBAS	Space Based Augmentation System
SID	Standard Instrument Departure
SOC	Start of Climb

SPS	Standard Positioning Service
STAR	Standard Instrument Arrival
TAA	Terminal Arrival Area / Terminal Arrival Altitude
TARA	Terminal Area RNAV Applications (EUROCONTROL Task Force)
TAS	True Air Speed
TERPS	Standard for Terminal Instrument Procedures (United States of America)
TF	Track to a Fix (ARINC 424 Path Terminator)
TMA	Terminal Control Area
TOPL	Take Off Performance Limits
TORA	Take Off Run Available
TSE	Total System Error
VA	Heading to an Altitude (ARINC 424 Path Terminator)
VD	Heading to a DME Distance (ARINC 424 Path Terminator)
VHF	Very High Frequency
VI	Heading to Intercept (ARINC 424 Path Terminator)
VM	Heading to a Manual Termination (ARINC 424 Path Terminator)
VNAV	Vertical Navigation
VOR	VHF Omni-directional Range
VPN	Virtual Private Network
VR	Heading to a VOR Radial (ARINC 424 Path Terminator)
WAAS	Wide Area Augmentation System (United States of America)
WGS 84	World Geodetic System 1984
XTT	Across Track Tolerance

ANNEX B - ARINC 424 PATH TERMINATORS

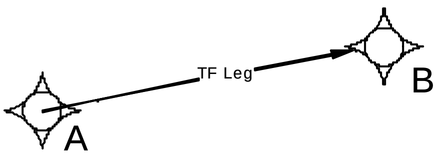
IF

All ARINC 424 routes start at an IF or “Initial fix”. An IF does not define a desired track in and of itself, but is used in conjunction with another leg type (e.g. TF) in order to define the desired path. (Required for P-RNAV and RNP-RNAV)



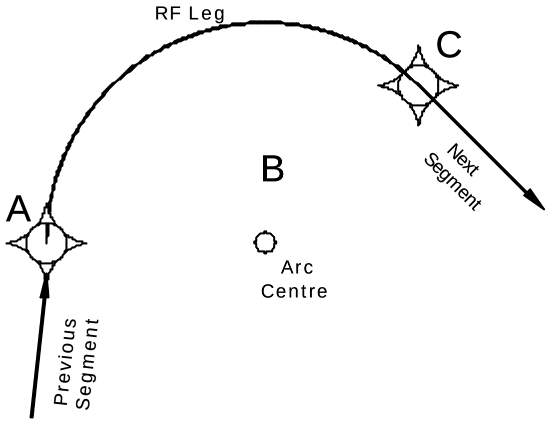
TF

The primary straight route segment for RNP is a TF route or a “Track to a fix”. The TF route is defined by a geodesic path between two waypoints. The first of the two waypoints is either the termination waypoint of the previous segment or an initial fix (IF). (Required for P-RNAV and RNP-RNAV)



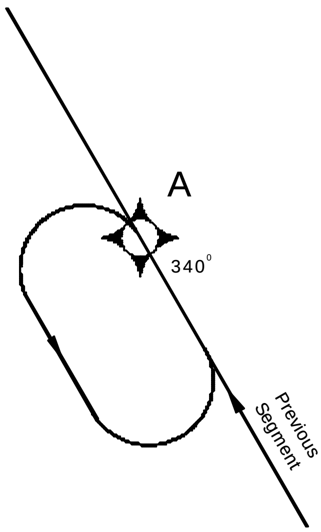
RF

The constant radius arc to a fix , or RF, segment is a circular path about a defined turn centre that terminates at a waypoint. The beginning of the arc segment is defined by the terminating waypoint of the previous segment. The waypoint at the end of the arc segment, the turn direction of the segment and the turn centre are provided by the navigation database. The radius is computed by the RNAV system as the distance from the turn centre to the termination waypoint. A single arc may be defined for any turn between 2° and 300°. (Required for RNP-RNAV but NOT for P-RNAV)



HF

An HF or “Holding/Racetrack to a fix” segment is a holding pattern path which terminates at the first crossing of the hold waypoint after the holding entry procedure has been performed. This is usually used for course reversal legs. (Approved for P-RNAV and required for RNP-RNAV)



HA

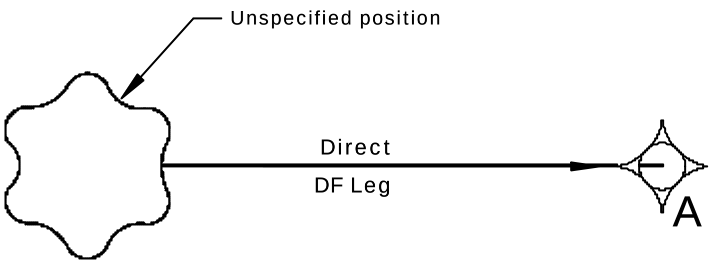
An HA or "Holding/Racetrack to an altitude" segment is a holding pattern path that automatically terminates at the next crossing of the hold waypoint when the aircraft's altitude is at, or above, the specified altitude. (Approved for P-RNAV and required for RNP-RNAV)

HM

An HM or "Holding/Racetrack to a manual termination" segment is a holding pattern path which is manually terminated by the flight crew. (Approved for P-RNAV and required for RNP-RNAV)

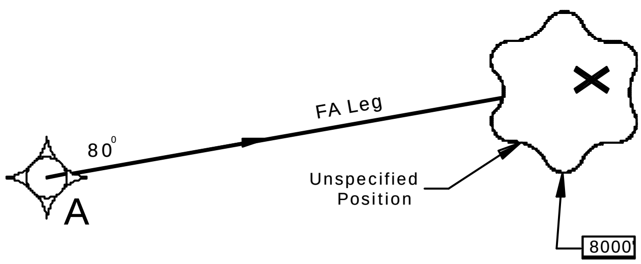
DF

A DF or "Direct to a fix" is used to define a route segment (geodesic path) from an unspecified position, on the aircraft's present track, to a specified fix/waypoint. Although the DF path terminator is acceptable for RNP, its use is undesirable because it does not provide a predictable, repeatable flight path. It is highly variable in its application. (Required for P-RNAV)



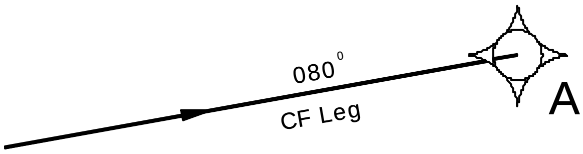
FA

An FA or a "Course from a fix to an altitude" is used to define a route segment (geodesic path) that begins at a fix/waypoint and terminates at a point where the aircraft altitude is at, or above, a specified altitude. No position is specified for the altitude point. The FA track is acceptable for RNP but undesirable because it does not provide a predictable, repeatable flight path, due to the unknown termination point. (Required for P-RNAV)



CF

A CF or “Course to a fix” is defined as a geodesic path that terminates at a fix/waypoint followed by a specific route segment. A CF is used to define the final segment of an approach and was previously the only path terminator permitted for this purpose. The CF leg is currently used in many approach procedures and, although not recommended, is expected to be used in some Terminal RNAV procedures during the transitional period. Eventually, it is anticipated that CF legs will be replaced by TF legs. (Approved for P-RNAV)

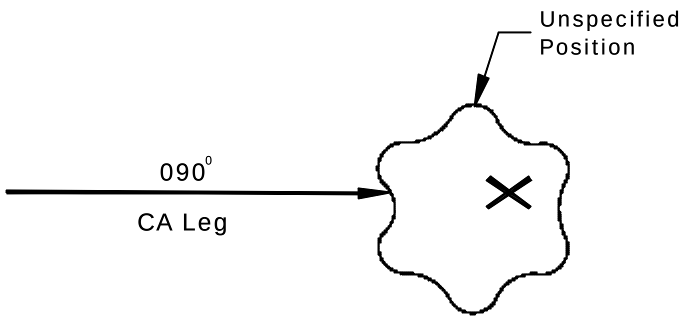


PI

A PI or “Procedure turn to intercept” is used to define the beginning of a procedure turn manoeuvre. (Not allowed in P-RNAV or RNP-RNAV procedures)

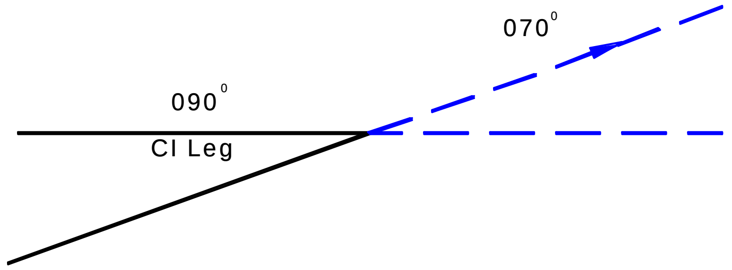
CA

A CA or “Course to an altitude” is used to define the course of an outbound route segment that terminates at an altitude with an unspecified position. (Not required for P-RNAV and not allowed in RNP-RNAV procedures)



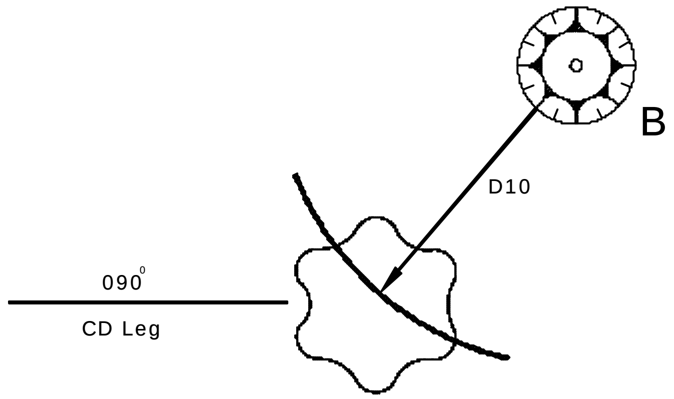
CI

A CI or "Course to intercept" is used to define a route segment that intersects the following segment and where no intercept point or turn point has been defined. (Not allowed in P-RNAV or RNP-RNAV procedures)



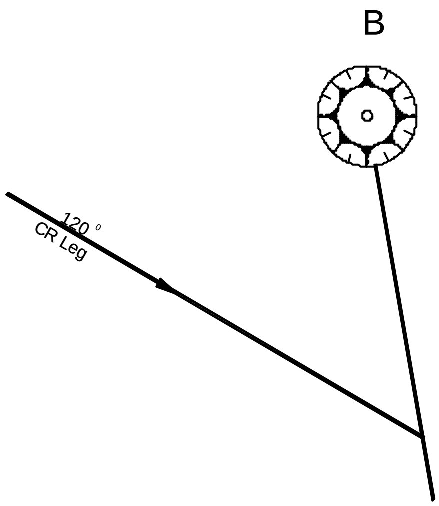
CD

A CD or "Course to a DME distance" is used to define a route segment that terminates at a DME distance from a navaid other than the one providing course guidance. (Not allowed in P-RNAV or RNP-RNAV procedures)



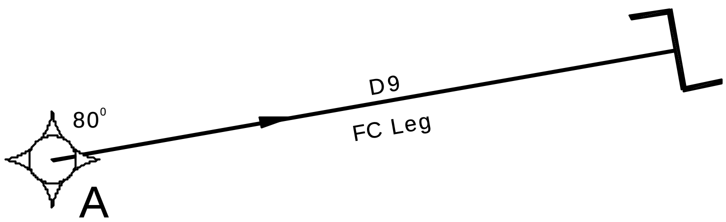
CR

A CR or a “Course to a VOR radial” is used to define a route segment that terminates at a crossing radial where an intercept point has not been defined. (Not allowed in P-RNAV or RNP-RNAV procedures)



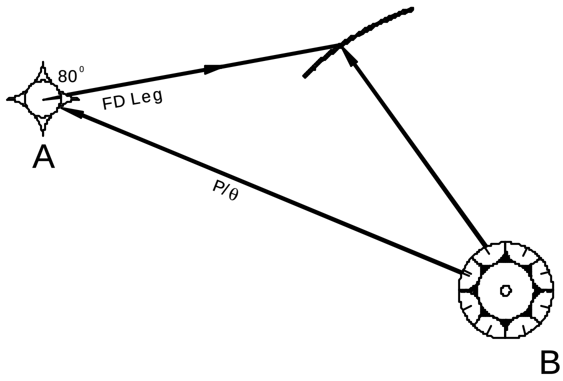
FC

An FC or “Course from a fix to a distance” is used to define a route segment from a fix to a specified distance with an unspecified position. (Not allowed in P-RNAV or RNP-RNAV procedures)



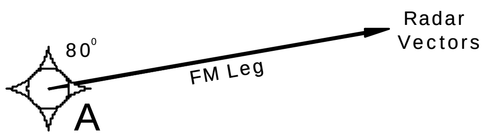
FD

An FD or “Course from a fix to a DME distance” is used to define route segments that begin at a fix and terminate at a DME distance from a navaid other than the one providing course guidance. (Not allowed in P-RNAV or RNP-RNAV procedures)



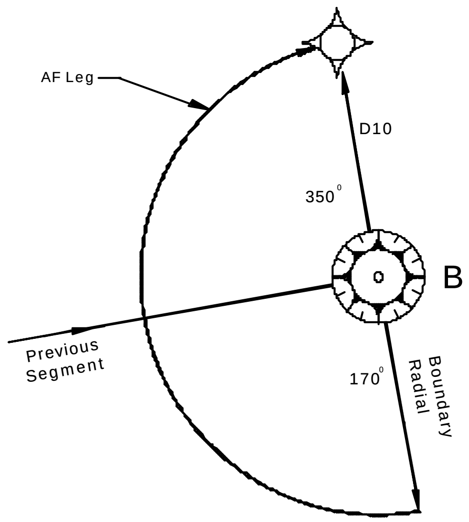
FM

An FM or “Course from a fix to a manual termination” is used when a route segment is expected to be terminated for radar vectors. (Not allowed in P-RNAV or RNP-RNAV procedures)



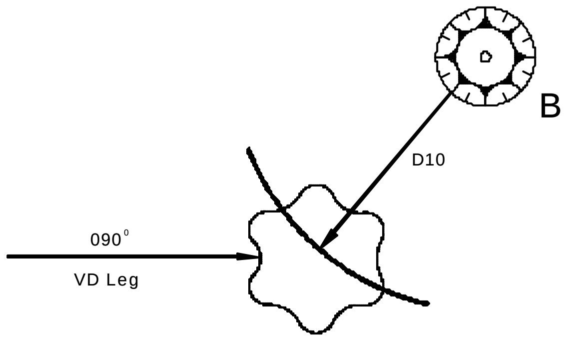
AF

An AF or "DME arc to a fix" is used to define an arc route segment that does not begin at a specified fix but does terminate at a specified fix. (Not allowed in P-RNAV or RNP-RNAV procedures)



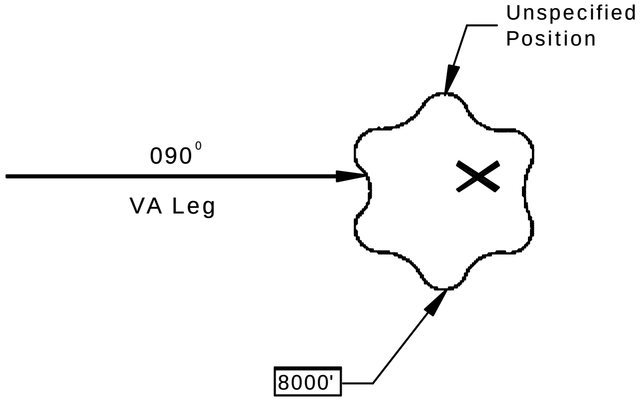
VD

A VD or "Heading to a DME distance" is used on departures where a heading rather than a track has been specified for climb-out. The position of the intercepted DME distance will vary around an arc, depending on the winds. (Not allowed in P-RNAV or RNP-RNAV procedures)



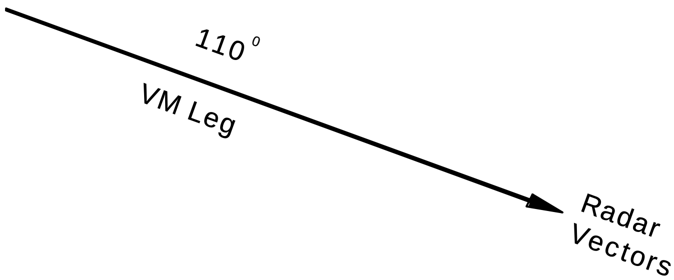
VA

A VA or "Heading to an altitude" is often used on departures where a heading rather than a track has been specified for climb-out. The segment terminates at a specified altitude without a terminating position. (Not required for P-RNAV and not allowed in RNP-RNAV procedures)



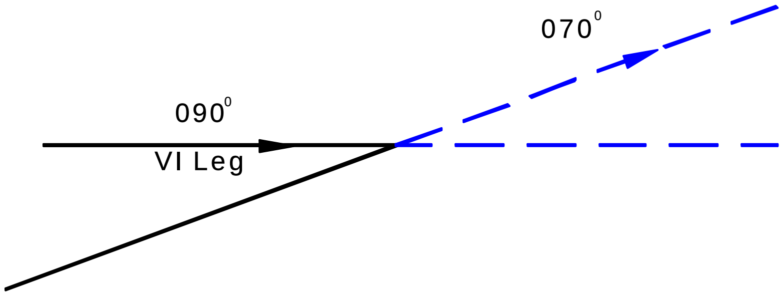
VM

A VM or "Heading to a manual termination" segment is very common in procedure design. These segments are coded in wherever radar vectoring is anticipated. (Not required for P-RNAV and not allowed in RNP-RNAV procedures)



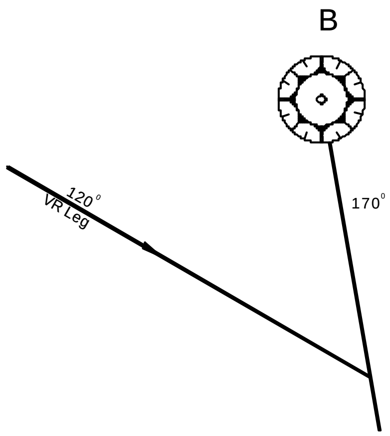
VI

A VI or “Heading to intercept” is used to define a route segment that intersects the following segment and where no intercept point or turn point has been defined. (Not allowed in P-RNAV or RNP procedures)



VR

A VR or “Heading to a VOR radial” is used to define a route segment that terminates at a crossing radial where an intercept point has not been defined. (Not allowed in P-RNAV or RNP procedures)



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