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CONTENTS

THE VALIDATION OF RNAV PROCEDURES

1 PROCEDURE DEVELOPMENT PROCESS

1.1 The development of an RNAV instrument flight procedure follows a series of steps from the origination of data through survey to the final publication of the procedure and subsequent coding of it for use in an airborne navigation database. At each step there should be quality control procedures in place to ensure that the necessary levels of accuracy and integrity are achieved and maintained. The main steps in the development process are illustrated overleaf. This document addresses the three steps that are shaded in the diagram. The other steps are covered in separate, existing documents, some of which are identified in the diagram.

1.2 The ICAO Obstacle Clearance Panel (OCP) recommends that suitable software applications be used for RNAV procedure design, as the construction of the obstacle clearance areas in the turns can be complicated. These tools can be used to draw the obstacle clearance areas that are used to identify the controlling obstacles, which in turn fix the minimum procedure altitudes, glide path angles and climb gradients. In addition to this, in some cases the designer is required to apply expert judgement to determine how best to interpret the existing criteria in order to overcome particular terrain, airspace or environmental constraints. Such specialist design work relies heavily upon the designer input and is extremely difficult to automate.

1.3 Once the procedure has been designed, it has to be described in an unambiguous fashion. An RNAV procedure is defined as a series of legs. Each leg is associated with an ARINC 424 path terminator code and is usually terminated at a waypoint which may be fly-over, fly-by or 'fixed-radius' (exceptions are those associated with CA, FA, FM, VA and VM path terminators). Only 13 of the 23 path terminator codes defined in ARINC 424 are considered to be acceptable for use on RNAV procedures in the ECAC area[1].

[1] CA, CF, DF, FA, FM, HA, HF, HM, IF, RF, TF, VA, VM.

Organisation	**Activity**	**Comment**
Procedure Design Office/ Procedure Owner, Navaid Engineering Office	Collate data concerning navaid infrastructure, obstacles and aerodrome	Supplied by approved surveyor/airport/government department. See EUROCONTROL Data Origination Standard.
Procedure Design Office	Design procedure.	Close co-operation with Navaid Service Provider and Users. See ICAO Doc 8168 and EUROCONTROL NAV.ET1.ST10
Procedure Design Office	Conduct independent review of design and check flyability if design is non-standard.	May be done by a third party.
Procedure Design Office/ Procedure Owner/ Navaid Engineering Office	Collate and check data to be issued to flight inspection organisation.	
Flight Inspection Organisation	Conduct Flight Inspection.	See ICAO Doc 8071 and EUROCONTROL 'Guidance Material for the Flight Inspection of RNAV Procedures'.
Procedure Design Office and Navaid Engineering Office	Analyse flight inspection report. Re-check flyability if necessary	Mainly for navaid coverage but may also address obstacle assessment and flyability.
Procedure Owner/ AIS/ Regulator	Obtain approval for publication	
Procedure Design Office/ Procedure Owner/ AIS/ ATC	Publish procedure and monitor operational application	

1.4 PANS-OPS Doc 8168 requires RNAV procedure descriptions to be clear and unambiguous and recommends a number of methods for describing RNAV procedures, as described below. The best method of publishing RNAV procedures is considered to be the tabular form with a supporting graphical representation (chart).

1.4.1 Formal Description:

(<u>*Waypoint*</u>) (underlined) denotes 'fly-over'.

(*Waypoint*) (not underlined) denotes 'fly-by' or RF waypoint as appropriate.

To (Waypoint) denotes a TF path terminator.

To (Waypoint) on course XXX° denotes a CF path terminator.

Direct to (Waypoint) denotes a DF path terminator.

(Waypoint) {R, NN.N, LatLong} denotes an RF path terminator, the radius and the centre point of a fixed radius turn in terminal airspace.

Climb on track XXX°, at or above yyy feet turn right/left denotes an FA path terminator.

From (Waypoint) to XXXX feet on track XXX° denotes an FA path terminator.

Climb on heading XXX°, at or above yyy feet turn left/right denotes a VA path terminator.

From (Waypoint) to XXXX feet on heading XXX° denotes a VA path terminator.

Continue on heading XXX° denotes a VM path terminator.

Continue on track XXX° denotes a FM path terminator.

1.4.2 Abbreviated Description. The description may be abbreviated by placing the leg constraints in brackets after the waypoint name as follows:

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:

i) 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

ii) NNNN is a number from 000 to 99999

iii) C may be one of the following:

+ for 'at or above'

- for 'at or below'

a blank space for 'at'

iv) 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 requires a DF path terminator when an arrow (→) should be used.

This is illustrated in the table below.

Formal Description	Abbreviated Description	Expected Path Terminator	Fly-over Required
Climb on track 047°M, at or above 800 ft turn right.	[M047, A800+; R]	FA or CA	N
Climb on heading 047°M, at or above 800 ft turn right.	[HDG M047; A800+; R]	VA	N
Direct to ARDAG at 3000ft	→ARDAG[A3000]	DF	N
To PF035 at or below 2000ft.	PF035[A2000-]	TF	Y
To PF025 at or above 4000ft, continue on heading 265°M and await radar vectors.	PF025[A4000+] - [HDG M265]	TF, VM or FM	N
To OTR on course 090°M at 210 kts	OTR[M090; K210]	CF	N
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]	TF, RF	N, N
To 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+]	TF, DF, TF	Y, N, N

1.4.3 Tabular Description. The procedure details can be tabulated with each leg defined in a separate row. This is illustrated in the tables below.

Path Descriptor	Fix Identifier (Waypoint Name)	Fly Over[2]	Course[3] ° M (° T)	Turn Direction	Altitude	Speed Limit	Magnetic Variation	Vertical Angle	Navigation Performance [4]
CA		-	201 (203.3)	-	400	-	-2.3	-	P-RNAV
DF	FOKSI	-	-	R	-	-	-	-	P-RNAV
TF	PF213	Y	345 (346.8)	-	+5000	-	-	-	P-RNAV
CF	TARTO	-	254 (256.1)	-	+FL100	250	-2.3	-	B-RNAV

Path Descriptor	Fix Identifier (Waypoint Name)	Fly Over	Course ° M (° T)	Turn Direction	Altitude	Speed Limit	Magnetic Variation	Vertical Angle/ Threshold Crossing Height	Navigation Performance
IF	SUSER	-	-	-	+5000	250	-	-	P-RNAV
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[5]	-	348 (345.8)	-	+770	-	+2.2	-	RNP 0.3
DF	SUSER	Y	-	L	+5000	-	-	-	P-RNAV

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2 Part of the ARINC 424 Waypoint Description Code.

3 ARINC 424 Outbound Magnetic Course or Inbound Magnetic Course as appropriate.

4 ARINC 424 RNP; but may also be used to identify sensor specific RNAV procedures

5 In FA and VM legs the 'from' waypoint is described.

1.5 Prior to publication, the procedure must be validated and, if necessary, flight inspected. This document provides guidance on the validation methodology covering both data checks and flyability checks. It assumes that:

a) The survey data has been checked and is error free;

b) The procedure has been designed and coded ready for publication;

c) A verification of the procedure design has been carried out to determine that the obstacle clearance criteria have been correctly applied. This should be carried out by a suitably qualified person who was not involved in the original design activity.

Guidance material concerning the flight inspection of RNAV procedures is provided in a separate document.

2 DATA CHECKS

2.1 GENERAL

2.1.1 There are a number of data checks that can be carried out:

a) Minimum data set check - to ensure that sufficient data has been provided to define the procedure. This includes all the waypoint identifiers necessary to define the procedure, the latitude and longitude values for all waypoints, all the path terminator codes necessary to define the procedure, all the supporting data necessary to support the path terminator codes, all the supporting data necessary to validate the procedure.

b) ARINC 424 check - to ensure that the path terminators which have been defined for each of the legs are being used in accordance with the rules laid down in ARINC 424.

c) Co-ordinate check to ensure that the path length and true bearing provided for each leg is the same as that calculated using the waypoint co-ordinates.

d) Check for maximum track angle change between legs (≤120° in general, but ≤90° at IF and ≤45° at FAF)

e) Gradient checks to ensure that the altitude constraints applied at the waypoints are consistent with the required minimum climb gradient or the published glide path angle.

f) Minimum distance between waypoint check to ensure that the actual distance between each waypoint is adequate to allow the aircraft to complete the required manoeuvre. This requires knowledge of the track angle change at the preceding and subsequent waypoints, the maximum speed (including maximum tailwind), altitude and bank angle.

2.1.2 These checks can be automated or manual. They should be conducted by the design office prior to publication. They are usually also addressed during the subsequent database population and packing process.

2.2 MINIMUM DATA SET

2.2.1 This check is to ensure that adequate data has been provided; that the data is in the correct format and that the data values are in the correct ranges. The minimum data set comprises:

a) Country Code (ICAO list of country codes)

b) Airport Code (ICAO list of airport codes)

c) Route Identifier

d) Procedure Type (SID/STAR/APP)

e) RNP value (In ECAC this may include B-RNAV or P-RNAV)

f) Applicable aircraft categories

g) Number of legs

h) Individual leg data comprising:

   v) Serial number

   vi) Fix Identifier ('To' waypoint for CF, DF, RF, TF; 'From' waypoint for FA, FM, IF)

   vii) Waypoint Co-ordinates

   viii) Waypoint Use

      - Terminal/Enroute (Waypoints in the terminal area that are used by more than one airport or are used for direct to clearances from the en-route are identified by 5LNCs and are stored in the en-route table)

- IAF/IF/FAF/MAPt/Holding Point/Start of STAR/End of SID

- Site of navaid

- Fly-over/Fly-by/Fixed radius

ix) Path Terminator (CA, CF, DF, FA, FM, IF, RF, TF, VA, VM)

x) Turn Direction (recommended if turn<90°; required if turn >90°)

xi) Speed Limit (When specified, the speed limit is applied at the waypoint. General restrictions such as 250 kts below FL 100 are associated with airspace data.)

xii) Altitude (Altitude constraints are also applied at the waypoint and may comprise two values to define altitude window)

xiii) Minimum Angle of Bank (not used in database coding but used to determine minimum leg length)

xiv) Vertical Angle/Min Climb Gradient (When specified)

xv) Arc Radius (RF only)

xvi) Centre Fix (RF only)

xvii) True Track (or Magnetic Track and Magnetic Variation)

xviii) Leg Distance/Hold distance or time

xix) Recommended Navaid (When specified)

xx) Recommended Navaid Co-ordinates (When specified)

i) Transition Altitude

2.3 ARINC 424 CHECK

2.3.1 Once the minimum data check has been completed, certain basic ARINC 424 rule checks should be applied:

2.3.2 Each procedure may only start and finish with the path terminators specified below:

Procedure	Start Leg	Finish Leg
SID[6]	CA, CF, FA, VA	CF, DF, FM, HA, RF[7], TF, VM
STAR	IF	CF, DF, FM, HM, RF, TF, VM[8]
Approach	IF	CF, TF, RF
Missed Approach	CA, CF, DF, FA, HA, HM, RF, VM	CF, DF, FM, HM, RF, TF, VM

Table 1 - Path Terminators (Start and Finish)

2.3.3 The path terminator on the previous leg may limit the choice of path terminator on the subsequent leg. The permitted leg sequences are detailed in Table 2. A shaded space indicates the “current leg/next leg” sequence is not permitted.

6 The only valid starting path terminators for the SID, from a procedure design perspective, are FA, CA, CF or VA. VA may be used for parallel departures where aircraft are required to follow a heading rather than a track after take-off. atabase suppliers may also use VA in place of FA when coding equivalent SIDs from adjacent parallel runways in order to minimize duplicate coding (Many databases in older RNAV systems have capacities of less than 200 kilo bytes). As most autopilots cannot be engaged below 500ft agl on a SID, an initial leg turning at 500ft agl may be coded as VA to improve consistency in track behaviour. 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.

7 RF may only be used for RNP procedures flown by aircraft equipped with systems that are compatible with ARINC 424-17, or later.

8 FM or VM may be used to terminate ‘Open STARs’ when radar vectoring is provided to final approach. The choice of track (FM) or heading (VM) depends upon ATC requirements.

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

Table 2 - 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.

2.3.4 The following basic rules apply:

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

b) TF to flyover should only be followed by TF or CF. If a procedure requires a DF after a flyover then the previous leg should be coded CF or DF.

c) DF cannot follow a fly-by waypoint.

d) The waypoint at the start and end of an RF leg is not coded as fly-over.

2.3.5 If a published take-off requires a turn of greater than 15 degrees from the runway heading without an altitude specified before the turn, an FA, or CA, should be coded on the runway track to an altitude of 400 feet above the airport elevation (or as specified by source) before the turn or as the first leg of the departure[9].

2.3.6 If a STAR ends in vectors to a final approach (FM or VM leg), the Airport Reference Point Record is coded in the Waypoint Ident field of the STAR Record.

2.3.7 If a STAR ends in a sequence which aligns the aircraft inbound on the localizer course, the termination of the STAR sequence must be the Waypoint defined as the FACF for the localizer based Approach Procedure.[10]

2.3.8 The final approach must include IF, FAF and either a runway fix or missed approach point fix. The IF will also serve as the FACF.

2.3.9 If the MAPt is the runway threshold, the first Altitude constraint in the Missed Approach Point sequence must be equal to runway threshold elevation plus the published TCH.

2.3.10 The first leg of a Missed Approach Procedure must contain an altitude indicating a command to climb. This must be an “AT OR ABOVE” altitude terminating at least 400 feet above the airport elevation. FA should be followed by DF or CF. (DF recommended)

2.3.11 Each path terminator requires a minimum sub-set of data as shown in Table 3. This check should be carried out as part of the minimum dataset check.

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[9] While most straight departures should start with a CA/DF or a VA/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 start with a CF. 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 a CA or VA and the second as a CF or CA with the second leg course arranged to ensure that the earliest turn to intercept occurs at or after the required turning point

[10] This should be the Intermediate Fix (IF) of the approach procedure.

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

Table 3 - 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'

2.4 CO-ORDINATE CHECK

2.4.1 The range and bearing between the waypoints at the end of each leg should be calculated using the co-ordinates provided. The calculated values should then be compared with the true track and leg distance provided. Any differences greater than 0.5° and 0.1NM should be flagged.

2.4.2 The range and bearing between the waypoint and the recommended navaid should be calculated using the co-ordinates provided. The calculated values should then be compared with the bearing and distance to the recommended navaid, where this is provided. The values should equate to the nearest degree and 0.1NM.

2.4.3 For each FA leg, a phantom waypoint should be calculated on the track provided, at a distance from the DER equivalent to that necessary to achieve the min turn height using the minimum climb gradient. If the next leg is CF, the bearing between the phantom waypoint and the next waypoint should be within 45° of the published heading.

2.4.4 The inbound and outbound tracks associated with a RF leg must be tangential to the fixed radius turn.

2.5 TRACK ANGLE CHANGE CHECK

2.5.1 The track angle change between each leg should be calculated and checked against the following criteria:

a) No track angle change may be greater than 120°.

b) Track angle changes at the IF may be no greater than 90°.

c) Track angle changes at the FAF may be no greater than 45°.

2.6 GRADIENT CHECK

2.6.1 Where altitude constraints are provided, the vertical profile should be calculated and the gradient compared with the published VPA or published minimum climb gradient to meet obstacle or ATC constraints. If the profile is greater than the published values it should be flagged.

2.6.2 The profile calculation should be based upon the nominal track and should take account of the fly-by, fly-over and fixed-radius turn constraints. The algorithms detailed in Annex A may be used to determine the nominal track distance for each leg. The track distance is measured from the bisector of the fly-by and from the waypoint of the fly-over or fixed radius. The maximum speed is determined either by the speed restriction specified in the procedure or by applying values from the following table.

Aircraft Category	**A**	**B**	**C**	**D**	**E**
Departure (Normal)	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	150	180	240	250	250
Holding (Up to 14000 ft)	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 4 - Procedure Calculation IAS Values (kts)

2.7 MINIMUM DISTANCE CHECK

2.7.1 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, the type of transition at each end of the leg, the maximum speed allowed, the maximum altitude anticipated and the maximum angle of bank allowed. The algorithms used to calculate the minimum distances between waypoints are detailed in Annex B.

3 FLYABILITY CHECKS

3.1 If the procedure has been designed according to the PANS-OPS RNAV criteria and has passed the ARINC 424 coding checks then it should be flyable by most, if not all, aircraft. However, when the design encroaches on the limits of the criteria by using, for example, leg lengths that are shorter than recommended, turn angles that are greater than 120º, climb gradients that are greater than 7%, initial fly-by waypoints on SIDs within 3NM of the DER, descent gradients that are steeper than 3.5º or ILS interceptions that are greater than 45º, then it is recommended that the procedure undergoes a flyability check. Particular attention should be paid to the initial legs in SIDs and the final legs of STAR/Transitions.

3.2 The ultimate goal of the flyability check is to establish that the procedure is flyable by the anticipated range of aircraft types in all appropriate weight configurations and in all appropriate extremes of weather. Thus an empty aircraft departing on a cold day with a strong headwind, or crosswind, should be able to fly the procedure just as well as a fully laden aircraft departing on a still hot day. It follows that all flyability checks should be carried out using appropriate simulation software. It is highly unlikely that it will ever be possible to simulate all the possible aircraft/FMS combinations given the range of candidate aircraft and the cost of developing appropriate software.

3.3 The closer the simulation software is to the operational software, the greater the chance that the flyability check will identify any underlying problem. Certified full flight simulation facilities probably provide behaviour that is closest to reality. However, such simulators tend to be aircraft type specific and expensive to run. Specialist software tools which use operational hardware and software are considered to be an acceptable alternative despite the fact that they provide a lesser degree of authenticity.[11]

[11] A simulator that can fly the procedure using a range of aircraft albeit with only the logic used in one manufacturer's avionics would be considered to be a reasonable compromise solution

3.4 The flyability check process can be broken down into the following steps:

a) Obtain a packed navigation database containing the new coded procedures from the avionics manufacturer/licensed database provider.

b) Load the database in a flight simulator/specialist software tool and fly each new procedure under the following conditions:

i) Max weight, max temperature, still air.

ii) Max weight, max temperature, max crosswind.

iii) Min weight, min temperature, max crosswind.

iv) Min weight, min temperature, max headwind.

v) Max weight, min temperature, max tailwind on downwind leg (arrivals with anti-icing only).

If specific operating procedures, such as noise abatement procedures, are required then these must be included in each simulator run.

c) Analyse the resultant ground tracks and compare them with the nominal track of the procedure. Any divergence greater than 0.75 NM from the nominal track should be examined[12].

If a specific aircraft type, that is not modelled in the specialist tool, is expected to use the procedure and there is concern that its performance may differ significantly from the available models; or if such a specialist tool is not available; or if the results are inconclusive, then the procedure should be assessed using an appropriate full motion simulator.

3.5 Flyability checks can be carried out by a third party on behalf of the procedure design office, ANSP or airline. Where a design office has a close working relationship with an operator, it may often be possible to use the operator's resources to address any flyability issues that arise. This is particularly the case when an operator has a vested interest in the introduction of a particular procedure.

[12] Turns at altitude are likely to result in divergences of more than 1NM from the nominal track under certain weather conditions. This is usually taken account of in the procedure design.

3.6 Flyability checks may also be carried out during a flight inspection. In this case the assessment of flyability can cover all aspects of the instrument flight procedure including:

a) Aircraft manoeuvring in context of safe operating practices for the category of aircraft.

b) Cockpit workload.

c) Charting aspects.

d) Navigation database aspects.

In many instances, this involves a subjective assessment by the pilot, taking account of the aircraft types that are expected to use the procedure. This assessment is provided in a commentary in the flight inspection report. The flight inspection aircraft cannot replicate the performance of all the aircraft types that will be expected to use the procedure, but can be used to identify gross flyability errors[13]. Where a flight inspection is required to address flyability aspects, the procedure designer should identify which procedures, or parts of a procedure, should be reviewed by the flight inspector from a flyability perspective.

3.7 Where a procedure is not flyable by all aircraft types, it may be possible to restrict its use to specific aircraft types. Such a decision should only be made after close consultation with the State Regulator and comprehensive tests and trials involving the specific aircraft types. In such cases it is expected that the operators who benefit directly from such a decision will have provided substantial support to the flyability check process. An operator who subsequently wishes to obtain approval for an aircraft type that has previously been excluded, must make the case, supported by a comprehensive analysis, to the regulator.

[13] It is not possible for a flight inspection to meet the ultimate goal of the flyability check for RNAV procedures, detailed in paragraph 3.2. While an experienced flight inspection crew can use techniques to mimic many characteristics of larger aircraft, they cannot cover all aspects and additional checks may have to be carried out using simulation software.

ANNEX A – NOMINAL TRACK DISTANCE

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 highest allowable speed

Y_b = Turn initiation distance at waypoint 'b' for the highest allowable speed

r_a = Radius of turn for the highest speed at waypoint 'a'

r_b = Radius of turn for the highest speed at waypoint 'b'

α_a = Track angle change (degrees) at waypoint 'a'

α_b = Track angle change (degrees) at waypoint 'b'

Turn Initiation Distance: $Y = r \times \tan(0.5 \times \alpha)$

Radius of turn: $r = \frac{V}{20 \pi R}$

Rate of turn: $R = \frac{3431 \tan \phi}{\pi V}$ or 3 /sec, whichever is smaller.

V = highest speed

This is illustrated in Figure 1.

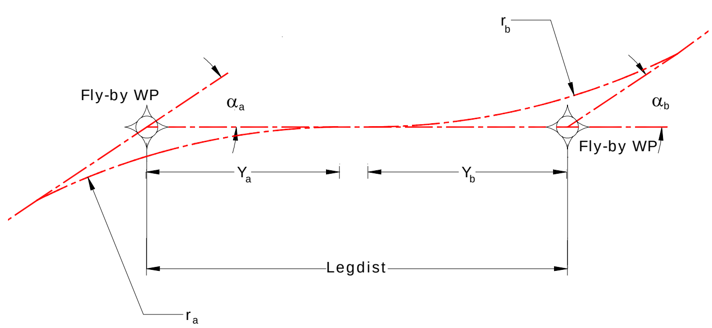

Figure 1 - Nominal Track Distance - Fly-by to Fly-by

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 highest allowable speed

r_a = Radius of turn for the highest allowable speed at waypoint 'a'

α_a = Track angle change (degrees) at waypoint 'a'

This is illustrated in Figure 2.

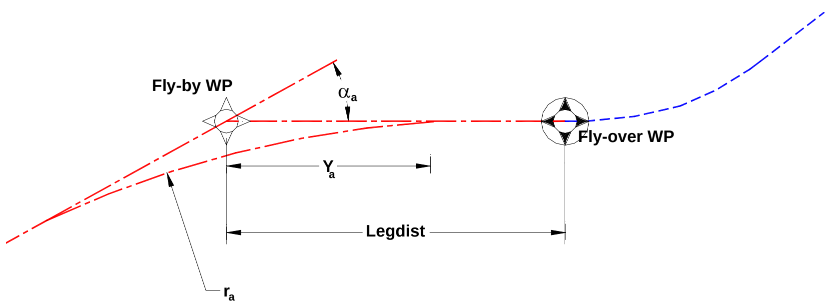

Figure 2 - Nominal Track Distance - Fly-by to Fly-over

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:

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

Where

Legdist = Geodesic distance between waypoints 'a' and 'b'.

r_{a1} = Radius of initial turn for the highest allowable speed at waypoint 'a'

α_a = Track angle change (degrees) at waypoint 'a'

This is illustrated in Figure 3.

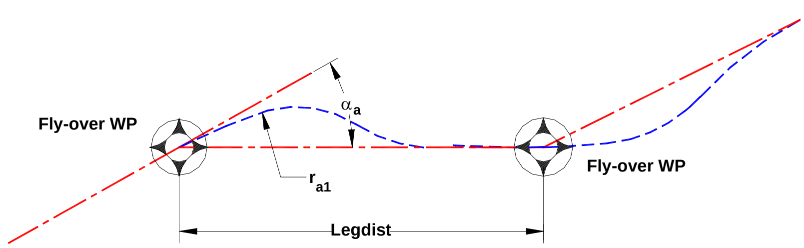

Figure 3 - Nominal Track Distance - Fly-over to Fly-over

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 DF path terminator as follows:

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

Where

Legdist = Geodesic distance between waypoints 'a' and 'b'.

Y_b = Turn initiation distance at waypoint 'b' for the highest allowable speed

r_{a1} = Radius of initial turn for the highest allowable speed at waypoint 'a'

r_b = Radius of turn for the highest allowable speed 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 4.

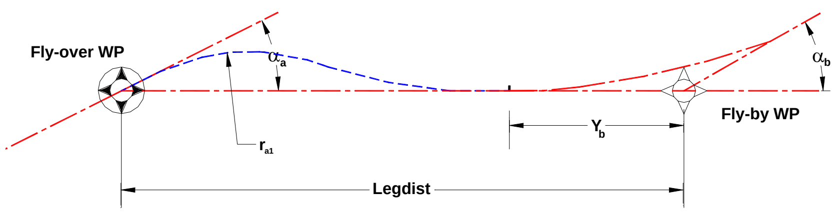

Figure 4 - Nominal Track Distance - Fly-over to Fly-by

Fixed Radius to Fly-by

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

$$TrackDist = Legdist - Y_b + \frac{r_b\pi\alpha_b}{360}$$

Where

Legdist = Geodesic distance between waypoints 'a' and 'b'.

Y_b = Turn initiation distance at waypoint 'b' for the highest allowable speed

r_b = Radius of turn for the highest allowable speed at waypoint 'b'

α_b = Track angle change (degrees) at waypoint 'b'

This is illustrated in Figure 5.

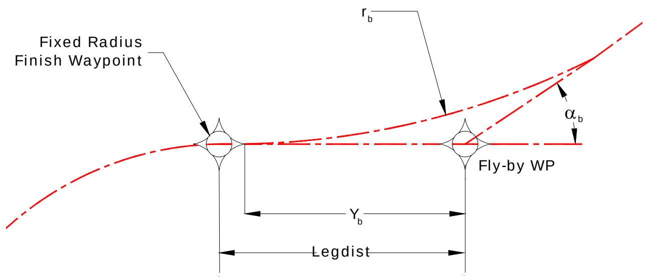

Figure 5 - Nominal Track Distance - Fixed Radius to Fly-by

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:

$$TrackDist = \frac{r\pi\alpha}{360}$$

Turns at Altitude

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.

ANNEX B – MINIMUM LEG DISTANCE

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-6.

The value may be calculated using the following formula:

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

$$MinLegLength = Y_1 + \left(\frac{(Pilot / SystemDelay)V}{3600}\right) + Y_2 + \left(\frac{(Pilot / SystemDelay)V}{3600}\right)$$

Where:

3 seconds are used for pilot/system delays in missed approach and departure segments

5 seconds are used for pilot/system delays in other terminal procedures.

Turn Initiation Distance: $Y = r \times \tan(0.5 \times \alpha)$

Radius of turn: $r = \frac{V}{20\pi R}$

Rate of turn: $R = \frac{3431 \tan \phi}{\pi V}$ or 3 /sec, whichever is smaller.

α = Track angle change

ϕ = maximum bank angle (degrees) min[½α or 15° (departures/missed approaches below 1000ft agl) or 20° (departures/missed approaches between 1000ft agl and 3000ft agl) or 25°].

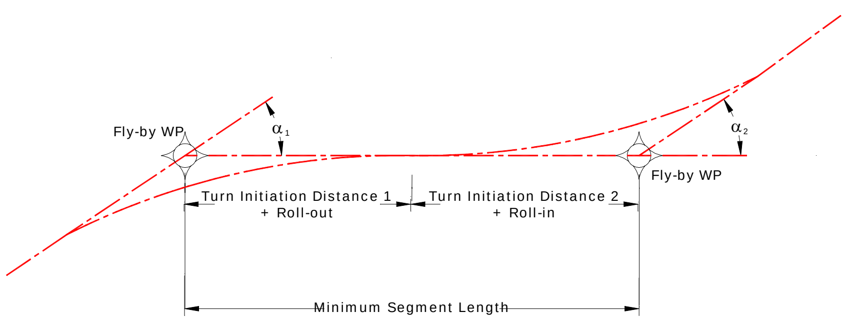

Figure-6 - Minimum Segment Length - Fly-by to Fly-by (Opposite directions)

b) If both turns are in the same direction, 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 7.

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

Min leg length = (Turn Initiation dist)$_1$+(Turn Initiation dist)$_2$

$$MinLegLength = r \times \tan(0.5 \times \alpha_1) + r \times \tan(0.5 \times \alpha_2)$$

Where:

r = Radius of turn

α_1 = First turn track angle change

α_2 = Second turn track angle change

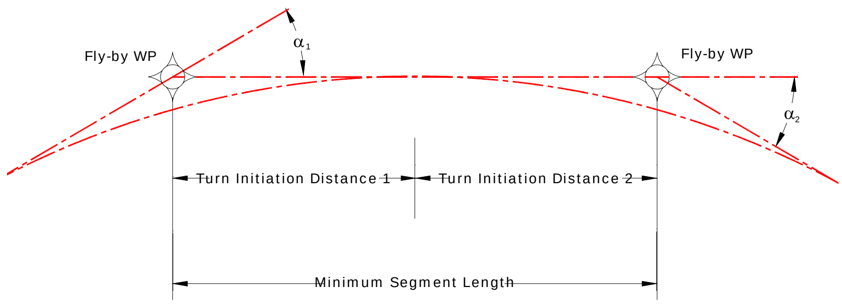

Figure 7 - Minimum Segment Length - Fly-by to Fly-by (Same Direction)

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 8.

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

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

$$MinLegLength = r \times \tan(0.5 \times \alpha_1) + \left(\frac{(Pilot / SystemDelay)V}{3600} \right)$$

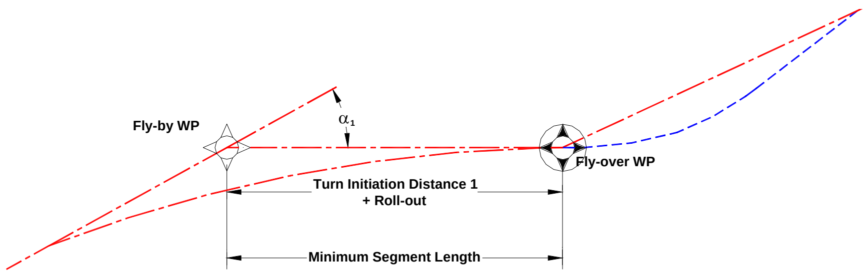

Figure 8 - Minimum Segment Length - Fly-by to Fly-over

Fly-over to Fly-over/Fixed Radius

The minimum leg length for fly-over to fly-over, or fly-over to 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 9.

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

This may be calculated using the following formula:

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

Where

α = First turn track angle change

30° = Recovery turn

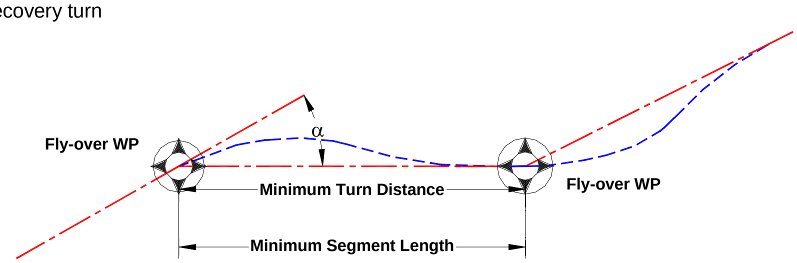

Figure 9 - Minimum Segment Length - Fly-over to Fly-over

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 10.

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

This may be calculated using the following formula:

$$L = r_1 \sin\alpha_1 + r_1 \cos\alpha_1 \tan 30 + r_1\left(\frac{1}{\sin 30} - \frac{2\cos\alpha_1}{\sin 60} \right) + r_2 \tan 15 + \frac{10V}{3600} + r_3 \tan(0.5\times\alpha_2) + \left(\frac{(Pilot / SystemDelay)V}{3600} \right)$$

Where

r_3 = Radius of the second turn.

α_1 = First turn track angle change

α_2 = Second turn track angle change

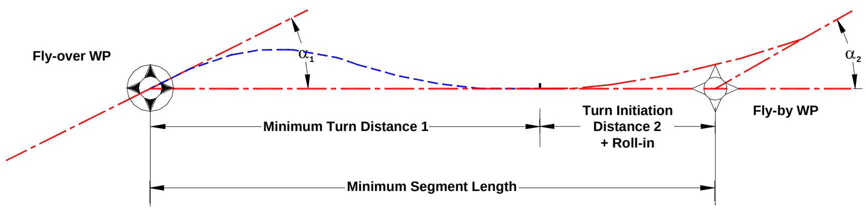

Figure 10 - Minimum Segment Length - Fly-over to Fly-by

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 11. This can be calculated using the following formula:

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

$$MinLegLength = r \times \tan(0.5\times\alpha_2) + \left(\frac{(Pilot/SystemDelay)V}{3600} \right)$$

Where:

r = Radius of second turn.

α_2 = Second turn track angle change

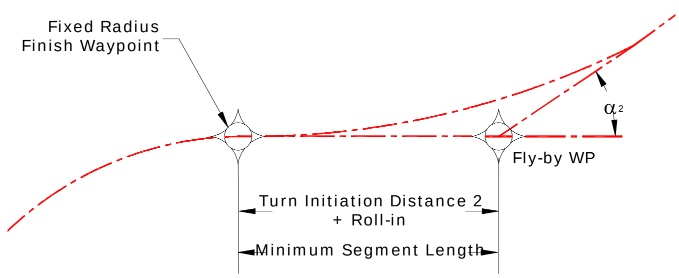

Figure 11 - Minimum Segment Length - Fixed Radius to Fly-by

Minimum Distances for B-RNAV Procedures

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.