ICAO

Doc 9905

Required Navigation Performance Authorization Required (RNP AR) Procedure Design Manual

Third Edition, 2021

Approved by and published under the authority of the Secretary General

INTERNATIONAL CIVIL AVIATION ORGANIZATION

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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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TABLE OF CONTENTS

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FOREWORD

Required navigation performance (RNP) was initially envisaged by the International Civil Aviation Organization (ICAO) as a means to facilitate change in airspace operation. ICAO recognized that global navigation satellite systems, the navigation infrastructure, operations, and aircraft systems were undergoing change faster than could be supported by their traditional technical standards processes. RNP was developed to allow the specification of airspace and operation requirements without the constraints of the slow process for specifying equipment and systems.

Initially, in order to support RNP operations, RNP procedure design criteria were developed and incorporated in the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS) (Doc 8168). However, lacking demand and general familiarity with the change in operations and implementation paradigm possible with RNP, the initial criteria were conservative in nature and specification. Consequently, as specific locations were identified where demanding RNP solutions were needed, ICAO criteria were found to be insufficient and lacking in the necessary support guidance for approving operations.

At the same time, one State in collaboration with industry and a key airline operator undertook the task to develop criteria that permitted the usage of RNP-capable aircraft to address a significant problem with airport access in obstacle-rich environments or terrain, under limiting weather conditions. These criteria for RNP procedures were documented in regulatory guidance, as part of the United States Federal Aviation Administration (FAA) Advisory Circular (AC) 120-29A.

The AC 120-29A RNP criteria permit a significant degree of flexibility and customization in procedure design. It extends beyond traditional procedure design guidance in its provision of criteria addressing relevant aspects of operational requirements that must be considered in the implementation of such special flight operations e.g., visual segment assessment, engine loss, extraction, tailored climb gradient and balked landing. However, such criteria can be very demanding and time-consuming as it must be evaluated and approved for every application. As a result, it was determined that a degree of standardization in lieu of maximum variability would facilitate not only procedure development but implementation as well.

In order to rationalize and support the implementation of RNP operations, ICAO established the Required Navigation Performance and Special Operational Requirements Study Group (RNPSORSG), which developed the *Performance-Based Navigation (PBN) Manual* (Doc 9613). The *PBN Manual* provides two types of navigation specifications for approach operations: RNP approach (RNP APCH) and RNP authorization required approach (RNP AR APCH). The RNP APCH navigation specification is intended to satisfy general RNP operational requirements and permit participation by aircraft with a basic level of RNP capability without a requirement for operational authorization. The other navigation specification, RNP AR APCH, which enables a higher level of navigation performance better able to address issues of airport access, such as obstacle-rich environments, and facilitate advances in air traffic management (ATM), requires the operator to meet additional aircraft and aircrew requirements and obtain operational authorization.

RNP AR procedures can provide significant operational and safety advantages over other area navigation (RNAV) procedures. This is done by incorporating additional navigational accuracy, integrity, and functional capabilities to permit operations using reduced obstacle clearance tolerances that enable approach and departure procedures to be implemented in circumstances where other types of approach and departure procedures are not operationally possible or satisfactory. Procedures implemented in accordance with this manual allow the exploitation of high-quality, managed lateral and vertical navigation (VNAV) capabilities that provide improvements in operational safety and reduced controlled flight into terrain (CFIT) risks.

This manual is intended for use by designers of instrument procedures based on the use of RNP avionics systems, where authorization is required (AR).

The manual includes design criteria to aid States in the implementation of RNP AR approach procedures in accordance with the PBN Manual, Volume II, Part C, Chapter 6. Similar criteria for departure procedures will be incorporated when developed.

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DEFINITIONS

Airspace concept. An airspace concept provides the outline and intended framework of operations within an airspace. An airspace concept is essentially a high-level statement of an airspace plan. Airspace concepts are developed to satisfy explicit strategic objectives such as improved safety, increased air traffic capacity and mitigation of environmental impact. Airspace concepts include details of the practical organization of the airspace and its users based on particular communications, navigation and surveillance/air traffic management (CNS/ATM) assumptions, e.g., air traffic services (ATS) route structure, separation minima, route spacing and obstacle clearance.

Approach procedure with vertical guidance (APV). A performance-based navigation (PBN) instrument approach procedure designed for 3D instrument approach operations Type A.

Area navigation (RNAV). A method of navigation that permits aircraft operation on any desired flight path within the coverage of ground-based or spaced-based navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

Note.— Area navigation includes performance-based navigation *as well as other operations that do not meet the definition of performance-based navigation.*

Datum crossing point (DCP). The DCP is a point on the glide path directly above the landing threshold point (LTP) or fictitious threshold point (FTP) at a height specified by the reference datum height (RDH).

Decision altitude (DA) or decision height (DH). A specified altitude or height in a 3D instrument approach operation at which a missed approach must be initiated if the required visual reference to continue the approach has not been established.

Note 1.— Decision altitude is referenced to mean sea level and decision height is referenced to the threshold elevation.

Note 2.— The required visual reference means that section of the visual aids or of the approach area which should have been in view for sufficient time for the pilot to have made an assessment of the aircraft position and rate of change of position, in relation to the desired flight path. In Category III operations with a decision height the required visual reference is that specified for the particular procedure and operation.

Note 3.— For convenience where both expressions are used they may be written in the form "decision altitude/height" and abbreviated "DA/H".

Navigation specification. A set of aircraft and air crew requirements needed to support performance-based navigation operations within a defined airspace. There are two kinds of navigation specifications:

RNP specification. A navigation specification based on area navigation that includes the requirement for performance monitoring and alerting, designated by the prefix RNP, e.g., RNP 4, RNP APCH.

RNAV specification. A navigation specification based on area navigation that does not include the requirement for performance monitoring and alerting, designated by the prefix RNAV, e.g., RNAV 5, RNAV 1.

Note.— The Performance-Based Navigation (PBN) Manual (Doc 9613), Volume II *contains detailed guidance on navigation specifications.*

Obstacle clearance surface (OCS). An obstacle evaluation surface used to determine the minimum obstacle clearance altitude at any point.

Performance-based navigation (PBN). Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.

Note.— Performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept.

Vertical path angle (VPA). Angle of the published final approach descent in Baro-VNAV procedures.

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ABBREVIATIONS AND ACRONYMS

ACT	Actual cold temperature
anpe	Actual navigation performance error
APCH	Approach
APV	Approach procedure with vertical guidance
AR	Authorization required
*ase	Altimetry system error
*atis	Automatic terminal information service
ATM	Air traffic management
ATS	Air traffic services
ATT	Along track tolerance
BARO-VNAV	Barometric vertical navigation
bg	Body geometry
CF	Course to a fix (ARINC leg type)
Cot	Cotangent
DA/H	Decision altitude/height
DER	Departure end of runway
DF	Direct to a fix (ARINC leg type)
D_{FAP}	Distance from threshold to FAP
D_{FROP}	Distance from threshold to final approach roll-out point
DTA	Distance of turn anticipation
FA	Course from a fix to an altitude (ARINC leg type)
FAA	Federal Aviation Administration
FAF	Final approach fix
FAP	Final approach point
FAS	Final approach segment
FM	Course from a fix to a manual termination (ARINC leg type)
FROP	Final approach roll-out point
ft	Feet
*fte	Flight technical error
FTP	Fictitious threshold point
GP	Glide path
GPI	Ground point of intercept
H	Altitude
HL	Height loss
IAF	Initial approach fix
IAS	Indicated airspeed
IF	Intermediate fix
ISA	International standard atmosphere
isad	International standard atmosphere temperature deviation
km	Kilometre
kt	Knot
LTP	Landing threshold point
LTP_{ELEV}	Landing threshold point elevation

* These abbreviations and acronyms come from the *Performance-Based Navigation (PBN) Manua*l (Doc 9613).

m	Metre
MA	Missed approach
MAPt	Missed approach point
MAS	Missed approach segment(s)
MOC	Minimum obstacle clearance
NA	Not available
NM	Nautical mile
OAS	Obstacle assessment surface(s)
OCA/H	Obstacle clearance altitude/height
OCS	Obstacle clearance surface
PANS-OPS	Procedures for Air Navigation Services — Aircraft Operations
PBN	Performance-based navigation
R	Rate of turn
r	Radius
RA	Radio altimeter
RDH	Reference datum height
RF	Radius to fix (ARINC leg type)
RNAV	Area navigation
RNP	Required navigation performance
RNP AR	Required navigation performance authorization required
RNPSORSG	Required Navigation Performance and Special Operational Requirements Study Group
RSS	Root sum square
SI	International System of Units
SOC	Start of climb
SSR	Secondary surveillance radar
TAS	True airspeed
TF	Track to fix (ARINC leg type)
TP	Turning point
TrD	Transition distance
TWC	Tailwind component
V	Speed
VA	Heading to altitude (ARINC leg type)
vae	Vertical angle error
V_{at}	Speed at threshold
VEB	Vertical error budget
VASIS	Visual approach slope indicator system
VM	Heading to a manual termination (ARINC leg type)
VNAV	Vertical navigation
VPA	Vertical path angle
V_{slg}	Stall speed in landing configuration at maximum landing mass
V_{so}	Stall speed
WGS	World Geodetic System
wpr	Waypoint precision error

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Chapter 1

DESCRIPTION OF REQUIRED NAVIGATION PERFORMANCE AUTHORIZATION REQUIRED (RNP AR)

1.1 PURPOSE OF THE MANUAL

1.1.1 This manual is intended for use by designers of instrument procedures based on required navigation performance (RNP) using area navigation (RNAV) avionics systems, where authorization is required (AR).

1.1.2 This manual includes design criteria to aid States in the implementation of RNP AR approach (APCH) procedures in accordance with the *Performance-Based Navigation (PBN) Manual* (Doc 9613) (hereafter referred to as the PBN Manual), Volume II, Part C, Chapter 6.

1.1.3 This document is a procedure design document that addresses the procedure design criteria and the rationale explaining the application of the criteria. Information concerning the RNP AR concept of operations, implementation philosophy and operational use can be found in the PBN Manual and Annex 6 — *Operation of Aircraft*.

1.2 APPLICATION

1.2.1 RNP AR APCH operations are classified as 3D instrument approach operations Type A in accordance with Annex 6. This type of operation requires a positive vertical navigation (VNAV) guidance system for the final approach segment (FAS). The procedure design criteria in the manual are based on utilization of a barometric vertical navigation (BARO-VNAV) system meeting specified airworthiness requirements. Obstacle clearance is based on a statistical assessment of all the component errors referred to as a vertical error budget (VEB). Other suitably accurate vertical guidance may be implemented provided equivalent accuracy, integrity and containment can be assured. Other avionics meeting specified airworthiness requirements can be used as an alternate means of providing vertical guidance on RNP AR approaches designed in accordance with these criteria.

1.2.2 RNP AR APCH procedures may be designed to support multiple minima for various appropriate RNP, e.g., RNP 0.3, RNP 0.2, down to RNP 0.1. However, designers should not promulgate procedures with RNP less than 0.3 unless there is an operational benefit. Reductions in RNP reduce the alert limits and increase the possibility of an alert and a consequent go-around; therefore, the minimum RNP published should not be smaller than necessary to provide the required operational capability.

1.2.3 The design criteria in this manual are applicable to a range of aircraft types and cannot, therefore, take into account the full capability of some aircraft types. Consequently, procedures designed in accordance with this manual will provide an acceptable operational solution in many but not all circumstances. Alternative design solutions tailored to a specific aircraft type, specific performance parameters or special operating scenarios are not the subject of this manual.

1.2.4 The design principles laid out in the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168), Volume II — *Construction of Visual and Instrument Flight Procedures* apply as amplified or modified by criteria in this manual. While uniform application of the basic procedures in this document is very desirable, latitude is permitted for the development of detailed procedures, which may be needed to satisfy local conditions.

Chapter 2

RNP AR APPROACH PROCEDURE DESIGN

2.1 UNDERLYING PRINCIPLES

2.1.1 An RNP AR approach procedure is a practical application of the RNP AR APCH navigation specification, as defined in the PBN Manual. The procedure requires a lateral TSE that can be as low as ±0.1 nautical miles (NM) on any segment of the approach procedure. RNP AR APCH procedures are normally published where significant operational advantages can be achieved while preserving or improving safety of operation. The RNP AR certification and approval requirements are contained in the PBN Manual.

2.1.2 The design of procedures in accordance with the criteria in this manual assumes normal operations. It is the responsibility of the operator to provide contingency procedures for abnormal and emergency operations.

2.2 OBSTACLE CLEARANCE ALTITUDE/HEIGHT (OCA/H) AND DECISION ALTITUDE/HEIGHT (DA/H)

2.2.1 The OCA/H is the lowest altitude or height that establishes compliance with obstacle clearance criteria. DA/H is a specified altitude or height, operationally established, at or above the OCA/H, at which a missed approach must be initiated for a 3D approach operation if the required visual reference to continue the approach is not established.

2.2.2 An OCA/H is published for RNP AR procedures on the chart.

2.3 STANDARD CONDITIONS

OCA/H is promulgated for those categories of aircraft for which the procedure is designed. The OCH values shall be based on the following standard conditions:

a) final approach vertical protection is based on the use of a barometric VNAV system and the operational minimum DA/H is based on barometric altimeter;

b) aircraft lateral dimensions are considered in certification (no additional procedure design action is required in the lateral protection); and

c) early missed approach is safeguarded by the certification and approval process.

2.4 TERRAIN EFFECTS

The application of the VEB for obstacle protection relies on accurate altimetry. Rapidly rising terrain, significant ridgelines or cliffs, steep valley walls and deep canyons may be associated with Bernoulli/Venturi/orographic lifting effects that can impact vertical performance. Areas where significant variations in pressure may occur must be identified during the design process, and their effect on the proposed procedure must be considered during the design process and validated in the safety assessment.

2.5 LATERAL PROTECTION

For RNP AR procedures, the semi-width of the protection area is defined as 2 × RNP navigation accuracy requirement. There are no buffer or secondary areas. Table 2-1 lists RNP navigation accuracy requirements applicable to the specific instrument procedure segments.

Table 2-1. RNP navigation accuracy requirements

	RNP AR		
Segment		*Maximum*	*Minimum*
Initial		1	0.1
Intermediate		1	0.1
Final		0.3	0.1
Missed approach		1.0	0.1*
* See section 4.6 for operational implications associated with missed approach segments' (MAS) most stringent RNP navigation accuracy requirements.			

2.6 VERTICAL PROTECTION

2.6.1 In the APV segment (final approach and initial-, intermediate missed approach), obstacle clearance is provided by three obstacle assessment surfaces (OAS):

a) a final approach surface based on the VEB of the barometric altimeter system;

b) a horizontal surface, connected to the final approach surface at threshold level, based on a height loss (HL) and a transition distance (TrD), and

c) a missed approach (Z) surface, connected to the horizontal surface at threshold level.

Chapter 3

GENERAL CRITERIA

3.1 AIRCRAFT SPEED CATEGORIES

3.1.1 Aircraft performance differences have a direct effect on the airspace required for different manoeuvres. The most significant factor in performance is speed. Accordingly, five categories of typical aircraft have been established to provide a standardized basis for relating aircraft manoeuvrability to specific instrument approach procedures.

3.1.2 The criterion taken into consideration for the classification of aeroplanes by categories is the indicated airspeed (IAS) at threshold (V_{at}), which is equal to the stall speed (V_{so}) multiplied by 1.3, or stall speed in landing configuration at maximum certificated landing mass (V_{slg}) multiplied by 1.23. If both V_{so} and V_{slg} are available, the higher resulting V_{at} is used. The ranges of speeds (IAS) in Tables 3-1 a) and 3-1 b) are to be used in procedure design calculations. For conversion of these speeds to true airspeed (TAS), see section 3.1.6.

3.1.3 Aircraft categories will be referred to throughout this document by their letter designations as follows:

- Category A — less than 169 km/h (91 kt) IAS
- Category B — 169 km/h (91 kt) or more but less than 224 km/h (121 kt) IAS
- Category C — 224 km/h (121 kt) or more but less than 261 km/h (141 kt) IAS
- Category D — 261 km/h (141 kt) or more but less than 307 km/h (166 kt) IAS
- Category E — 307 km/h (166 kt) or more but less than 391 km/h (211 kt) IAS

Note.— If the rotorcraft and crew are certified and meet the RNP AR operations requirements, rotorcraft may be used to fly aircraft Category A RNP AR procedures.

Restriction on aircraft category and indicated airspeed

3.1.4 Where airspace requirements are critical for a specific category of aircraft, procedures may be based on lower speed category aircraft, provided use of the procedure is restricted to those categories. Alternatively, the procedure may be designated as limited to a specific maximum IAS for a particular segment without reference to category. TAS should be calculated using the procedure speeds given in Tables 3-1 a) and 3-1 b).

Table 3-1 a). IAS (km/h)

Segment		*IAS by aircraft category (CAT)*				
		CAT A	*CAT B*	*CAT C*	*CAT D*	*CAT E*
Maximum airspeed	Initial-, intermediate approach	280	335	445	465	467
	Final approach and intermediate missed approach	185	240	295	345	425
	Missed approach	205	280	445	490	510
Minimum airspeed restriction	Initial-, intermediate approach	165	220	295	345	345
	Final approach	130	155	215	240	285
	Missed approach	185	240	295	345	425

Table 3-1 b). IAS (kt)

Segment		*IAS by aircraft category (CAT)*				
		CAT A	*CAT B*	*CAT C*	*CAT D*	*CAT E*
Maximum airspeed	Initial-, intermediate approach	150	180	240	250	250
	Final approach and intermediate missed approach	100	130	160	185	230
	Missed approach	110	150	240	265	275
Minimum airspeed restriction	Initial-, intermediate approach	90	120	160	185	185
	Final approach	70	85	115	130	155
	Missed approach	100	130	160	185	230

3.1.5 Aircraft using these procedures may be from States using the International System of Units (SI) and with SI-unit airspeed indicators (ASIs). However, the standard non-SI unit aircraft category speeds are not exact conversions, they are rounded. The largest difference is for Category C, where the typical difference in turn radius can be 50 m. This is significant at the more stringent RNP navigation accuracy requirements (RNP 0.1 with a semi-width of only 370 m) and should be considered in turn boundary construction.

Calculating true airspeed

3.1.6 IAS to TAS conversion is computed using either ISA +15° or local statistical data for RNP AR procedures with the application of the following standard equations:

Non-SI units: $TAS = IAS * 171233 * [(288 + VAR) – 0.00198 * H]^{0.5}/(288 – 0.00198 * H)^{2.628}$

SI units: $TAS = IAS * 171233 * [(288 + VAR) – 0.006496 * H]^{0.5}/(288 – 0.006496 * H)^{2.628}$

where:

IAS = indicated airspeed (kt or km/h, as appropriate);

TAS = true airspeed (kt or km/h, as appropriate);

VAR = variation from international standard atmosphere (ISA) (standard value +15) or local data for 95 per cent high temperature, if available; and

H = altitude (ft or m, as appropriate).

3.2 CALCULATING TURN RADIUS AND BANK ANGLE

Speeds for turn calculations

3.2.1 Fly-over waypoints are not permitted between two track to fix (TF) segments of an RNP AR. For RNP AR procedures, the turn radius for fly-by and radius to fix (RF) turns is calculated using a speed V = TAS + designated tailwind.

3.2.2 Determine the TAS for the turn using the formulas in section 3.1.6, and the airspeed for the highest aircraft category from Table 3-1 a) or 3-1 b) for which the procedure is designed.

3.2.3 A speed restriction may be applied to reduce turn radius; however, the maximum speed must be operationally acceptable for the aircraft intended for the operation. Only one speed restriction per approach segment is permitted, and the fastest airspeed appropriate for the highest speed category of aircraft for which the procedure is authorized shall be used to determine that speed.

Calculating the turn radius for turns

3.2.4 The turn radius applied is based on a standard bank angle of 25 degrees at a TAS plus assumed tailwind. Locate the highest speed aircraft category that will be published on the approach procedure and use the appropriate IAS in Table 3-1 a) (SI units) or Table 3-1 b) (non-SI units), considering the highest altitude in the turn, to calculate the TAS using the appropriate formulas in section 3.1.6. For initial and intermediate segments, use the minimum altitude for the fix prior to the turn fix. Use the tailwind component (TWC) for the highest altitude within the turn according to ICAO standard wind, as outlined below:

TWC = 12h + 87 km/h

where:

h is in 1000 m above sea level;

or

TWC = 2h + 47 kts

where:

h is in 1000 ft above sea level.

For RF turns in the missed approach, the following wind values may be applied:

— 19 km/h (10 kt) at or below 152 m (500 ft) above AD elevation

— 37 km/h (20 kt) from 152 m (500 ft) to at or below 305 m (1 000 ft) above AD elevation

— 56 km/h (30 kt) from 305 m (1 000 ft) to at or below 610 m (2 000 ft) above AD elevation

— 74 km/h (40 kt) from 610 m (2 000 ft) to at or below 915 m (3 000 ft) above AD elevation

3.2.5 For the MAS, use the altitude based on a seven per cent gradient with origin at OCA/H − HL.

3.2.6 Other tailwind gradients, or specific values, may be used after a site-specific determination of wind has been carried out based on that location's meteorological history (using available information from other sources). The source and values used should be documented.

3.2.7 Calculate the appropriate TWC, according to section 3.2.4, for the highest altitude within the turn and add the value to TAS. Determine the radius of turn (r).

1) Calculate the rate of turn (R) in degrees/second as follows:

$$R = (6\,355 \tan \alpha)/(\pi * V)$$

where:

V = (TAS + wind speed) in km/h; and
α = bank angle

or

$$R = (3\,431 \tan \alpha)/(\pi * V)$$

where:

V = (TAS + wind speed) in kt; and
α = bank angle

up to a maximum value of three degrees/second.

2) Calculate the turn radius (r) for a given value of R as follows:

$$r = V/(20 * \pi * R)$$

where:

V = (TAS + wind speed)

Turn radii based on non-standard bank angles

3.2.8 The minimum allowable RF segment radius must ensure a maximum RF segment design bank angle of 25 degrees. Larger radii are allowed for smooth transitions, maintaining stabilized approaches, lower minima or to achieve specific leg lengths.

3.2.9 These criteria apply to construction at or below FL 190. Where turns above FL 190 are required, a bank angle of 15 degrees should be used.

Fly-by turns — Distance of turn anticipation (DTA)

3.2.10 The DTA is the distance measured from the turn fix to the start and end points of a fly-by turn. The minimum length of a segment cannot be less than the sum of the DTAs associated with the start and end fix of the segment (see Figure 3-1).

DTA = r tan(A/2)

where:

r = radius of turn for the TAS + tailwind for the fastest aircraft speed category for which the procedure is designed, calculated in accordance with section 3.2.7; and

A = turn angle.

Note 1.— These criteria differ from the formulas in the Procedures for Air Navigation Services — Aircraft Operations (*PANS-OPS – Doc 8168*)*, Volume II, Part 1, Section 2, Chapter 1, Tables III-2-1-1 through III-2-1-20 because the roll-in/ roll-out distance is covered in RNP certification.*

Note 2.— The nominal distances for calculations of descent gradients are measured along the arc from the turn point to the bisector for the inbound leg component and along the arc length from the bisector to the roll-out point for the outbound leg component.

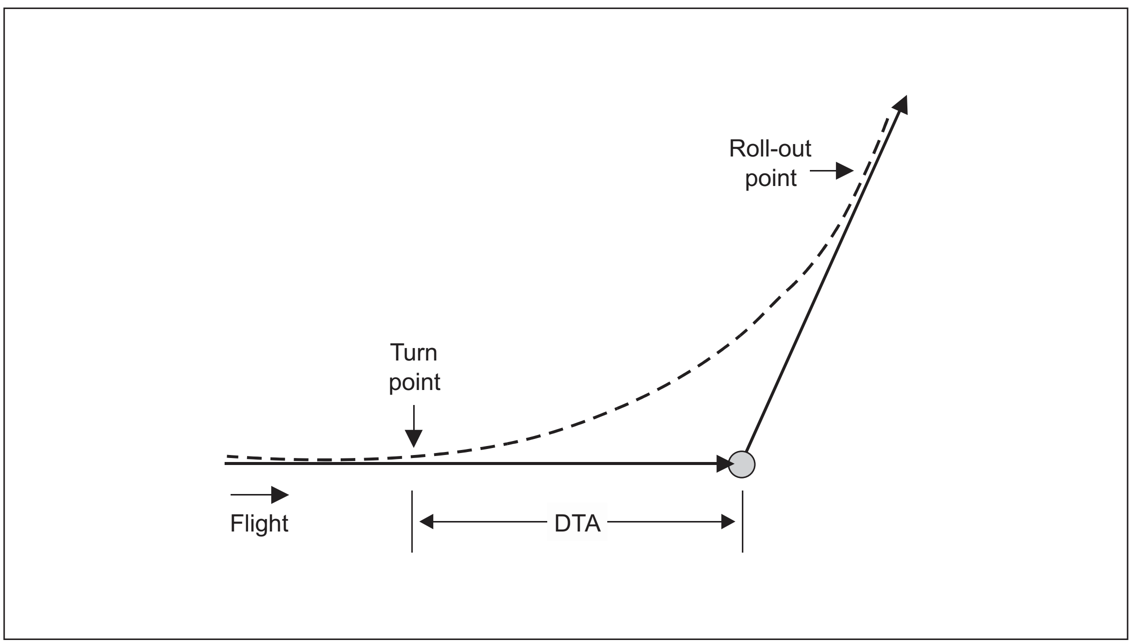

Figure 3-1. Distance of turn anticipation (DTA)

Calculation of bank angle for specific radius to fix leg

3.2.11 Where RF legs are necessary, the bank angle required for a given TAS, tailwind speed and turn radius is:

SI units:

$$\alpha = \arctan (TAS + W)^2/(127094 * r); \text{ given } R = (6355 * \tan \alpha)/[\pi*(TAS + W)] \leq 3°/\text{sec}$$

non-SI units:

$$\alpha = \arctan (TAS + W)^2/(68625 * r); \text{ given } R = (3431 * \tan \alpha)/[(\pi*(TAS + W)] \leq 3°/\text{sec}$$

where:

W = tailwind speed; and
r = turn radius.

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Chapter 4

PROCEDURE CONSTRUCTION

4.1 GENERAL PRINCIPLES

Segments and legs

4.1.1 The initial and intermediate segments provide a smooth transition from the en-route or STAR environment to the FAS. Descent to the vertical path intercept and configuring the aircraft for final approach must be accomplished in these segments. RNP segments should be designed using the most appropriate leg type (track to fix or ARINC leg type) (TF or RF)) to satisfy obstruction and operational requirements in initial, intermediate, final and MAS.

4.1.2 Other leg types, as indicated in Doc 9613, while not preferred, may be used when necessary. These additional leg types include:

a) direct to a fix (DF);

b) course to a fix (CF); and

c) course from a fix to an altitude (FA).

Procedure design should avoid any application of heading to altitude (VA) and manual path terminators (course from a fix to a manual termination (FM) heading to a manual termination (VM)) to the maximum extent practicable.

4.1.3 Whenever the RNP navigation accuracy requirement is less than 1.0 NM, DF or CF legs cannot be applied and the only turn methods must be fly-by or RF. Whenever the RNP navigation accuracy requirement is less than 0.3 NM and in the final approach segment, the only turn method must be RF.

Fixes

Fix identification

4.1.4 Approach procedure design employs the same fixes that are used in the PANS-OPS general criteria. Each fix shall be identified as specified in the *Procedures for Air Navigation Services — Aeronautical Information Management* (PANS-AIM, Doc 10066), Appendix 1, Table A1-4.

Stepdown fixes

4.1.5 Stepdown fixes are not permitted in the final approach segment of RNP AR approach procedures.

Frame of reference

4.1.6 Positions of obstacles are related to a conventional x, y, z coordinate system with its origin at landing threshold point (LTP) and parallel to the World Geodetic System (WGS) WGS-84 ellipsoid (see Figure 4-1). The x-axis is parallel to the final approach track; positive x is the distance before threshold and negative x is the distance after threshold. The y-axis is at a right angle to the x-axis. The z-axis is vertical, with heights above threshold being positive.

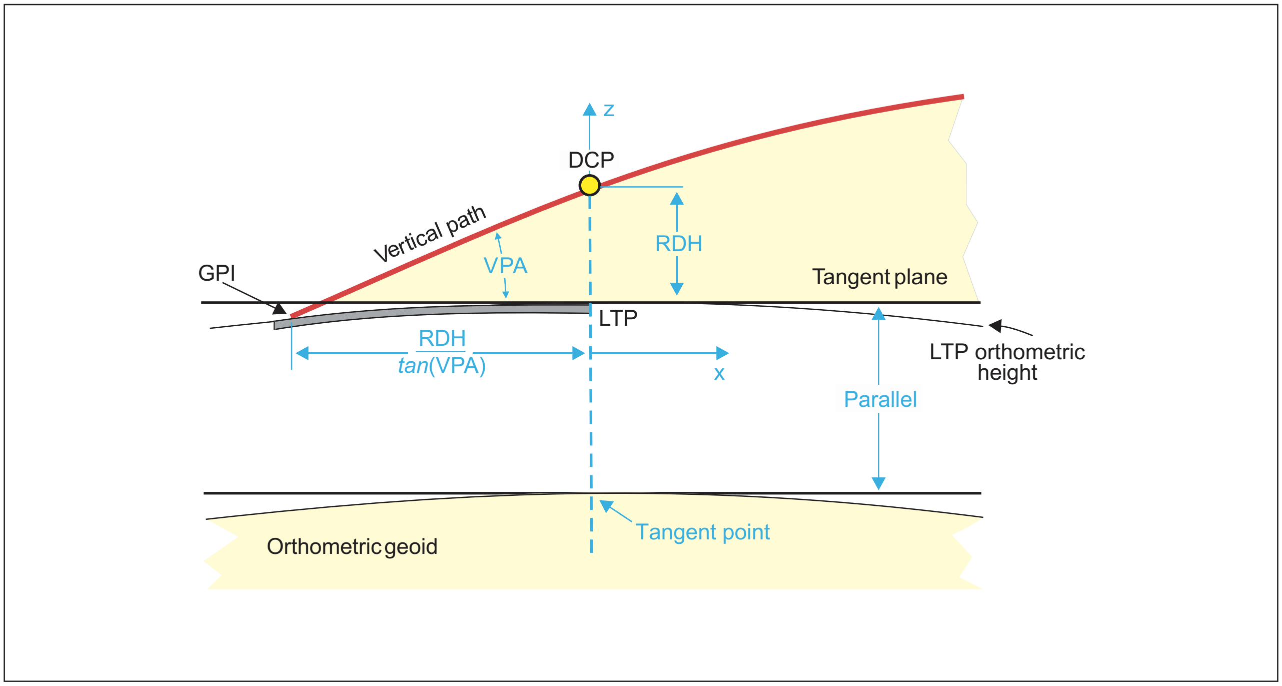


Figure 4-1. Coordinate system baseline

Required navigation performance segment width

4.1.7 RNP navigation accuracy requirements are specified in increments of a hundredth (0.01) of a NM. Segment width is defined as 4 × the RNP navigation accuracy requirement (see Figure 4-2). The possible RNP navigation accuracy requirements for instrument approach procedures are listed in Table 2-1.

4.1.8 The maximum RNP navigation accuracy requirements listed in Table 2-1 should be applied unless a more stringent navigation accuracy requirement is necessary to achieve the required ground track or lowest OCA/H. Once a more stringent navigation accuracy requirement is applied, a less stringent navigation accuracy requirement should not be applied until the start of the missed approach. The RNP accuracy value should only decrease in the initial, intermediate and final approach segments, and only increase in the missed approach segment. For each line of minima, the RNP accuracy value must not change within the final segment. The most stringent RNP navigation accuracy requirements are listed in the "Minimum" column of Table 2-1.

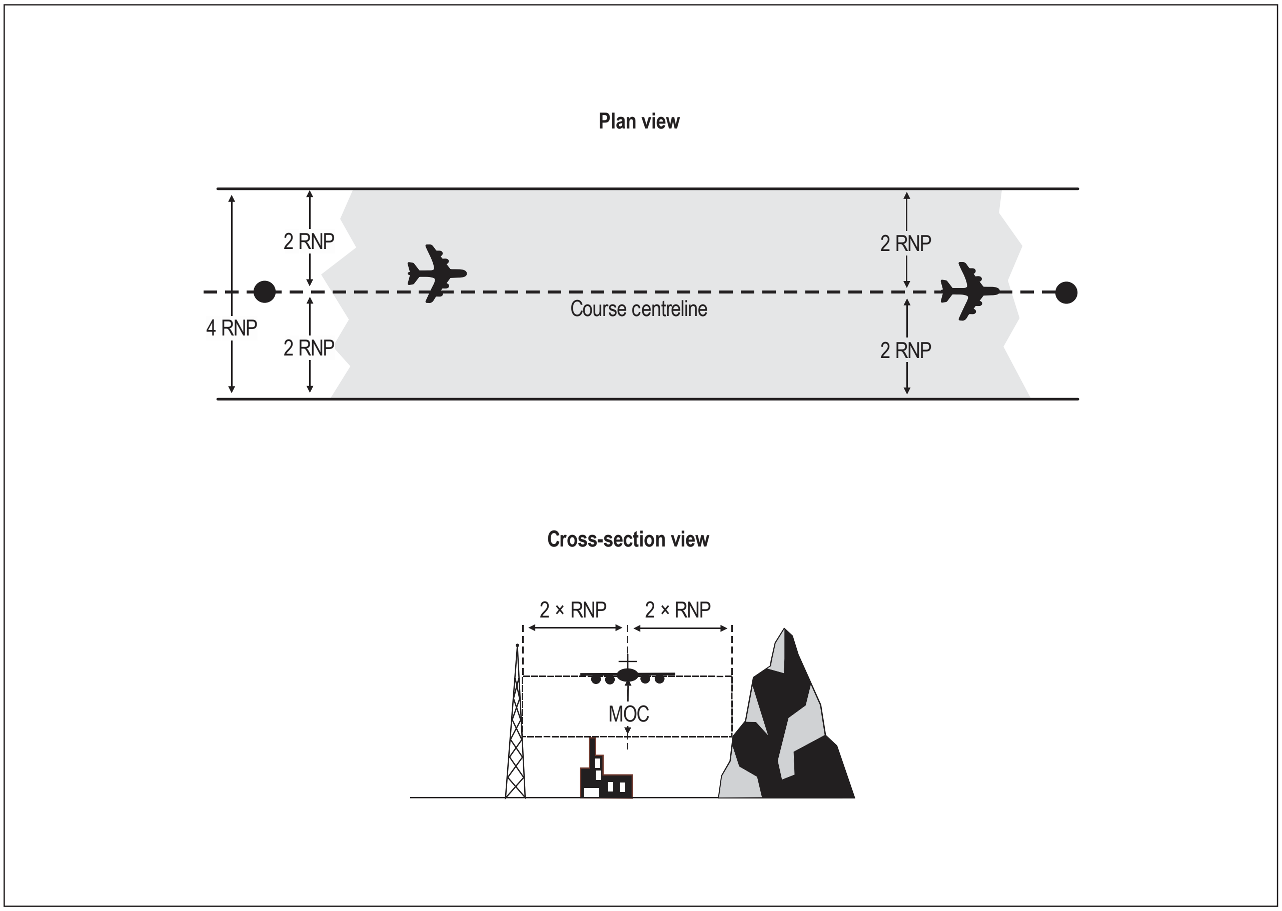


Figure 4-2. RNP segment widths

Required navigation performance segment length

4.1.9 Segments should be designed with sufficient length to allow the required descent to be as close to the optimum gradient as possible and to take account of DTA where turns are required. The minimum straight segment (any segment) length is the maximum of:

a) the sum of RNP navigation accuracy values associated with the two fixes (the RNP associated with the fix is the RNP of the preceding segment); or

b) DTA1 + DTA2.

Section 4.1.10 applies where RNP changes occur (RNP value changes 1 × RNP prior to fix). For obstacle clearance calculations, the segment extends 1 × RNP before the first fix to 1 × RNP past the second fix.

Changing segment width
(Required navigation performance navigation accuracy requirements)

4.1.10 Changes in the RNP navigation accuracy requirements must be completed upon the aircraft reaching the fix; therefore, the area within ±1 RNP navigation accuracy requirement of the fix must be evaluated for both segments. The change to a more stringent RNP navigation accuracy requirement is illustrated in Figure 4-3, the change to a less stringent RNP navigation accuracy requirement is illustrated in Figure 4-4, and RNP navigation accuracy requirement changes involving RF legs are illustrated in Figure 4-5 and 4-6. The construction for changing to a more stringent RNP navigation accuracy requirement always involves the abrupt changes shown on the figures referenced in this paragraph. The specific constructions applicable for changing to a less stringent RNP navigation accuracy requirement are detailed in the following paragraphs separately for the different turn methods.

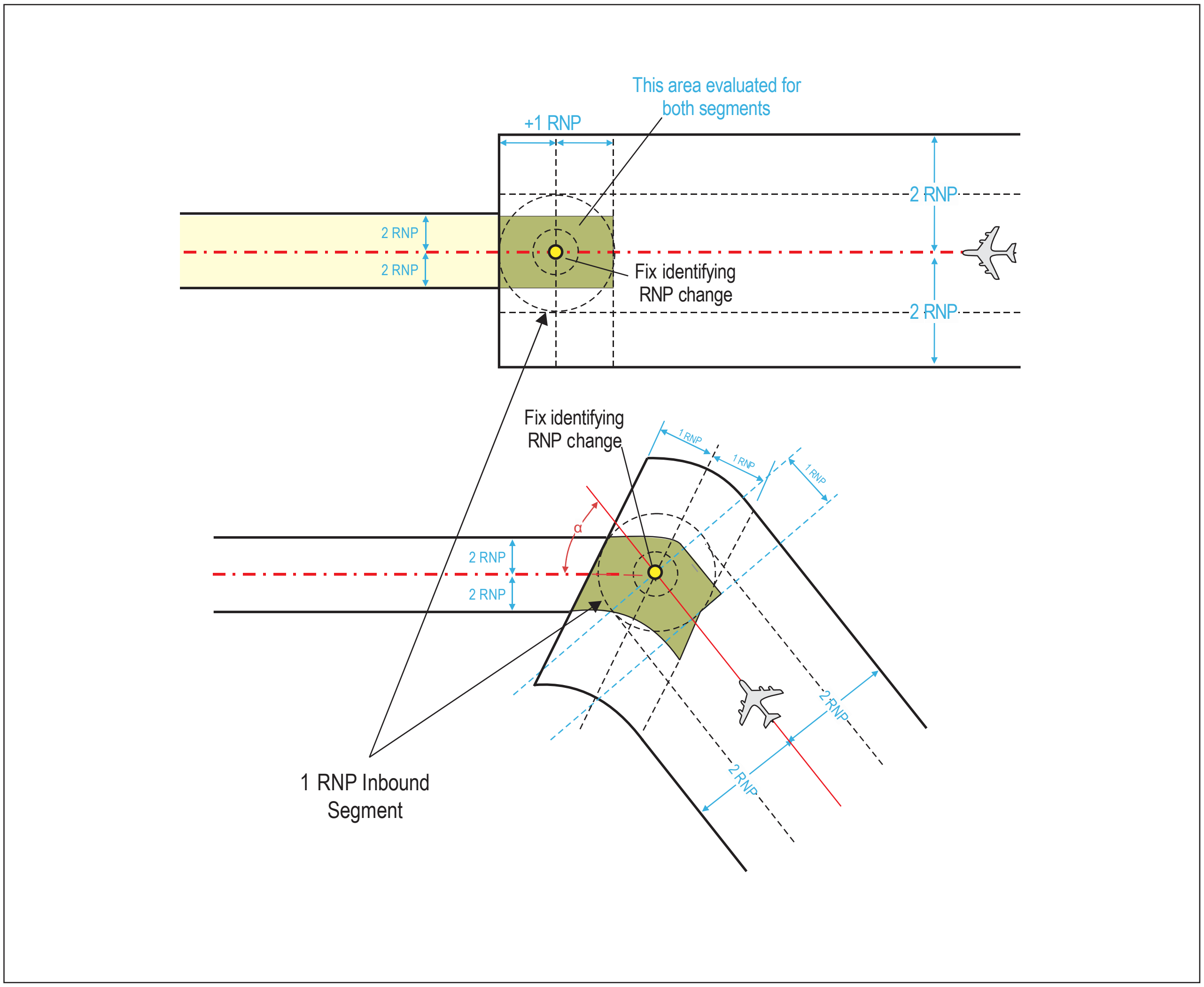


Figure 4-3. RNP reduction (straight and turning segment)

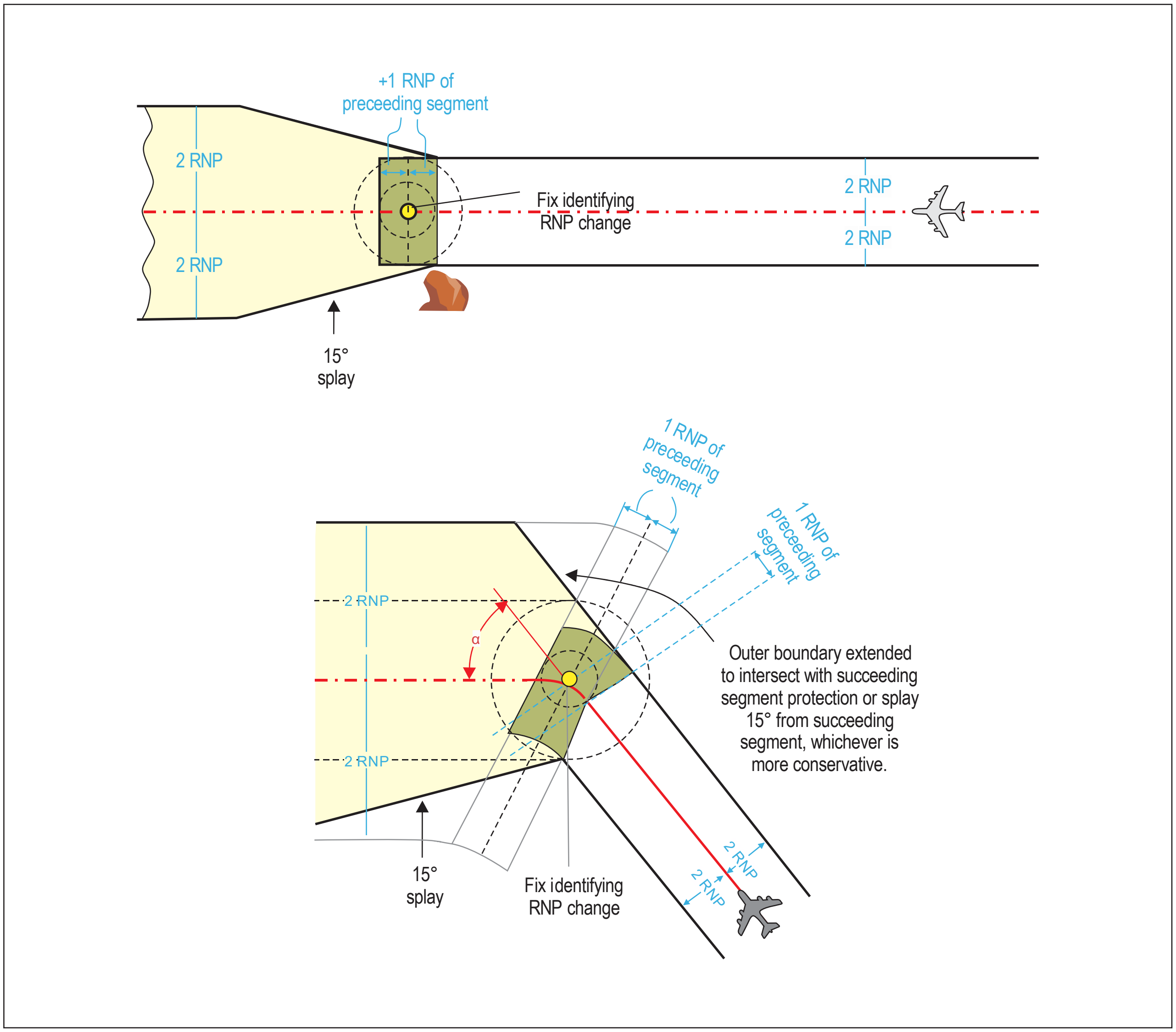


Figure 4-4. RNP navigation accuracy requirement increase (straight and turning segments)

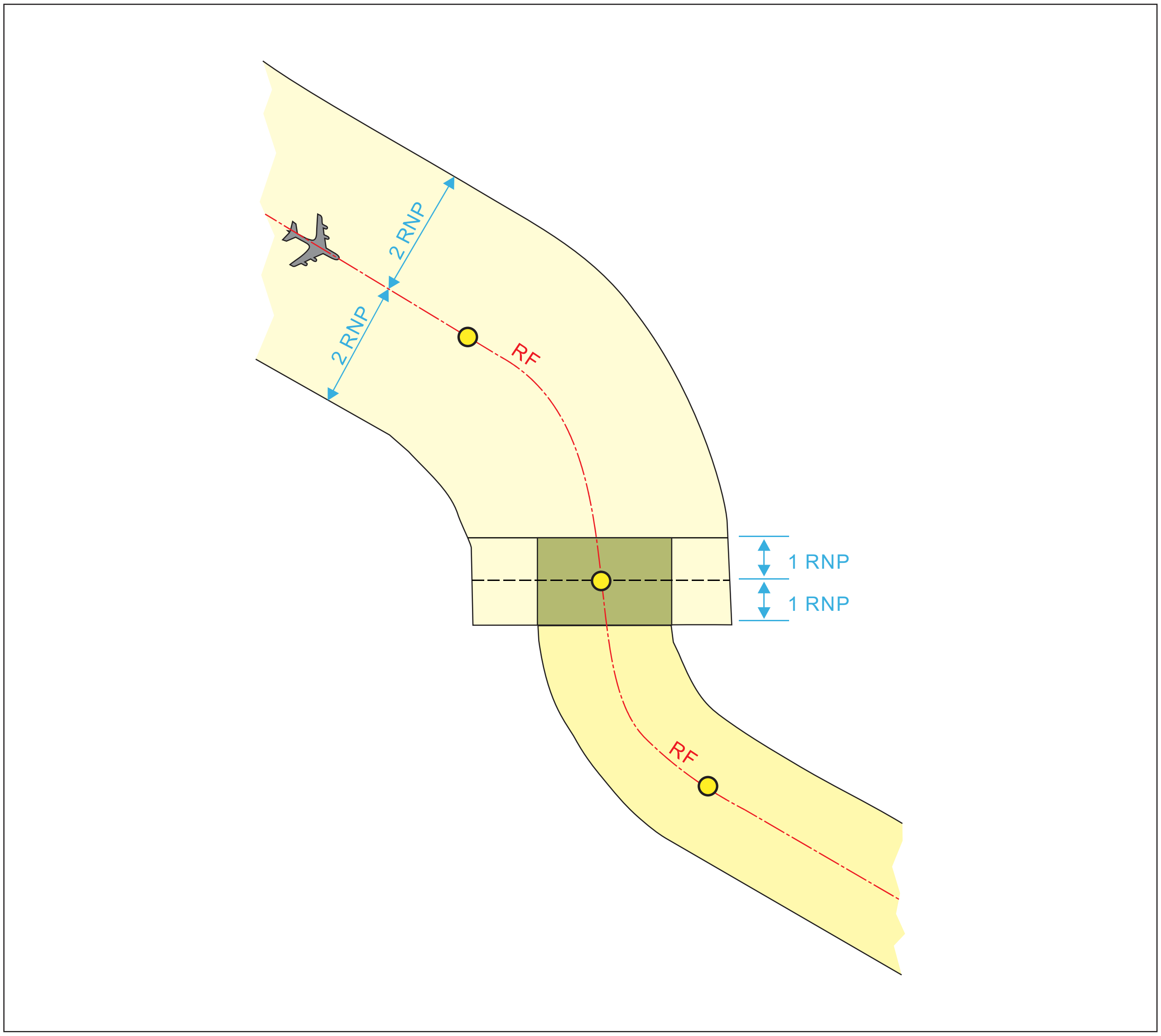


Figure 4-5. Changing to a more stringent RNP navigation accuracy requirement in RF turns

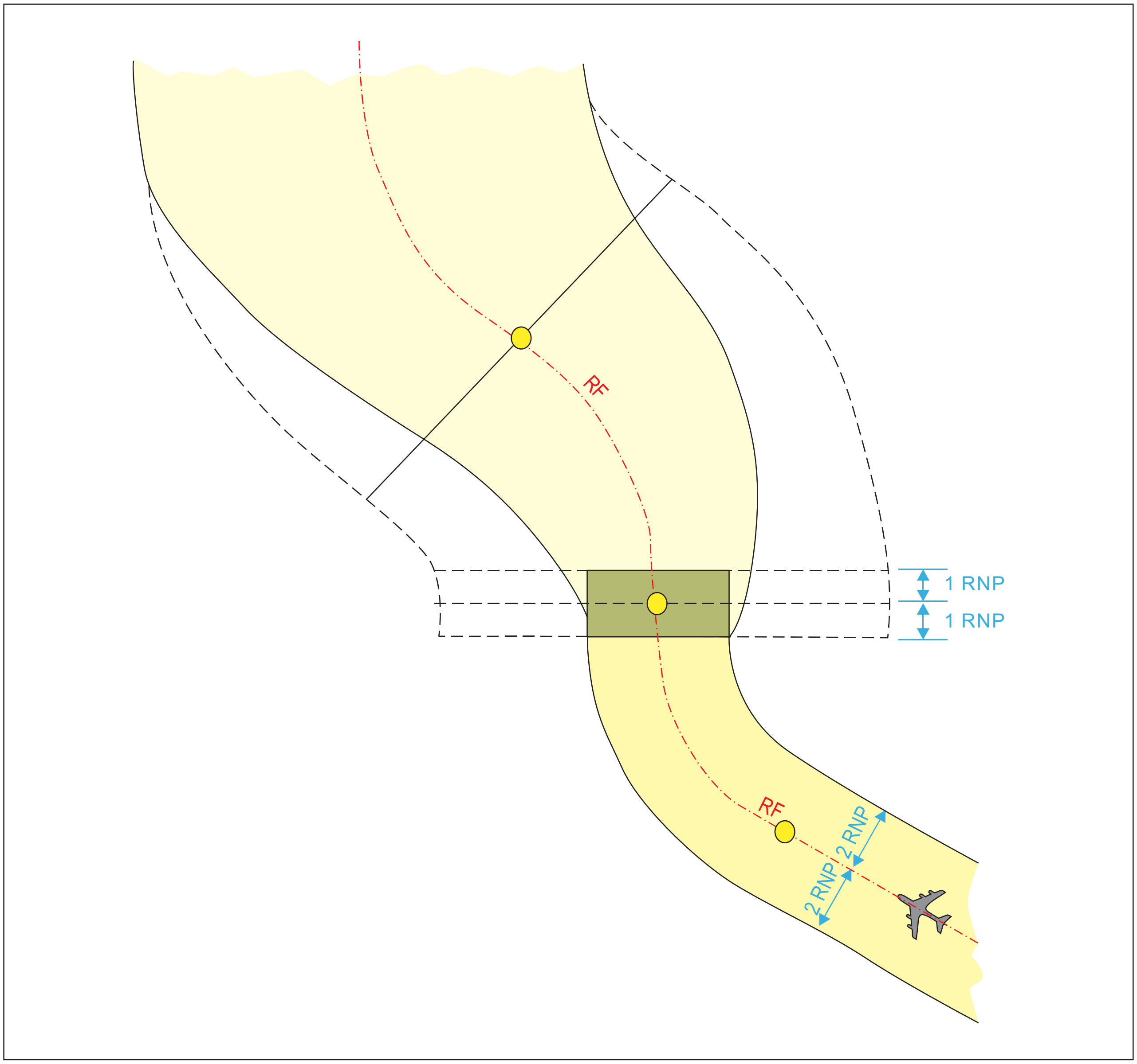


Figure 4-6 Changing to a less stringent navigation accuracy requirement in RF turns

Track to fix leg segment

4.1.11 A TF leg is a geodesic flight path between two fixes and is the normal standard leg used in RNP AR procedures. TF legs, except at the missed approach point (MAPt), are linked by fly-by waypoints or RF legs.

Area construction for turns at fly-by waypoints joining two TF legs

4.1.12 This construction is specific to RNP AR procedures, and only primary areas are used: ½ AW = 2 × RNP; buffer areas are not applied. Turn angles should be limited to a maximum of 70 degrees where aircraft are expected to cross (fly-by) the fix at altitudes above FL 190, and to 90 degrees at and below FL 190. When obstructions prevent use of this construction, use of an RF leg should be considered (see section 4.1.14). The fly-by turn area is constructed using the following steps:

STEP 1: Determine the required ground track. Calculate the turn radius (r) as described in section 3.2.7. Construct the turning flight path tangent to the inbound and outbound legs. The centre will be located on the bisector (see Figures 4-7 and 4-8).

STEP 2: Construct the outer boundary tangential to the inbound and outbound segment outer boundaries, with a radius of 2 × RNP and centre located at the fix.

STEP 3: Construct the inner turn boundary tangential to the inbound and outbound segment inner boundaries, with radius of (r + 1 RNP). The centre is located on the bisector (see Figure 4-8).

4.1.13 The evaluation for the succeeding segment starts at a distance of 1 RNP before the turn fix (see Figure 4-7) or at 1 RNP before the angle bisector line (see Figure 4-8), whichever is encountered first.

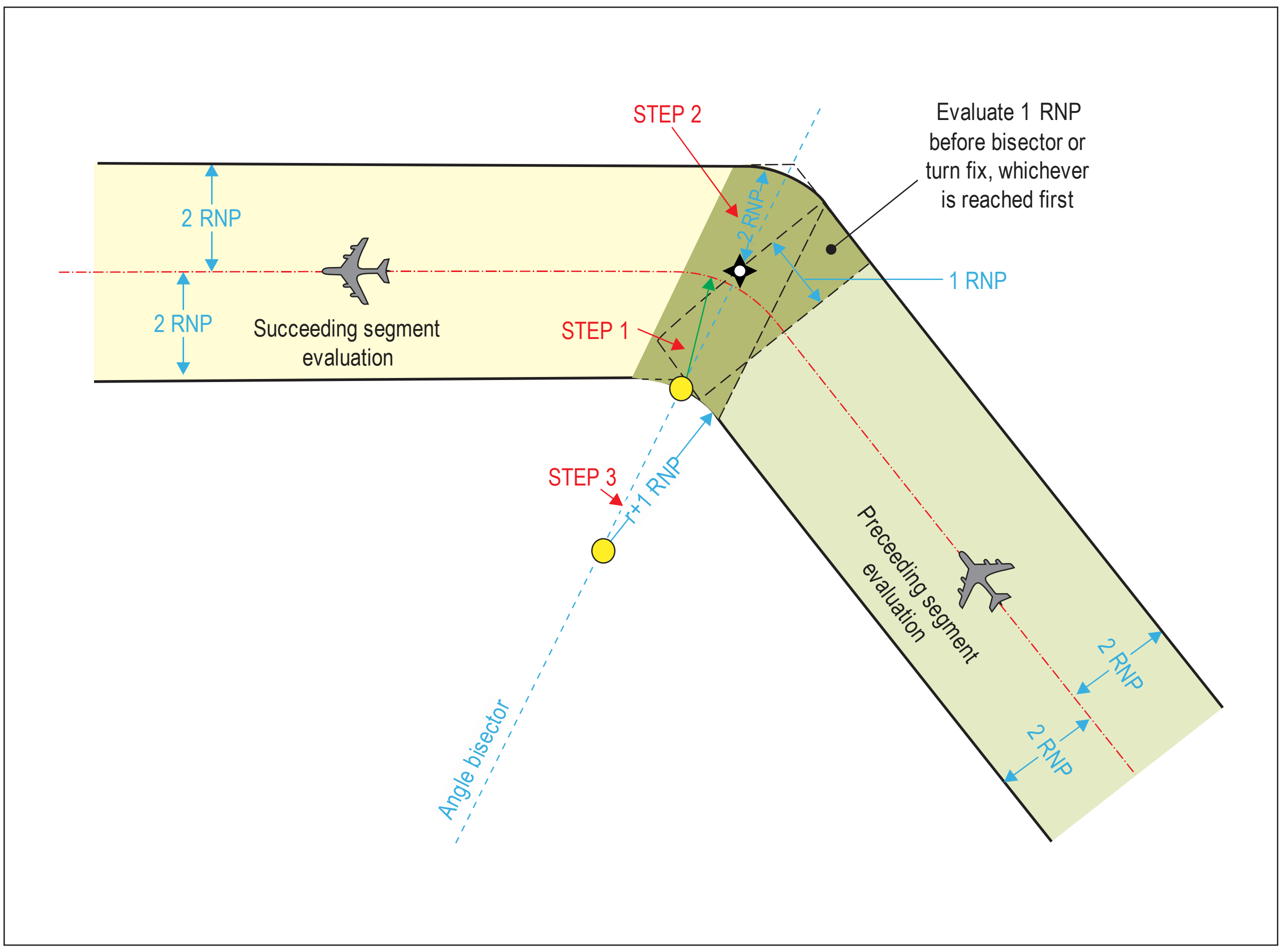


Figure 4-7. Small turn at fly-by fix

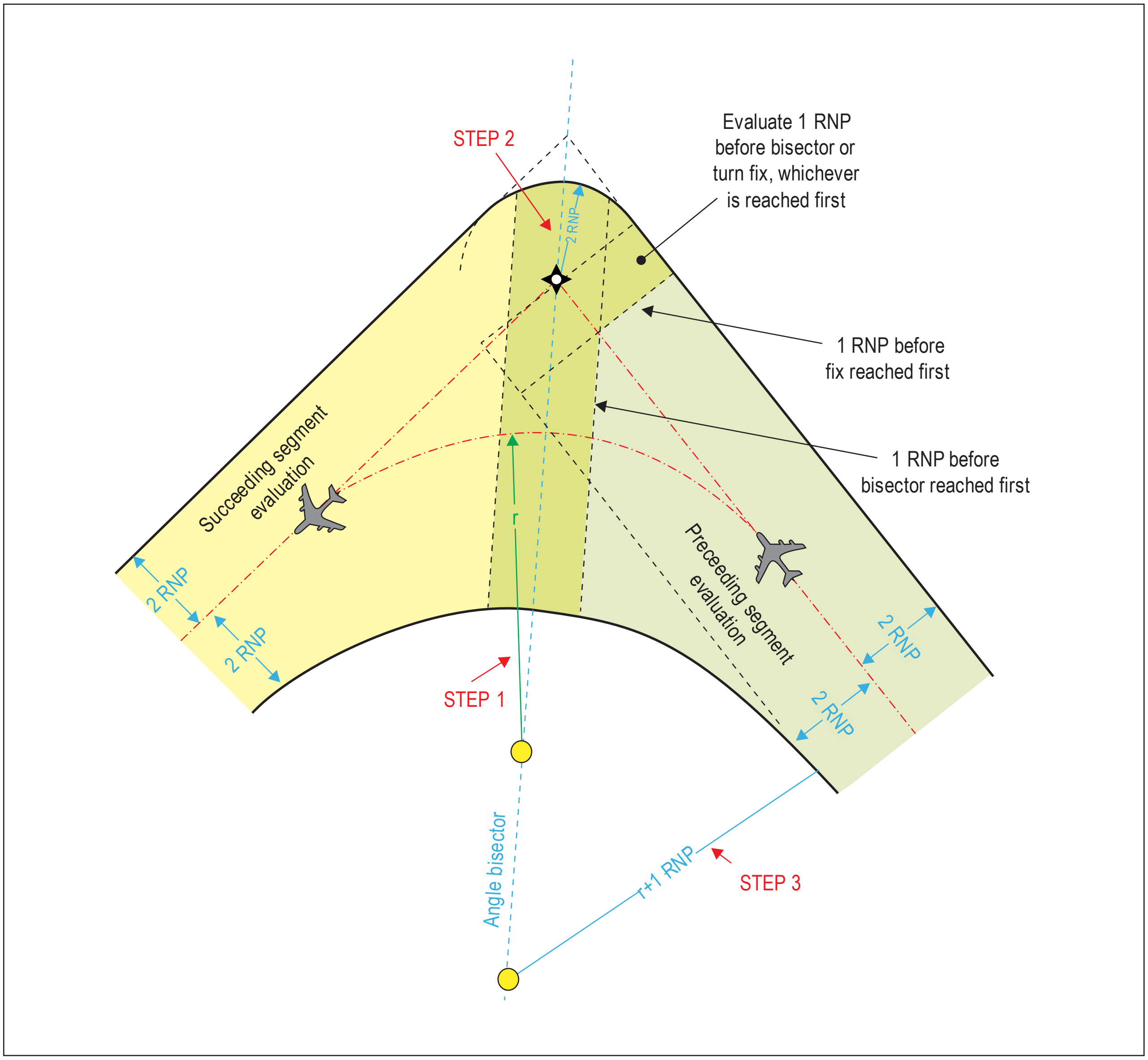


Figure 4-8. Large turn at fly-by fix

4.1.14 The construction for changing to a less stringent RNP navigation accuracy requirement at a fly-by turn involves the following (see Figure 4-4):

a) on the inner side the area edge splays out 15 degrees from the nominal track of the succeeding segment, beginning where the area edge of the preceding segment intersects the start of the evaluation of the succeeding segment (see section 4.1.13). The splay extends until intersecting with the 2 x RNP half width of the succeeding segment, from where the area edge continues with a 2 x RNP constant half width; and

b) on the outer side the area edge extends parallel to the preceding segment until intersecting with the 2 x RNP half width of the succeeding segment, from where the area edge continues with a 2 x RNP constant half width. For turns of less than 15 degrees, the area edge splays out 15 degrees from the nominal track of the succeeding segment, beginning where the area edge of the preceding segment intersects the start of the evaluation of the succeeding segment (see section 4.1.13). The splay extends until intersecting with the 2 x RNP half width of the succeeding segment, from where the area edge continues with a 2 x RNP constant width.

Radius to fix turns

RF leg construction

4.1.15 RF legs provide a repeatable, fixed-radius ground track in a turn and are the preferred method for track changes.

4.1.16 The RF leg is specified using the following parameters:

a) a beginning point at the path terminator fix of the inbound segment and an end point at the beginning fix of the outbound segment; and

b) the centre of the turn located at the intersection of the bisector and any turn radius (or on the intersection of the radius perpendicular to the inbound track at the initiation point and the radius perpendicular to the outbound track at the termination point).

Parameters a) and b) must each specify the same turn arc that is tangent to the inbound leg at its termination fix and tangent to the outbound leg at its originating fix. Taken together, they over-specify the turn. However, this is resolved by the data coder selecting the parameters required for the specific navigation system. (See Figure 4-9.)

4.1.17 The turn area is bounded by concentric arcs. The minimum turn radius is 2 × RNP.

STEP 1: Determine the ground track necessary to avoid obstacles. Calculate the turn(s) and associated radii (r) necessary to best achieve the ground track. Apply sections 3.2.8 and 4.5.13 to verify the bank angle associated with “r” is lower than the maximum specified design values.

STEP 2: Locate the turn centre at a perpendicular distance “r” from the inbound and outbound segments. This is the common centre for the nominal turn track, outer boundary and inner boundary arcs.

STEP 3: Construct the flight path. Draw an arc of radius “r” from the tangent point on the inbound course to the tangent point on the outbound track.

STEP 4: Construct the outer turn area boundary. Draw an arc of radius (r + 2 x RNP) from the tangent point on the inbound segment outer boundary to the tangent point on the outbound track outer boundary.

STEP 5: Construct the inner turn area boundary. Draw an arc of radius (r – 2 x RNP) from the tangent point on the inbound segment inner boundary to the tangent point on the inner boundary of the outbound track.

STEP 6: The height of the surface is constant along a radial line in a manner similar to a spiral staircase, as illustrated in Figure 4-10 a) for approach and Figure 4-10 b) for missed approach. To determine the height of the surface for an RF leg in the approach, calculate the height based on the gradient along the nominal track and apply the height across a radial line through the point. To determine the height of the surface for an RF leg in the missed approach, the distance for the gradient is based on an arc length calculated using a radius of (r – 0.1 NM).

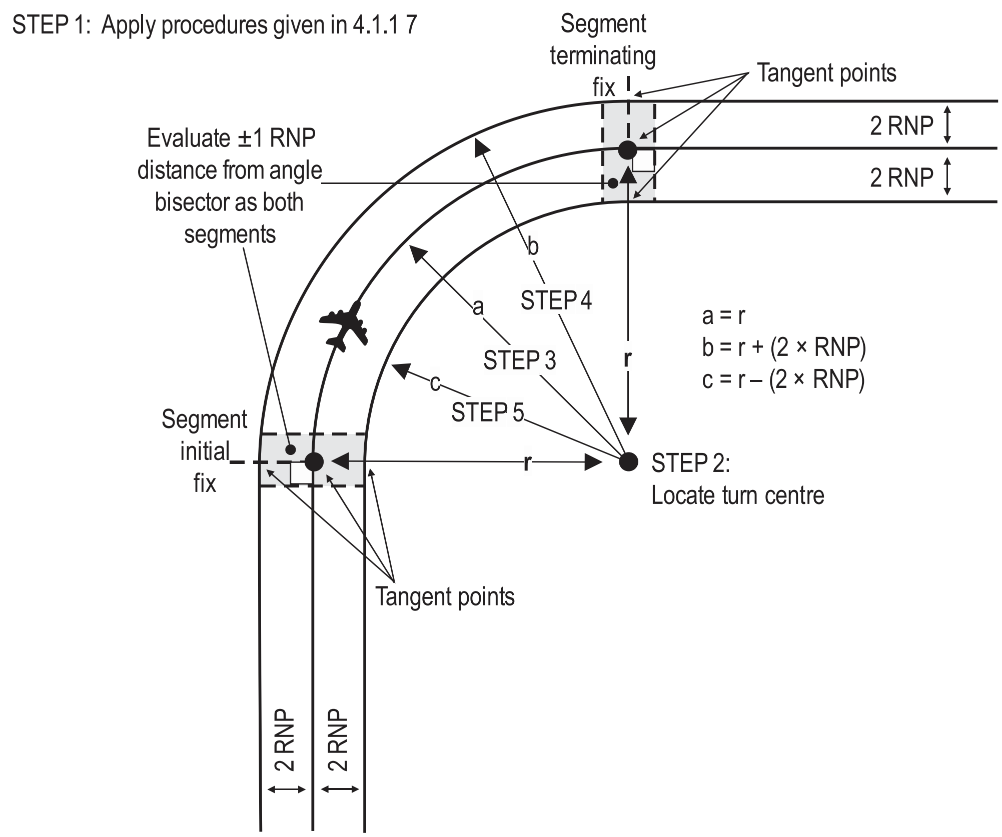


Figure 4-9. RF turn construction

4.1.18 The construction for changing to a less stringent RNP navigation accuracy requirement in RF turns involves the following (see Figure 4-6). The area boundary is defined by a line starting at 1 x RNP (of preceding segment) before the fix and splaying outward at 15 degrees relative to the nominal track until reaching 2 x RNP half width in the succeeding segment. If 2 x RNP half width is not achieved by the splay within the next segment, then the splay continues relative to the nominal track into the further segment until reaching the applicable width of that segment. For straight legs (e.g., TF leg before/after an RF) the splaying area edge will result in a straight line; for RF legs the splaying area edge will result in a spiral.

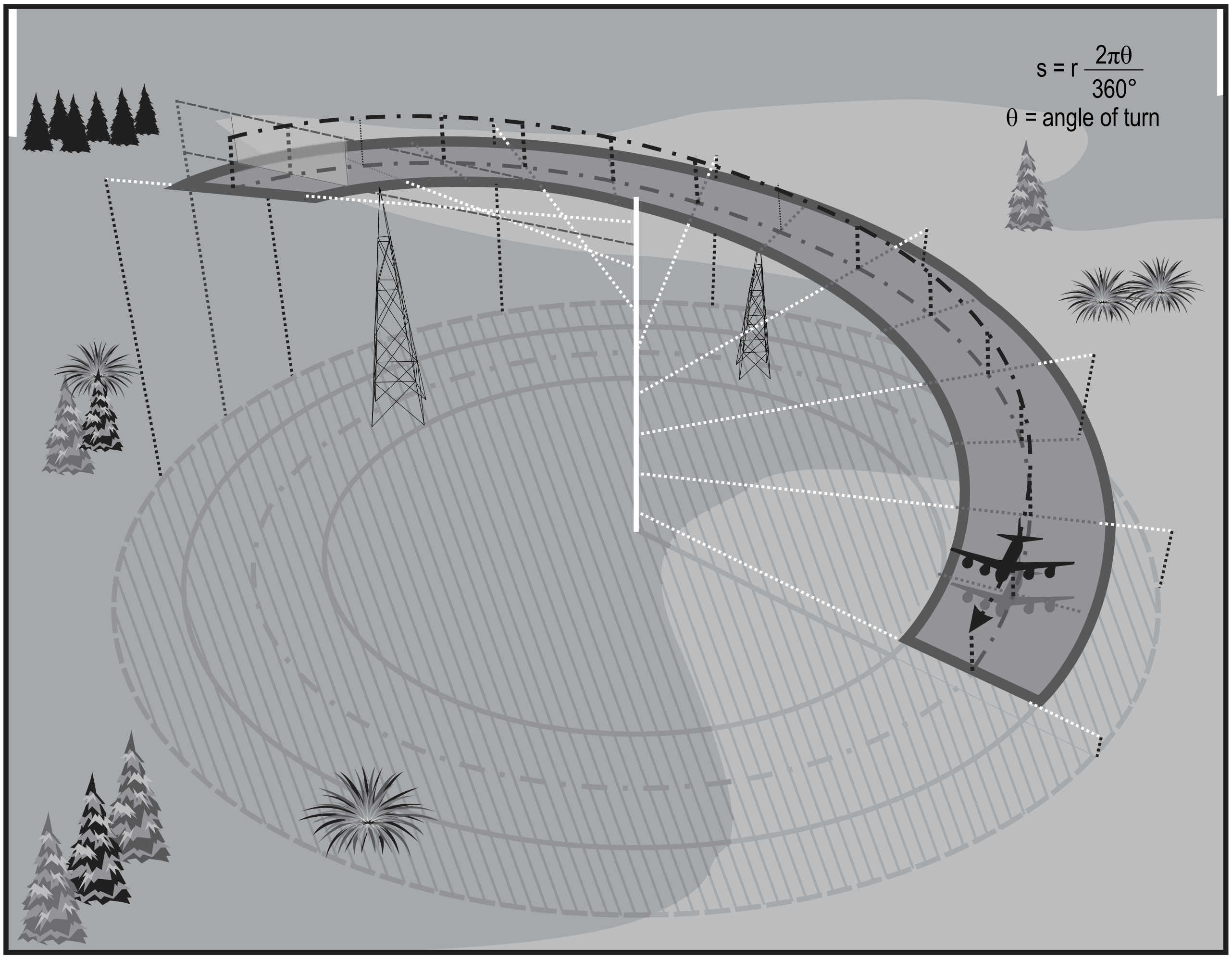


Figure 4-10 a). Obstacle clearance surface (OCS) for RF approach segments

Calculation of descent gradients

4.1.19 Descent gradients are calculated between the nominal fix positions. For RF segments, the distance used is the arc distance between the nominal fix positions. See Table 4-1 for standard and maximum descent gradient values.

Table 4-1. Descent gradient constraints

	Descent gradient	
Segment	*Standard*	*Maximum*
Initial	4% (2.4°)	8% (4.7°)

Segment	*Descent gradient*	
	Standard	*Maximum*
Intermediate	≤2.5% (1.4°)	Equal to designed final segment gradient
Final	5.2% (3°)	See section 4.4.16

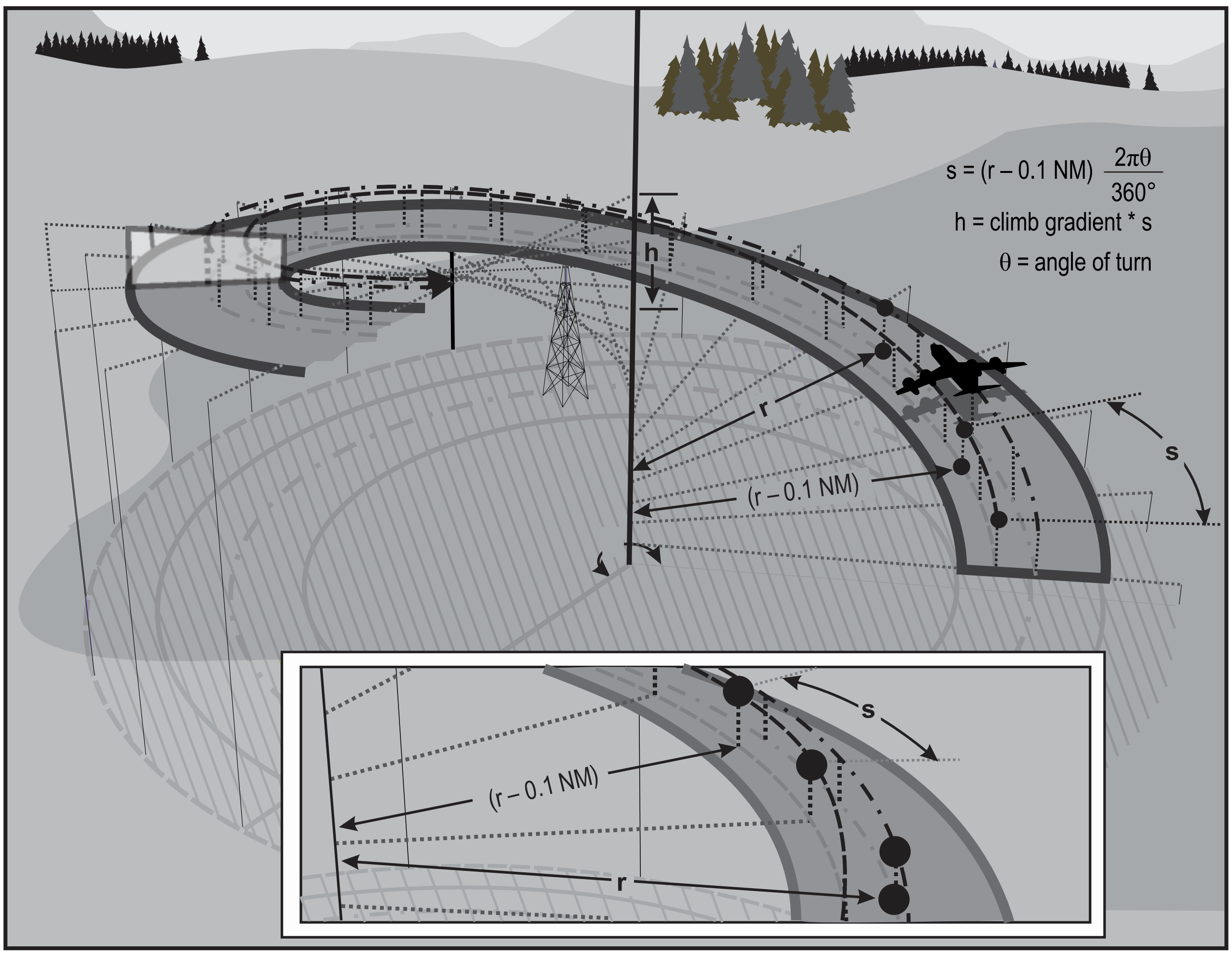


Figure 4-10 b). OCS for RF missed approach segments (MAS)

4.1.20 While not the preferred turn methods, for other than fly-by or RF turns, the criteria in PANS-OPS, Vol. II. Part III, Section 2, Chapter 1 and Chapter 2 apply with the use of primary only areas as amplified or modified by criteria in this manual. Where along track tolerance (ATT) is used in PANS-OPS, it must be replaced by 1 x RNP of the preceding segment.

Mountainous terrain

4.1.21 In mountainous terrain, minimum obstacle clearance (MOC) for the initial, intermediate and missed approach segments should be increased by as much as 100 per cent.

4.2 INITIAL APPROACH SEGMENT

Required navigation performance navigation accuracy requirement

4.2.1 In the initial approach segment the least stringent and the optimum RNP navigation accuracy requirement is 1.0 NM. The most stringent is 0.1 NM.

Length

4.2.2 Segments should be designed with sufficient length to allow the required descent to be as close to the optimum gradient as possible. See sections 4.1.9 and 4.1.10 for criteria on minimum length and RNP navigation accuracy requirement changes.

4.2.3 The maximum initial segment length (total of all component segments) is 50 NM. When possible, a procedure design principle is that initial segment lengths should be shortened from this maximum, with the utilization of arrival segments.

Alignment

4.2.4 The normal arrival for an RNP AR procedure will be via a direct RNP or RNAV route. However, RNP AR procedures can also incorporate the normal T-bar arrangement. This is based on a runway-aligned final segment preceded by an intermediate segment and up to three initial segments arranged either side of and along the final approach track to form a T. Y-bar construction should not be used since it entails up to 110° turns.

4.2.5 RNAV enables the geometry of approach procedure design to be very flexible. The “T” configuration is preferred where obstructions and air traffic flow allow. The approach design should provide the least complex configuration possible to achieve the desired minimum OCA/H. See Figure 4-11 for the basic T-bar construction.

4.2.6 Turns for connecting TF legs should normally be restricted to 90 degrees. For turns greater than this, RF legs should be used and may be considered for all turns. For the T configurations, offset initial approach fixes (IAFs) are located such that a course change of 90 degrees is required at the intermediate fix (IF). The capture region for tracks inbound to the offset IAF extends 180 degrees about the IAFs, providing a direct entry when the course change at the IF is 90 degrees.

Lateral initial segments

4.2.7 The lateral initial segments are based on course differences of 90 degrees from the intermediate segment track. This arrangement ensures that entry from within a capture region requires a change of course at the IAF not greater than 90 degrees.

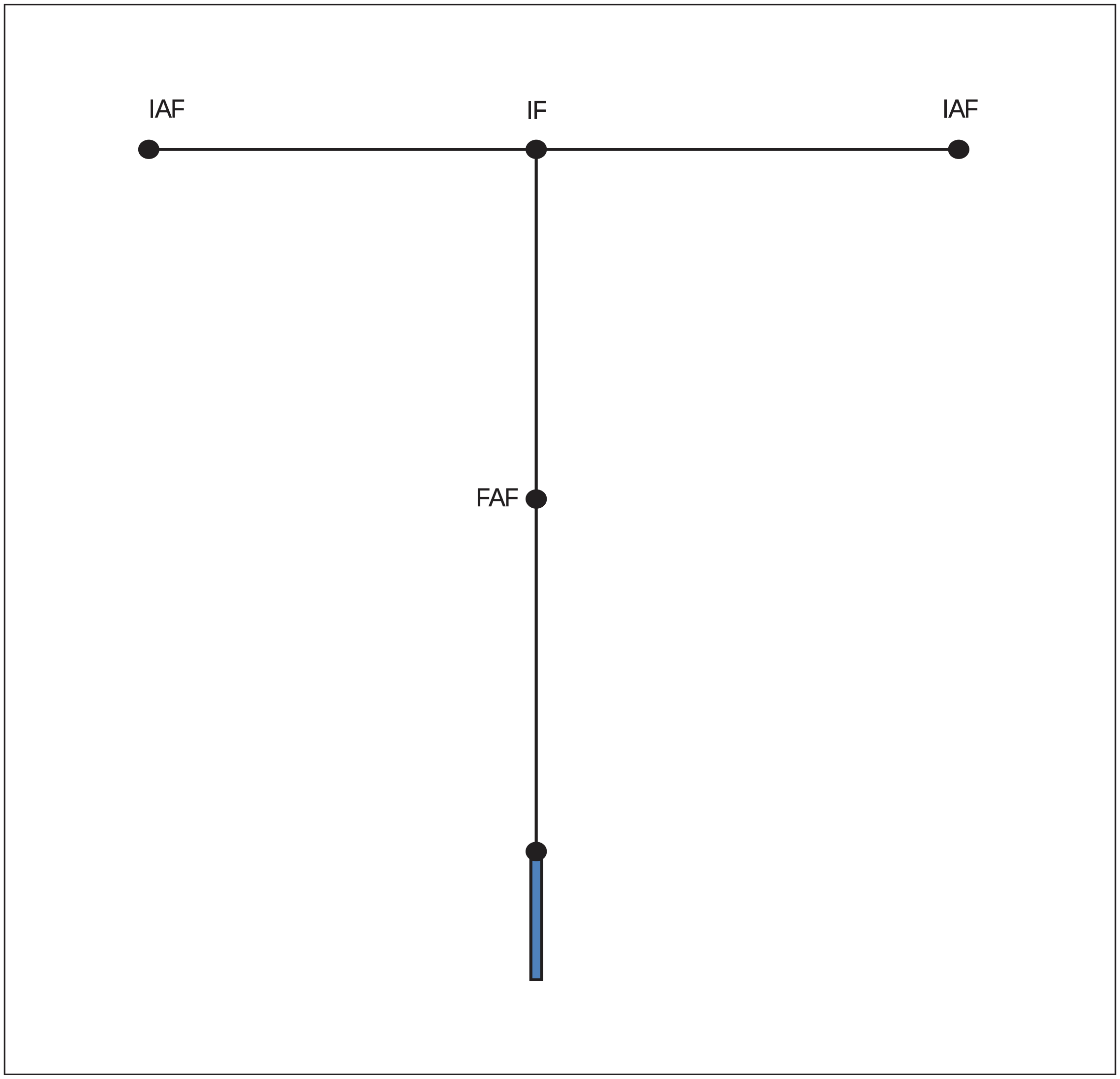


Figure 4-11. Application of basic T

Central initial segment

4.2.8 It is normally aligned with the intermediate segment. Its capture region is 90 degrees either side of the initial segment track, the angle being identical to the course change at the IF for the corresponding offset IAF.

Restricted initial segments

4.2.9 Where one or both offset IAFs are not provided, a direct entry will not be available from all directions. In such cases, a holding pattern may be provided at the IF/IAF to enable entry to the procedure via a procedure turn.

4.2.10 If holding patterns are to be provided, the preferred configuration is located at the IAF and aligned with the initial segment.

Descent gradient

4.2.11 See Table 4-1 for standard and maximum descent values.

Minimum altitudes

4.2.12 Minimum altitudes in the initial approach segment shall be established in 50-m or 100-ft increments, as appropriate. The altitude selected shall provide an MOC of 300 m (984 ft) above obstacles and must not be lower than any altitude specified for any portion of the intermediate or final approach segments.

Procedure altitudes/heights

4.2.13 All initial approach segments shall have procedure altitudes/heights established and published. Procedure altitudes/heights shall not be less than the OCA/H and shall be developed in coordination with air traffic control (ATC), taking into account the aircraft requirements. The initial segment procedure altitude/height should be established to allow the aircraft to intercept the FAS descent gradient/angle from within the intermediate segment.

4.3 INTERMEDIATE APPROACH SEGMENT

4.3.1 The intermediate approach segment blends the initial approach segment into the FAS. It is the segment in which aircraft configuration, speed and positioning adjustments are made for entry into the FAS.

RNP navigation accuracy requirement

4.3.2 In the intermediate approach segment, the least stringent and the optimum RNP navigation accuracy requirement is 1.0 NM. The most stringent is 0.1 NM.

Length

4.3.3 Segments should be designed with sufficient length to allow the required descent to be as close to the optimum gradient as possible. See sections 4.1.9 and 4.1.10 for criteria on minimum length and RNP navigation accuracy requirement changes.

Alignment

4.3.4 The intermediate approach segment should be aligned with the FAS whenever possible. Fly-by turns at the final approach point (FAP) are limited to a maximum of 15-degree track change at the fix. Turns of more than 15 degrees should employ an RF leg.

Descent gradient

4.3.5 The optimum descent gradient in the intermediate segment is less than or equal to 2.5 per cent (1.4 degrees). The maximum descent gradient is the same as the designed final approach gradient. If a descent angle higher than optimum is used, the evaluation should ensure that sufficient flexibility is provided for the continuous descent operation.

4.3.6 If a higher than optimum gradient is required, a prior segment must make provision for the aircraft to configure for final segment descent.

4.3.7 Where a track change using a fly-by turn occurs at the FAP, the reduction in track distance may be ignored as the difference is negligible (maximum 15-degree turn).

Minimum obstacle clearance altitude

4.3.8 The minimum obstacle clearance altitude is the height of the highest obstacle above sea level within the intermediate approach segment area plus the MOC of 150 m (492 ft).

4.3.9 The procedure altitude/height in the intermediate approach segment shall be established in 50-m or 100-ft increments, as appropriate.

Procedure altitudes/heights

4.3.10 Procedure altitudes/heights in the intermediate segment shall be established to allow the aircraft to intercept a prescribed final approach descent.

Minimum obstacle clearance (MOC)

4.3.11 The final approach obstacle assessment surface based on the VEB (OAS_{VEB}) extends up to its intersection with the horizontal obstacle clearance surface (OCS) of the intermediate segment. This intersection may occur before or after the FAP.

Note.— The explanation of the determination of the VEB is presented in Appendix A (SI Units) and Appendix B (non-SI Units) of this manual.

4.3.12 When this intersection is before the FAP, the final approach surface is extended into the intermediate segment and becomes the intermediate segment OCS up to the point where it intersects the horizontal intermediate OCS based on 150 m (492 ft) MOC (see Figure 4-12).

4.3.13 When this intersection is after the FAP, the final approach OAS_{VEB} levels off at the intersection to continue horizontally, joining the intermediate segment OCS (see Figure 4-13).

Note.— If the procedure altitude has to be raised because of obstacles in the intermediate segment, the FAP must be moved and the VEB must be recalculated.

4.4 FINAL APPROACH SEGMENT

RNP navigation accuracy requirement

4.4.1 In the FAS, the least stringent RNP navigation accuracy requirement is 0.3 NM and the most stringent RNP navigation accuracy requirement is 0.1 NM. A more stringent than maximum RNP navigation accuracy requirement should only be used if a significant operational advantage can be obtained.

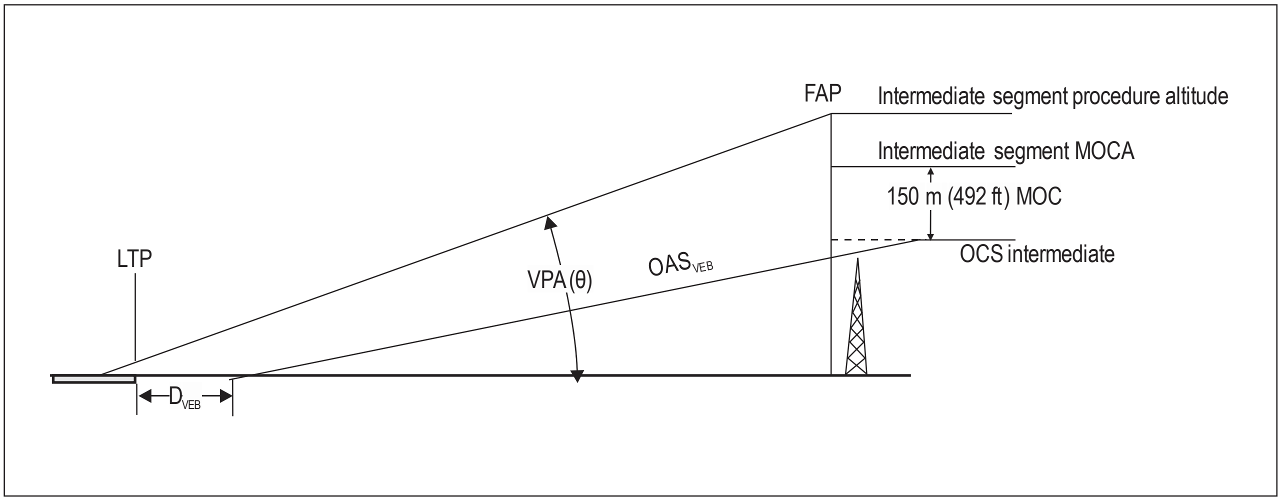


Figure 4-12. Intermediate segment MOC 1

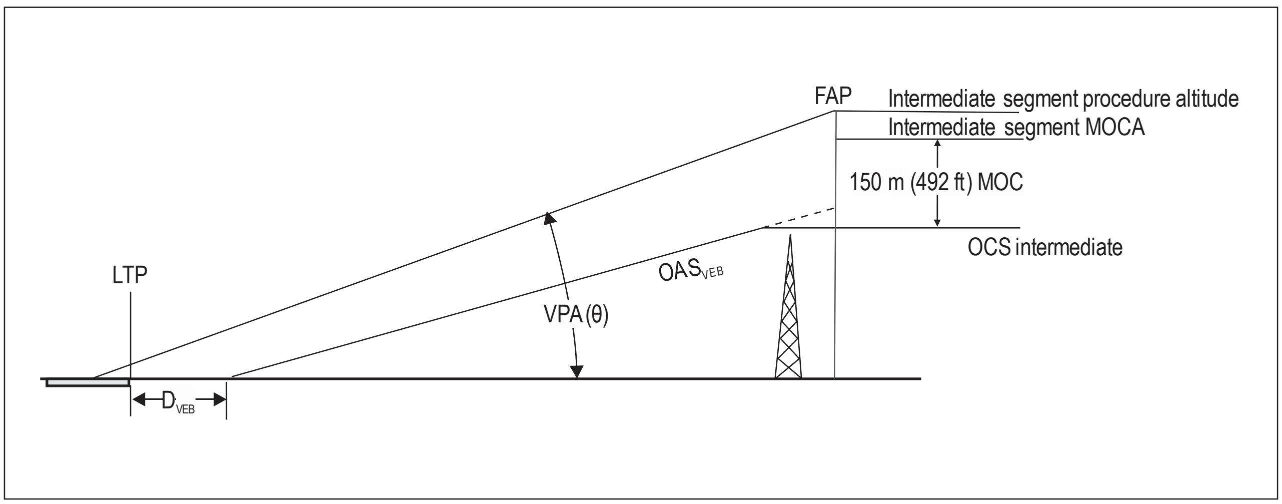


Figure 4-13. Intermediate segment MOC 2

4.4.2 Where approaches with RNP navigation accuracy requirements less than 0.3 NM are published, OCA/H should also be published for an RNP navigation accuracy requirement of 0.3 NM, whenever practicable. In a case where publication of a minima line based on a navigation accuracy requirement of 0.3 NM is not possible due to other constraints, then the published navigation accuracy requirement should be as high as practicable.

Note.— A navigation accuracy requirement more stringent than 0.3 NM may be required when an RF leg in the final approach restricts the necessary increase in OCA/H.

Length

4.4.3 No maximum length is specified. For minimum length, criteria in PANS-OPS, Vol. II Part I, Section 4, Chapter 5 apply. The length must accommodate the descent required and must provide a straight stabilized segment prior to OCA/H.

Alignment

Straight-in approaches

4.4.4 The optimum final approach alignment is a TF segment straight in from FAP to LTP on the extended runway centreline (see Figure 4-11). If necessary, the last TF track of the final segment may be offset by up to five degrees. An offset must not be implemented as a noise abatement measure. Where the track is offset:

a) it must intersect the extended runway centreline at a point where the nominal vertical path angle (VPA) reaches a height, called intercept height, of at least 55 m (180 ft) above the LTP;

b) the OCA/H for the procedure must be at least: intercept altitude/height + 20 m (66 ft); and

c) the procedure shall be annotated: “Final approach track offset … degrees” (tenth of degrees).

4.4.5 RF turns are allowed in the final segment, subject to meeting the conditions in section 4.4.10.

Location of FAP

4.4.6 The FAP is a point on the final approach track where the VPA extending from reference datum height (RDH) above the LTP (fictitious threshold point (FTP) if offset) intersects the intermediate segment altitude.

4.4.7 In all cases, the nominal FAP shall be identified as a named waypoint. In case of a straight final approach segment, the latitude and longitude of the FAP is calculated geodetically from the LTP/FTP using:

a) the reciprocal of the true track of the final approach TF leg (true track — 180 degrees); and

b) the required distance from LTP (FTP if offset) to the FAP.

Calculation of FAP-LTP distance

4.4.8 When the FAS contains an RF leg, the FAP to LTP distance can be calculated as follows:

D_{FAP} = (a - RDH) * tan(VPA) = $d_1 + d_{arc} + d_2$

where:

a = FAP altitude – THR elevation;

D_{FAP} = total distance from FAP to LTP (FTP if offset);

d_1 = distance from FAP to start of the RF turn;

d_{arc} = arc length of RF leg, as seen in section 4.4.11; and

d_2 = distance from final approach roll-out point (FROP) to LTP (FTP if offset).

The calculations are planar for distances and angles regarding the final approach segment. The vertical path maintains a gradient relative to the earth and follows an arcing path, as illustrated in Figure 4-14. Unlike the ILS glide path, the curvature of the earth has a negligible effect in the vertical plane, so calculations based on planar trigonometry are adequate.

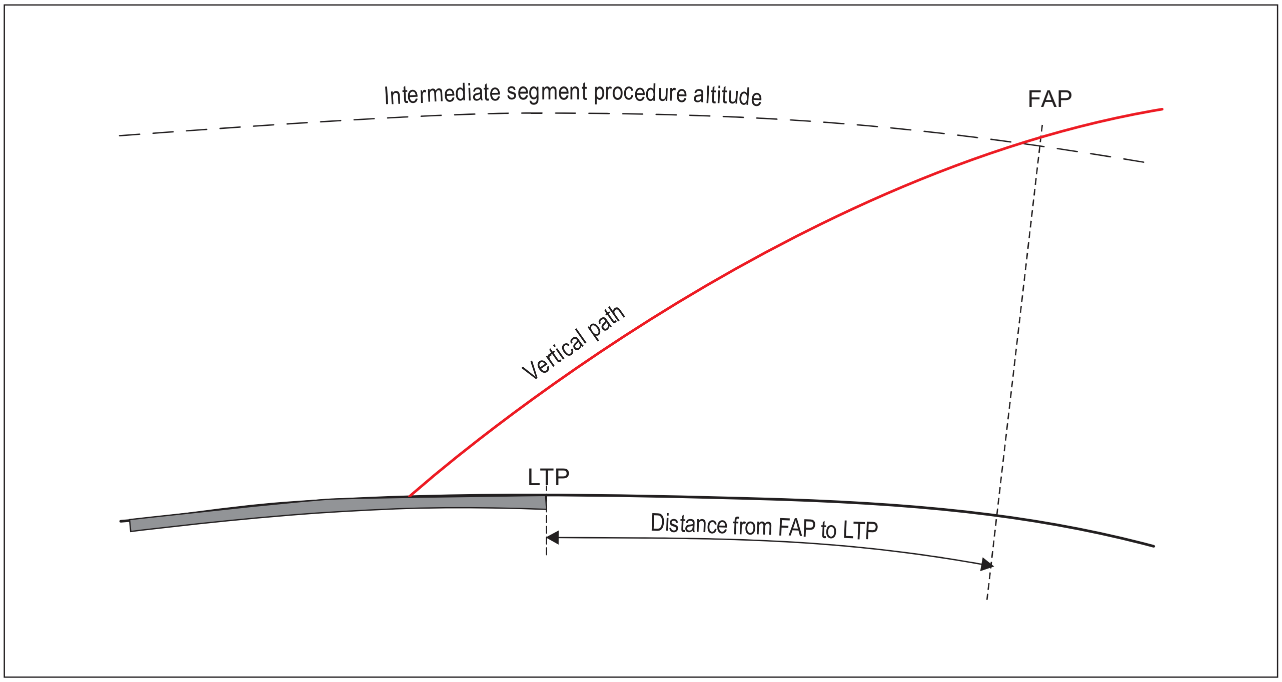


Figure 4-14. FAP to LTP distance

Turns in the final approach segment

4.4.9 A final segment may be designed using an RF leg segment when obstacles or operational requirements prevent a straight approach from the FAP to the LTP. Fly-by turns are not allowed.

Requirement for straight segment prior to OCH

4.4.10 Procedures that incorporate an RF leg in the final segment shall establish the aircraft at a FROP aligned with the last straight TF leg prior to the greater of:

a) 150 m (492 ft) above LTP elevation,

SI units: $D_{150} = \frac{150 - RDH}{\tan(VPA)}$ meters;

Non-SI units: $D_{150} = \frac{492 - RDH}{\tan(VPA)}$ feet; or

b) a minimum distance of 926 m (0.5 NM) before the point OCA/H is reached on the nominal vertical path (see Figures 4-15 and 4-16).

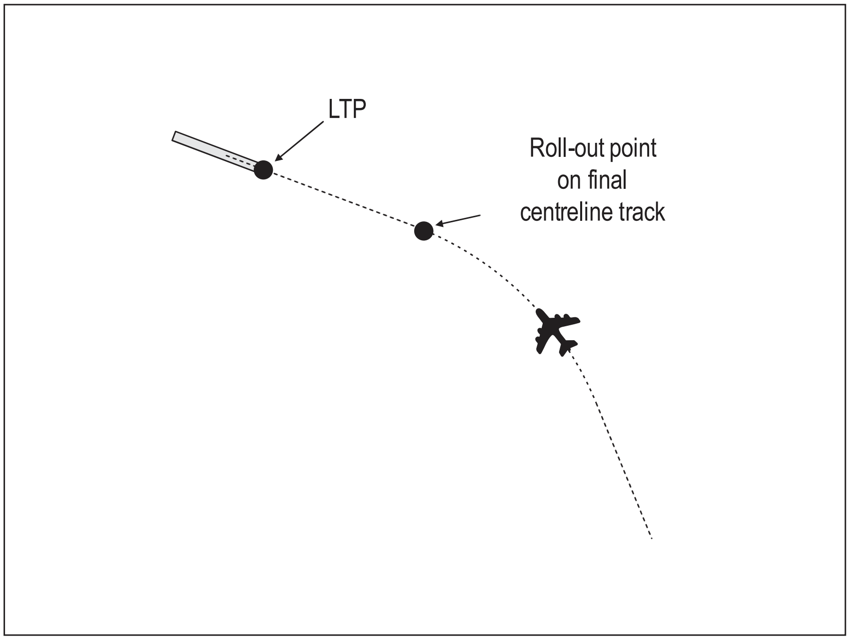


Figure 4-15. FROP

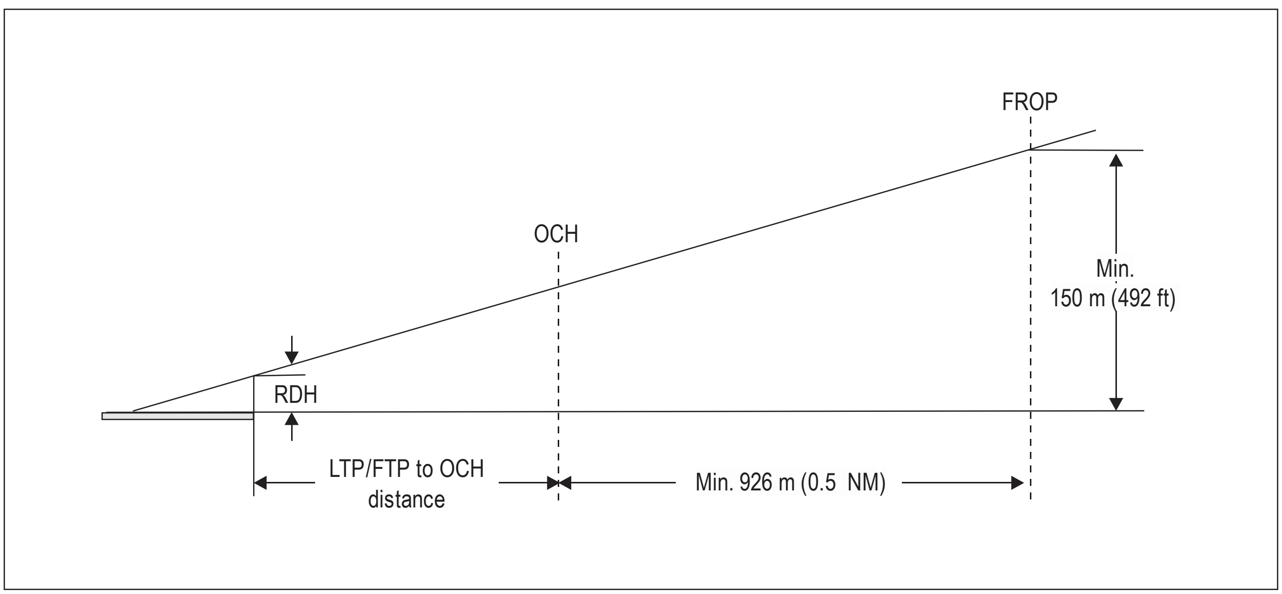


Figure 4-16. Constraints on OCH and FROP

4.4.11 The number of degrees of arc given a specific arc length may be calculated from:

degrees of arc = $(180*LENGTH_{RF})/(\pi*r)$

where r = radius of RF leg.

Conversely, the length of an arc given a specific number of degrees of turn may be calculated from:

length of arc = (degrees of arc * π * r)/180.

Determining FAP WGS-84 coordinates in an RF segment

4.4.12 This method may be used for calculating WGS-84 latitude and longitude (see Figure 4-16). This method ignores a true geodetic calculation error, based on the requirements of waypoint publication resolution. Several software packages will calculate a geographical coordinate derived from Cartesian measurements from the LTP. Use the following formulas and method to obtain the Cartesian values.

STEP 1: Determine the flight track distance (D_{FAP}) from LTP to FAP using the formula in section 4.4.8.

STEP 2: Determine the distance (D_{FROP}) from LTP to the FROP (see Figure 4-17).

STEP 3: Subtract D_{FROP} from D_{FAP} to calculate the distance around the arc to the FAP from the FROP.

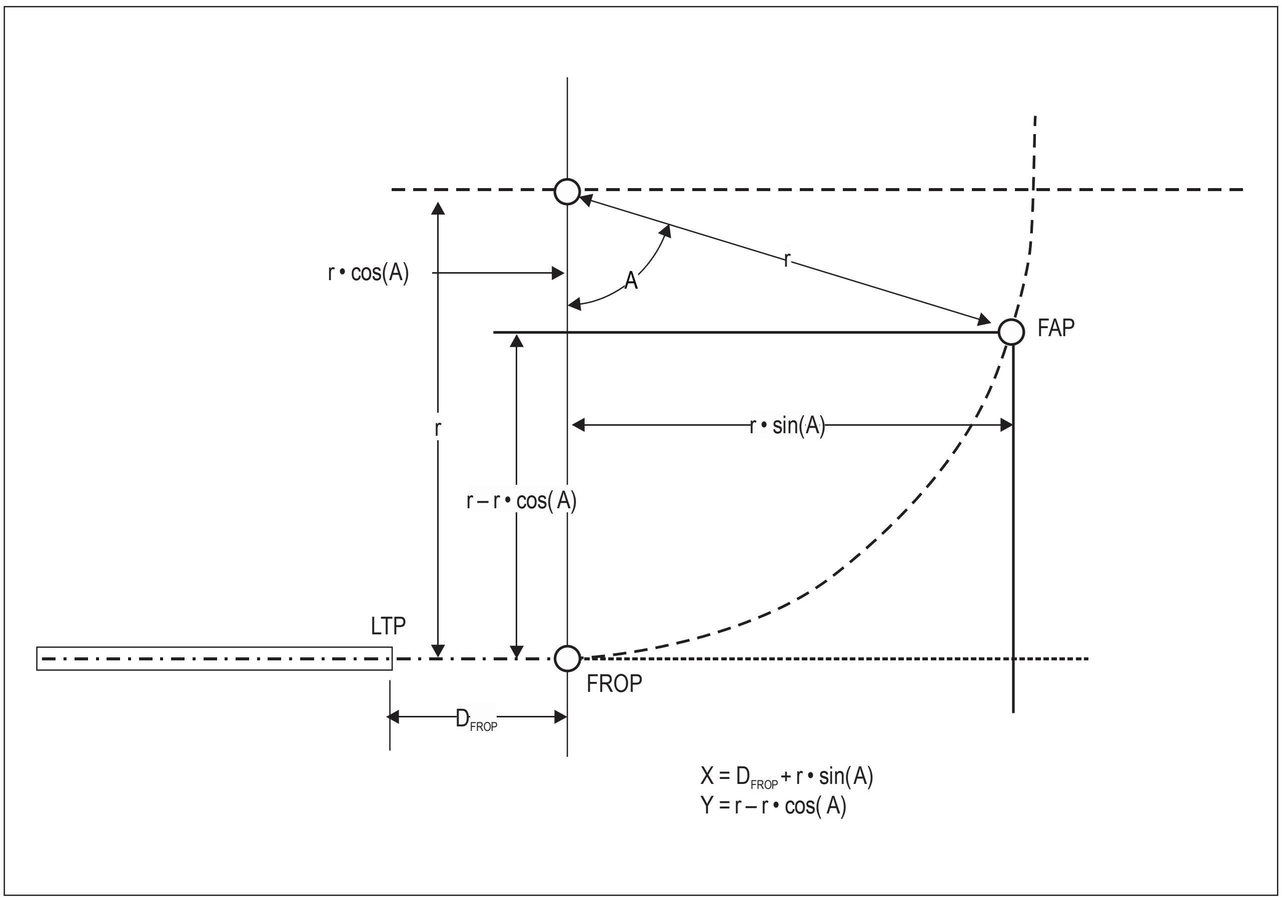


Figure 4-17. FAP within an RF leg

4.4.13 If the FAP is in the RF segment, determine its X, Y coordinates from:

$X = D_{FROP} + r * \sin A$; and

$Y = r – r * \cos A$

where:

X and Y are measured on a conventional right-hand Cartesian coordinate system with a positive X-axis aligned with the reciprocal of the runway azimuth.

r = radius of RF leg; and

A = turn angle.

4.4.14 The turn altitude is determined by projecting the vertical path from RDH out to the fix at which the turn commences along the nominal flight track.

Vertical path angle requirements

4.4.15 A procedure must not have a promulgated VPA that is less than 2.5 degrees. The effective VPA will differ from the promulgated VPA as it is dependent upon temperature and aerodrome elevation. The optimum VPA is 3 degrees. The promulgated VPA must be such that the effective VPA throughout the year is as close as possible to 3.0 degrees for the given aerodrome elevation and prevailing temperatures. The following conditions apply:

a) the effective VPA at the minimum temperature limit must remain greater than or equal to 2.5 degrees; and

b) the effective VPA at the highest prevailing temperature should remain less than or equal to 3.5 degrees.

4.4.16 The temperature above which the effective VPA will exceed 3.5 degrees must be published on the chart, along with the minimum temperature limit above which the procedure is authorized.

RDH values and recommended ranges for aircraft categories

4.4.17 The standard RDH value is 15m (50 ft). For short runways (Code 1 and 2) the RDH can be as low as 12 m (40 ft). To the extent practicable, the VPA for an RNP AR procedure to a runway served by a visual approach slope indicator system (VASIS) should be optimized to equal the VASIS glide path (GP) angle at the prevailing temperature for the aerodrome. A note must be published on the chart if the effective VPA at the prevailing temperature differs by more than 0.2 degrees from the VASIS GP angle.

Effect of temperature on VPA

4.4.18 RNP final segment OAS is based on vertical guidance provided by BARO-VNAV. The effective VPA (actual angle flown) depends on the temperature deviation from the standard ISA associated with airport elevation. The high temperature limit on the chart (see section 4.4.16) informs about when the effective VPA becomes higher than 3.5 degrees. The low temperature limit assures obstacle protection for the lowest expected temperature and prevents the effective VPA from going below 2.5 degrees. ISA for the airport may be calculated using the following formulas:

SI units : $ISA_{airport} = 15 – (0.065 * Airport_{elev})$ C° ; and

Non-SI units: $ISA_{airport} = 15 – (0.00198 * Airport_{elev})$ C°

4.4.19 The approach procedure should offer obstacle protection within a temperature range that can reasonably be expected to exist at the airport. Establish the lower temperature limit (actual cold temperature (ACT°C)) from the five-year history (or longer). For each year, determine the month with the lowest average temperature. Then within each month determine the coldest temperature. The average of the five values is the average coldest temperature. Determine the difference (ΔISA_{LOW}) between this temperature and the ISA temperature for the airport using the following formula:

$$\Delta ISA_{LOW} = -(ISA°C - ACT°C)$$

Note.— Geopotential height includes a correction to account for the variation in acceleration of gravity (g) (average 9.8067 m/sec^2) with heights. However, the effect is negligible at the minimum altitudes considered for obstacle clearance: the difference between geometric height and geopotential height increases from zero at mean sea level to –18 m (–59 ft) at 10 972 m (36 000 ft).

Calculation of minimum effective VPA

4.4.20 The minimum effective VPA is obtained by reducing the design VPA by deducting the cold temperature altimeter error from the design altitude of VPA at the FAP and calculating the reduced angle from the origin of the VPA at threshold level. (See Figure 4-17.)

Low temperature limit

4.4.21 The effective VPA at the minimum promulgated temperature must not be less than 2.5 degrees. The nominal VPA, in some cases, may be raised above 3.0 degrees. However, consideration must be given to: aircraft performance at the higher VPA; high temperature effects; and the regulatory constraints on the maximum VPA for the aircraft.

4.4.21.1 If the temperature history for the location indicates the low temperature limitation is frequently encountered, consideration should be given to raising the VPA to the lowest angle that will make the approach more frequently usable.

4.4.21.1.1 The minimum VPA is the larger of 2.5 degrees, or (see Figure 4-18):

$$Min_{VPA} = \arctan[(a - RDH - \Delta h)/D_{FAP}]$$

where:

a = FAP altitude — THR elevation (m or ft, as appropriate);

RDH = reference datum height (m or ft, as appropriate);

D_{FAP} = LTP (or FTP if offset) to nominal FAP distance (m or ft as appropriate); and

$\Delta h = (\Delta ISA_{LOW} / Lo) * \ln[1 + Lo * a / (To + Lo * h_{THR})]$;

where:

Lo = standard temperature lapse rate with pressure altitude in the first layer (sea level to tropopause) of the ISA (-0.0065 °/m or -0.00198 °/ft as appropriate);

To = standard temperature at sea level (288.15 K);

h_{THR} = THR elevation (m or ft as appropriate).

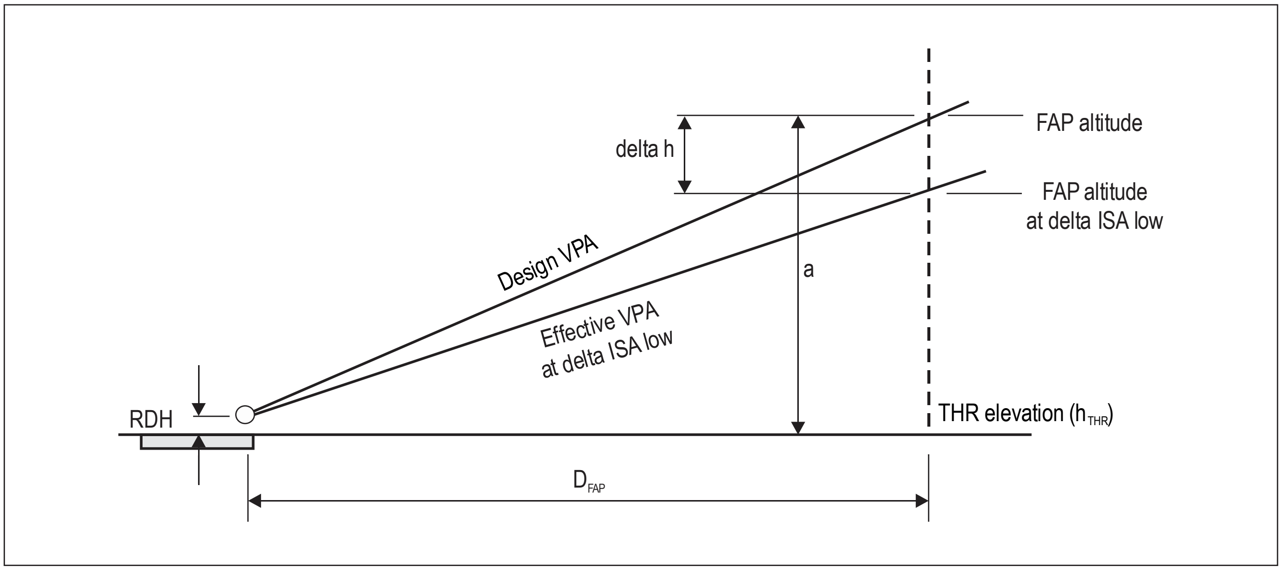


Figure 4-18. Effective VPA cold temperature

4.4.21.1.2 If the effective VPA is less than 2.5 degrees, calculate the ΔISA_{LOW} to achieve an angle of 2.5 degrees using the following formula:

$$\Delta ISA_{LOW} = Lo * (\tan 2.5 * D_{FAP} + RDH - a) / \ln[1 + Lo * a / (To + Lo * h_{THR})]$$

where:

the items in the formula are the same as in section 4.4.21.1.1.

4.4.21.1.3 Determine the published low temperature limitation "NA below" for the procedure using the ΔISA_{LOW} derived from the equation in section 4.4.21.1.1 or 4.4.21.1.2, as appropriate, with the following formula:

$$NA_{below} = ISA + \Delta ISA_{LOW}$$

Calculation of the published temperature where the effective VPA reaches 3.5 degrees

4.4.22 The effective VPA of 3.5 degrees is obtained by increasing the design VPA by adding the high temperature altimeter error to the design altitude of VPA at the FAP and calculating the temperature deviation (ΔISA_{HIGH}) when the effective VPA of 3.5 degrees is reached (see Figure 4-19).

4.4.22.1 To accomplish this, determine the maximum ΔISA_{High} (above ISA) that will produce the effective VPA of 3.5 degrees using the following formula:

$$\Delta ISA_{HIGH} = Lo * (\tan(3.5) * D_{FAP} + RDH - a)/\ln[1 + Lo * a / (To + Lo * h_{THR})]$$

where:

the items in the formula are the same as in section 4.4.21.1.1.

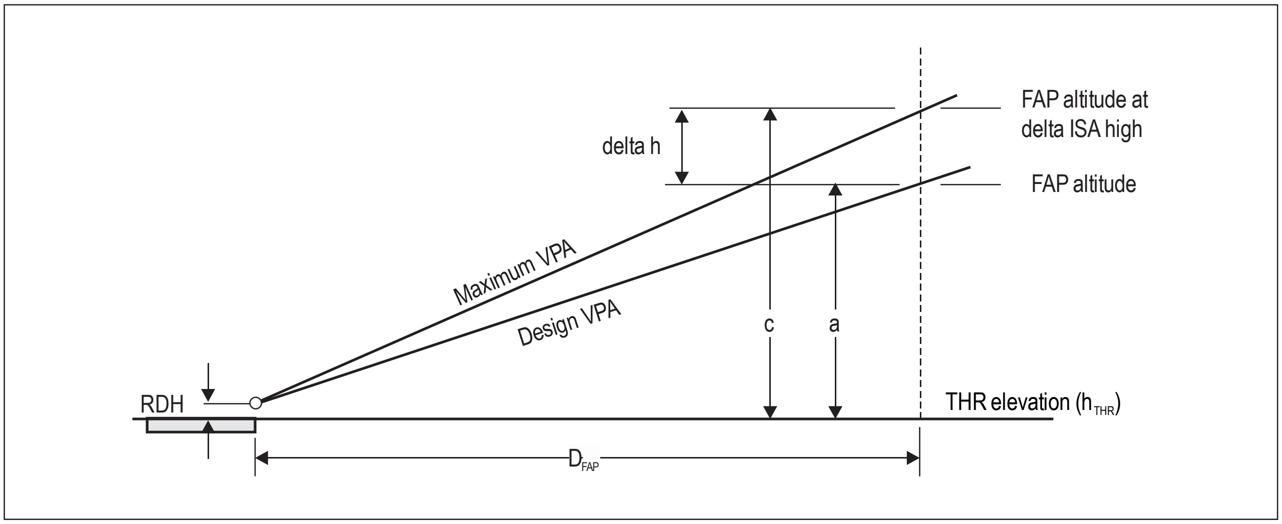


Figure 4-19. Effective VPA hot temperature

4.4.22.2 The published high temperature is determined with the following formula:

$STEEP_{above} = ISA_{airport} + \Delta ISA_{High}$

VEB

4.4.23 Calculation of the VEB is described in Appendices 1 and 2.

Final approach OAS

4.4.24 The distance of the final approach OAS origin from LTP (D_{VEB}) and its slope are defined by the VEB.

4.4.25 The height of the OAS at any distance "x" from the LTP can be calculated according to planar trigonometry as follows:

$OAS_{HGT} = OAS_{gradient} * (x - D_{VEB})$

where:

OAS_{HGT} = height of the VEB OAS (m or ft, as appropriate);

x = distance from LTP (FTP if offset) to obstacle (m or ft, as appropriate);

D_{VEB} = distance from LTP (FTP if offset) to the THR level intercept of the VEB OAS (m or ft, as appropriate); and

$OAS_{gradient}$ = value as derived from Appendix A or B, as appropriate.

Note.— D_{VEB} and the tangent of the final approach OAS are both obtained from Appendix A (SI units) or Appendix B (non-SI units).

Adjustment for aircraft body geometry (bg)

4.4.26 Where the final approach is a straight segment, the OAS gradient is the same for the straight and curved path portions. However, the obstacle clearance margin is increased to account for the difference in the flight paths of the navigation reference point on the aircraft and the wheels. For wings level, this is assumed to be 8 m (26 ft) if aircraft- or category specific values cannot be applied. Additional adjustment for bg during a bank is calculated as follows:

bg = 40 * sin(design bank angle + 5°) m; or

bg = 132 * sin(design bank angle + 5°) ft

The maximum design bank angle equals 25 degrees; however, other bank angles may be applied. The adjustment of the obstacle clearance margin for the curved section of the final approach and the relative orientation of the VEB OAS for the straight and curved sections are illustrated in Figure 4-20.

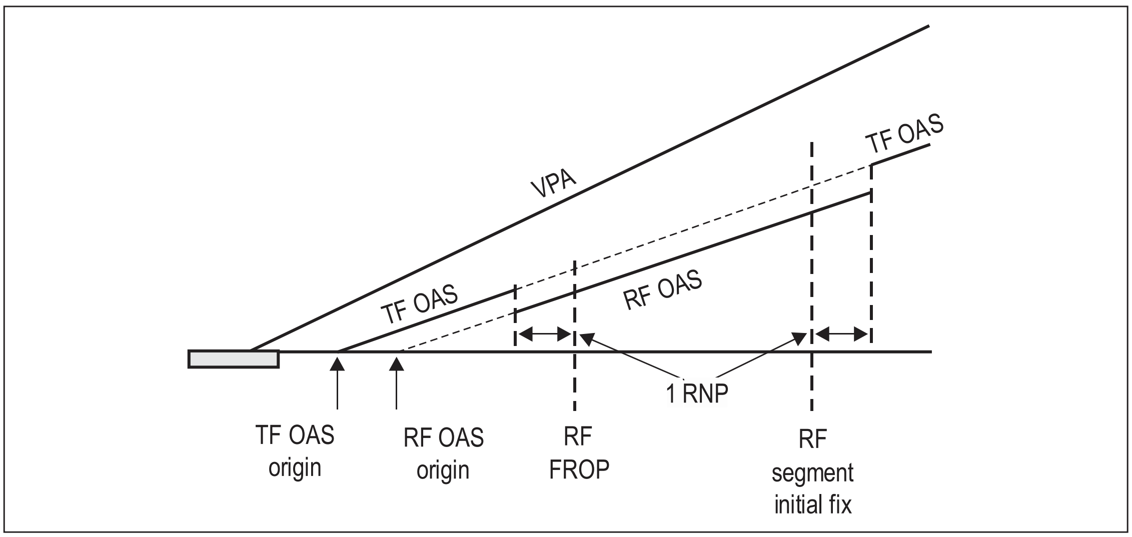


Figure 4-20. OAS adjustment for TF and RF legs

Interaction of VPA with VEB

4.4.27 D_{VEB} decreases slightly when the VPA is increased. Therefore, if the angle is increased to eliminate a penetration, the VEB must be recalculated, and the OAS re-evaluated.

Protection of the visual segment

4.4.28 The visual segment must be protected according to PANS-OPS, Vol. II. Part I, Section 4, Chapter 5 5.4.6, but the VSS obstacle assessment is laterally limited to 2 RNP, and the VSS OCS obstacle assessment is laterally limited to 1 RNP on both sides of the nominal approach track.

4.5 MISSED APPROACH SEGMENT

4.5.1 The MAS begins RNP_{FAS} prior to LTP (FTP if offset) and terminates at the point at which a new approach, holding or return to en-route flight is initiated.

General principles

4.5.2 The maximum RNP navigation accuracy requirement for missed approach is 1.0 NM. The default design goal must be to use RNP navigation accuracy requirement of 1.0 NM throughout the whole length of the missed approach. The standard MAS splays from the FAS width from 1 RNP_{FAS} prior to LTP (FTP if offset), at 15 degrees relative to the nominal track, to a width of ±2 NM (RNP 1.0). (See Figure 4-21.)

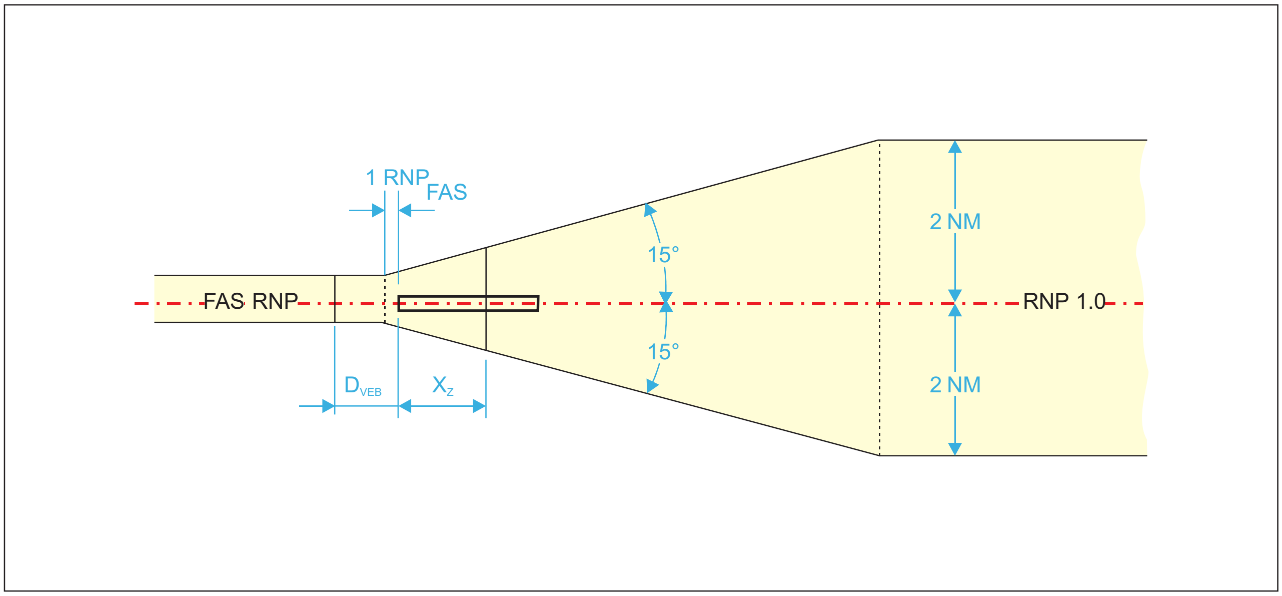


Figure 4-21. Missed approach splay

4.5.3 If a significant operational advantage can be achieved, a more stringent RNP navigation accuracy requirement, down to 0.1 NM, can be specified. The RNP navigation accuracy requirement specified for missed approach must not be more stringent than the RNP for the final approach.

4.5.4 The missed approach OAS (Z) slope is 2.5 per cent with provision for additional increased gradients for use by aircraft whose climb performance permits the operational advantage of the lower OCA/H associated with these gradients, with the approval of the appropriate authority. In case of the application of a higher climb gradient, an OCH for 2.5 per cent or an alternate procedure with a gradient of 2.5 per cent should also be made available.

4.5.5 In a case where a 2.5 per cent gradient is not possible due to other constraints, the missed approach OAS is the minimum practicable gradient.

Note.— A minimum gradient greater than 2.5 per cent may be required when an RF leg in the final approach restricts the necessary increase in OCA/H.

RNP navigation accuracy requirements for missed approach

4.5.6 For missed approaches using RNP navigation accuracy requirements less than 1.0 NM (see Figure 4-22), the following constraints apply:

a) where missed approach obstacles would result in an unfavorable OCA/H when applying an RNP of 1.0 NM, the missed approach RNP navigation accuracy requirement may be limited until past the obstruction. The least stringent RNP navigation accuracy requirement that clears the obstruction must be used;

b) a change to RNP navigation accuracy requirement of 1.0 NM must be applied as soon as the obstacle situation allows. Protection according to RNP 1.0 NM must be applied at 1 RNP before the fix marking the change, however, the area expansion described in sections 4.1.10 through 4.1.18, and illustrated in Figure 4-23, may be used until reaching the area width for RNP navigation accuracy requirement of 1.0 NM; and

c) missed approach RNP navigation accuracy requirements less than 1.0 NM may limit the population of aircraft that can fly the procedure and result in a more demanding, specific operational approval process, therefore RNP less than 1.0 NM must only be implemented in the missed approach where other mitigations (e.g., increased climb gradients or alternate routing) cannot offer an acceptable solution. If applied, a charting note is required.

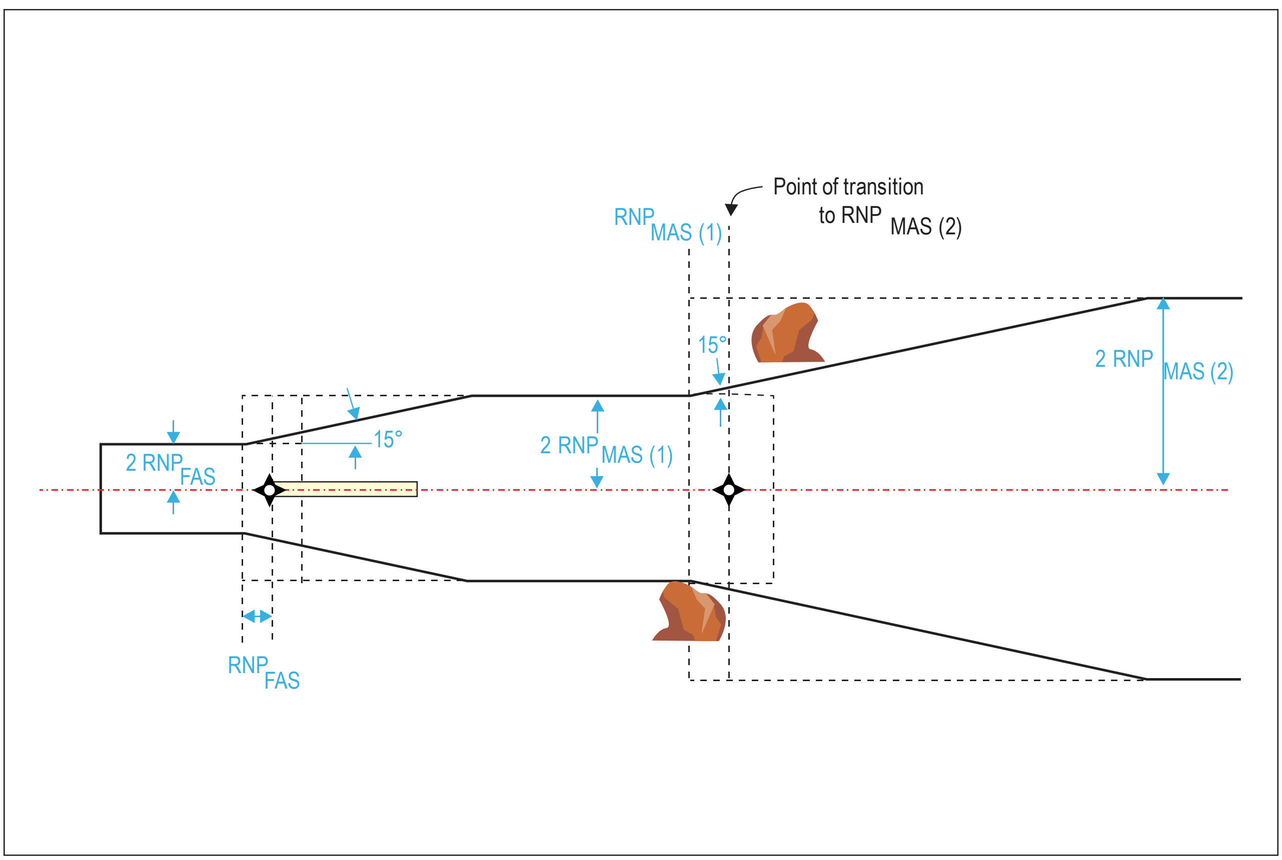


Figure 4-22. Reduced RNP navigation accuracy requirements in missed approach

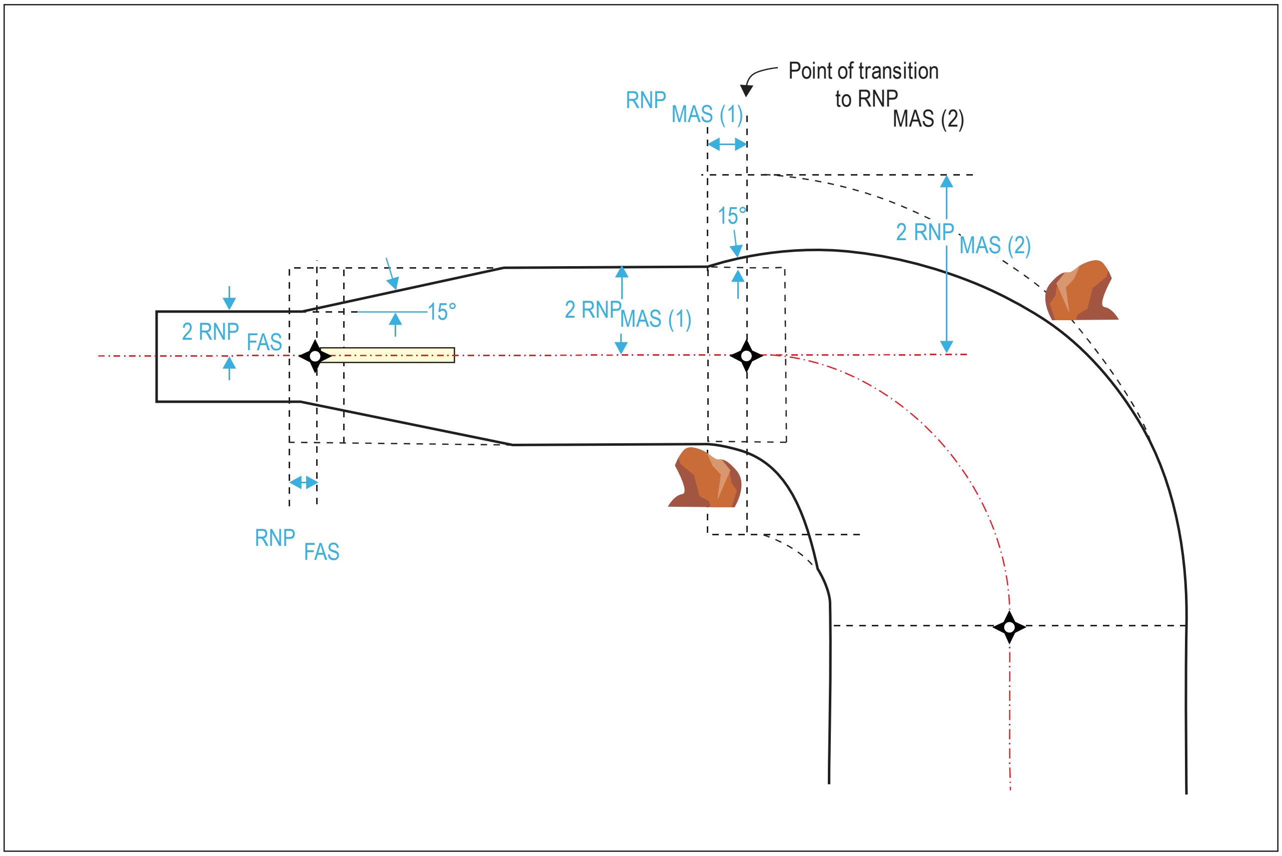


Figure 4-23 Changing to a less stringent RNP navigation accuracy requirement in a missed approach turn

Missed approach OAS (Z surface)

4.5.7 The Z surface connects to the horizontal surface at its origin, Xz. For the calculation of Xz, see section 4.5.8 below. The Z surface ends at the earliest turning point of the missed approach turn. For applicable obstacle clearance values, see "OCH Calculation" in sections 4.6.4 through 4.6.6. See Figures 4-24, 4-25 and 4-26 for illustration of the following process.

Calculation of the origin of the Z surface (Xz)

4.5.8 The range of the Z surface origin at THR level, relative to LTP/FTP is:

$$Xz = [(HL_{Cat} – RDH)/\tan(VPA)] – TrD$$

where:

HL_{Cat} = Pressure altimeter height loss for the aircraft category;

RDH = reference datum height;

tan(VPA) = gradient of the VPA;

and

TrD = transition distance;

$$TrD = \frac{t \times MaxGndSpeed}{3600} + 4/3\sqrt{anpe^2 + wpr^2 + fte^2}$$

where:

t = 15 seconds;

MaxGndSpeed = maximum final approach TAS for the aircraft category expressed as distance travelled per hour, calculated at aerodrome elevation and ISA + 15 (or local statistical data) plus a 19 km/h (10 kt) tailwind;

Actual navigation performance error (anpe) = 1.225 × RNP (99.7 per cent along-track error, in m of ft as appropriate);

Waypoint precision error (wpr) = 18.3 m (60 ft) (99.7 per cent waypoint resolution error);

Flight technical error (fte) = 22.9/tan VPA m, (75/tan VPA ft) (99.7 per cent flight technical error).

Note.— The parameters listed above must be converted to units appropriate for the units used for MaxGndSpeed for calculation of TrD in NM or km as desired.

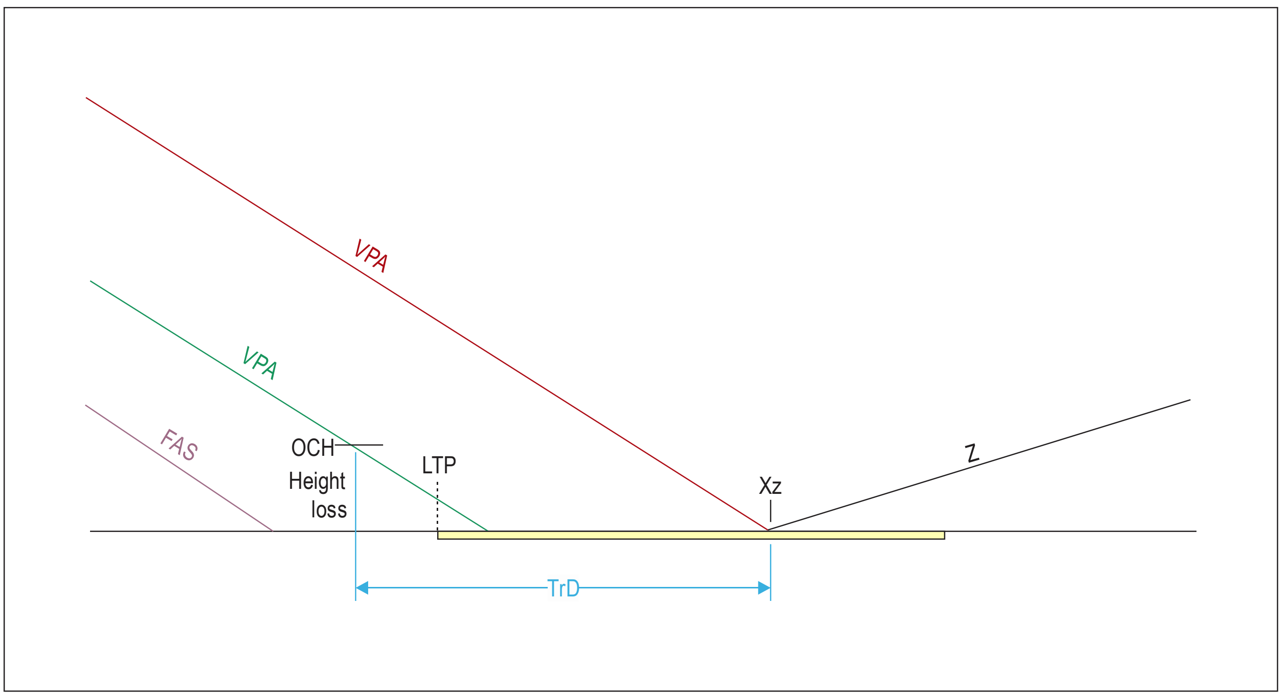


Figure 4-24. Determination of the origin of the Z surface (Xz)

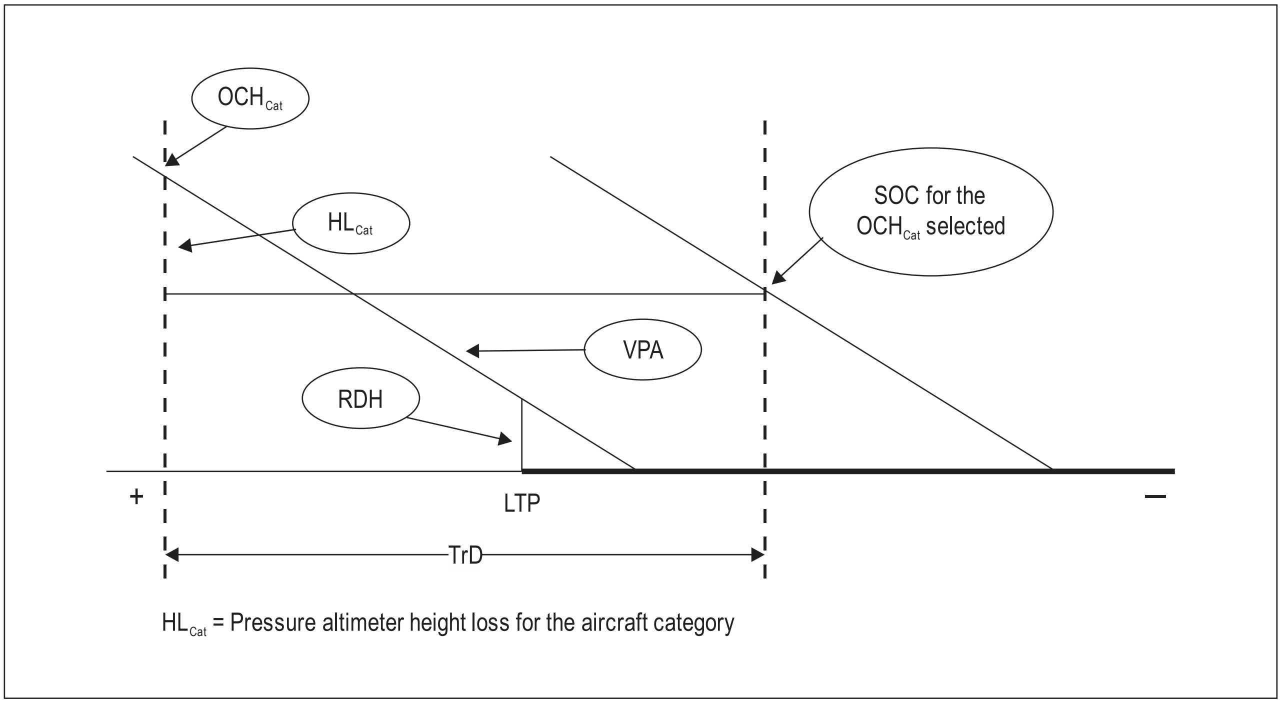


Figure 4-25. Determination of SOC

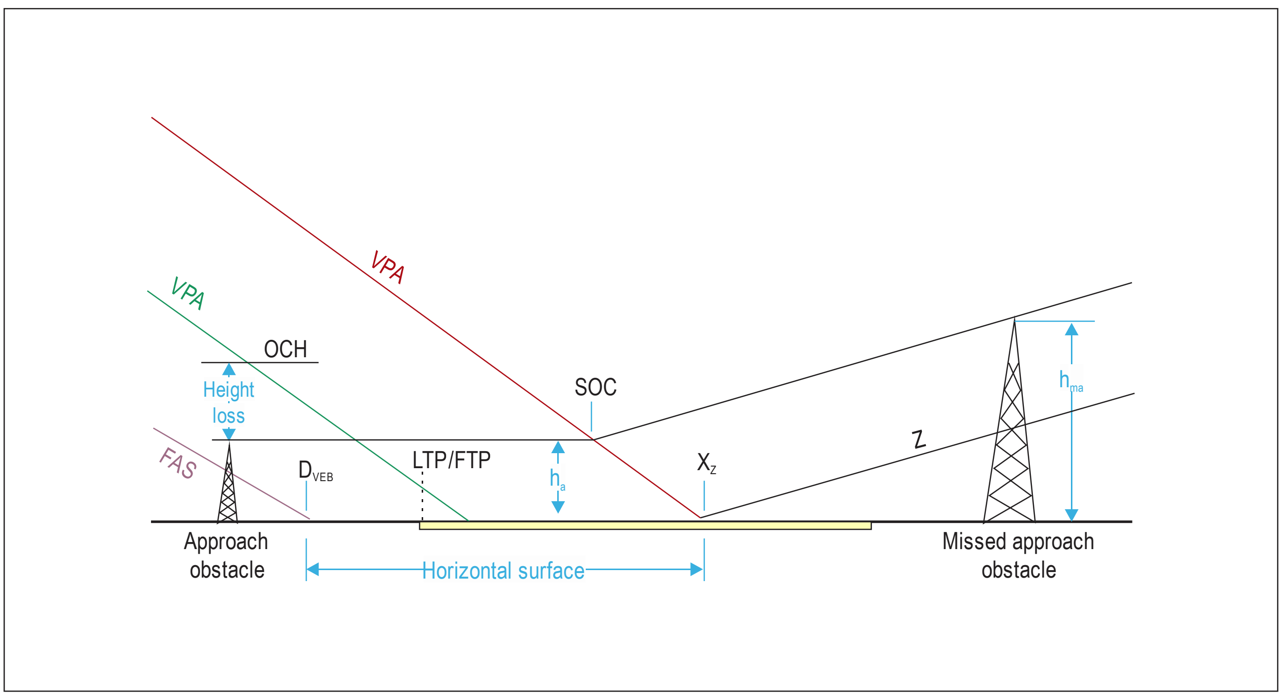


Figure 4-26. Origin of the missed approach surface (Z) and OCH calculation

4.5.9 Position of the start of climb (SOC)

a) the height of the SOC above THR is calculated as follows:

$OCH_{Cat} – HL_{Cat}$

Note.— The actual navigation performance error (anpe), waypoint precision error (wpr) and fte are the 99.7 per cent probability factors from the VEB projected to the horizontal plane and factored by 4/3 to give a $10E^{-5}$ margin.

HL_{Cat} = Pressure altimeter height loss for the aircraft category

b) the range of the SOC is calculated as follows:

$XSOC_{Cat} = [(OCH_{Cat} – RDH)/tan(VPA)] – TrD$

where:

$XSOC_{Cat}$ = range of the SOC for the aircraft category, positive before threshold, negative after threshold;

OCH_{Cat} = OCH for the aircraft category (the minimum value is the pressure altimeter height loss for the category;

RDH = reference datum height;

tan(VPA) = gradient of the VPA;

and

TrD = transition distance, as of section 4.5.8.

Permitted leg types

4.5.10 The missed approach may consist of a series of segments. The recommended leg types are RF and TF. Other leg types compatible with the RNP AR navigation specification may be used (see Doc 9613, Vol. II, Part C, Chapter 6, 6.3.3.4.)

4.5.11 Whenever the RNP navigation accuracy requirement is less than 1.0 NM, DF or CF legs cannot be applied.

Turning missed approach

4.5.12 The number and magnitude of turns add complexity to a procedure; therefore, their use should be limited.

4.5.13 If the missed approach RNP navigation accuracy requirement is less than 1.0 NM, missed approach turns must limit bank angles to 15 degrees; maximum speed limits may be imposed to achieve a specific radius and, if possible, RF turns should not start before departure end of runway (DER).

4.5.14 Whenever the RNP navigation accuracy requirement is less than 1.0 NM, the only turn methods are fly-by or RF. Whenever the RNP navigation accuracy requirement is less than 0.3 NM, the only turn method is RF.

4.6 DETERMINATION OF OBSTACLE CLEARANCE ALTITUDE/HEIGHT

4.6.1 OCA/H calculation involves a set of OAS: the final approach surface (FAS) based on the VEB, the missed approach surface (Z) and the horizontal surface between them. If the OAS is penetrated, the aircraft category-related height loss allowance is added to the height of the highest approach obstacle or to the largest equivalent height of the missed approach OAS penetrations, whichever is greater. This value becomes the OCA/H (see Figures 4-25 and 4-26).

Accountable obstacles

4.6.2 Accountable obstacles are those penetrating the OAS. They are divided into approach obstacles and missed approach obstacles, as follows (see Figure 4-26).

- Approach obstacles are those before Xz.
- Missed approach obstacles are those after Xz.

4.6.3 However, in some cases the above categorization of obstacles may produce an excessive penalty for certain missed approach obstacles. Alternatively, missed approach obstacles may therefore be defined as those above the VPA' plane, which is the plane surface parallel to the plane of the vertical path and with origin at Xz, i.e. obstacle height greater than (Xz + x)*tan(VPA), where x is the x coordinate of the obstacle (negative after THR).

OCH calculation

4.6.4 First, determine the height of the highest approach obstacle penetrating the final approach OAS or the horizontal plane from D_{veb} to the origin of the Z surface.

4.6.5 Next, reduce the heights of all missed approach obstacles to the height of equivalent approach obstacles by the formula given below:

$$h_a = [(h_{ma} + MOC) * \cot Z - (X_Z - x)]/(\cot VPA + \cot Z)$$

where:

h_a = height of the equivalent approach obstacle;

h_{ma} = height of the missed approach obstacle;

X = distance of the obstacle from threshold (positive prior to the LTP threshold, negative after);

cot Z = cotangent of the Z surface angle;

cot(VPA) = cotangent of the VPA; and

X_Z = X coordinate of the origin of the missed approach surface.

4.6.6 MOC is 0 m (0 ft) for a straight missed approach; 30 m (98 ft) for turns up to 15 degrees; 50 m (164 ft) for turns greater than 15 degrees. For RF turns, the MOC equals the body geometry allowance according to section 4.4.26. Any increased MOC due to a turn must continue to be maintained for the rest of the missed approach.

Straight missed approach

4.6.7 Determine OCH for the procedure by adding the pressure altimeter height loss allowance, defined in Table 4-2, to the height of the highest approach obstacle (real or equivalent).

$$OCH = h_a + HL \text{ margin}$$

OCH calculation (turns in the missed approach — except RF)

4.6.8 Obstacle elevation/height shall be less than:

$$(OCA/H - HL) + (d_z + d_o)\tan Z - MOC$$

where:

d_o = shortest distance from the obstacle to the earliest turning point (TP) (see Figures 4-23 and 4-24);

d_z = horizontal distance from SOC to the earliest TP;

and MOC is:

50 m (164 ft) (Cat H, 40 m (132 ft)) for turns more than 15 degrees and 30 m (98 ft) for turns 15 degrees or less.

4.6.9 If the obstacle elevation/height penetrates the Z surface, the OCA/H must be increased or the TP moved to obtain the required clearance.

Application of RF legs in a turning missed approach

4.6.10 When an RF leg is used in a missed approach, the along-track distance during the RF turn for inclusion in the track distance to calculate the gradient of the OAS is the arc length(s) based on a turn radius of (r – 0.1 NM) (see Figures 4-9 b) and 4-27.)

4.6.11 The height of the surface at any point on the track is constant radially across the surface. The slope is only in the direction of the nominal flight vector tangent to the nominal track at any point and has a lateral slope of zero along any radius.

4.6.12 Obstacle elevation/height shall be less than

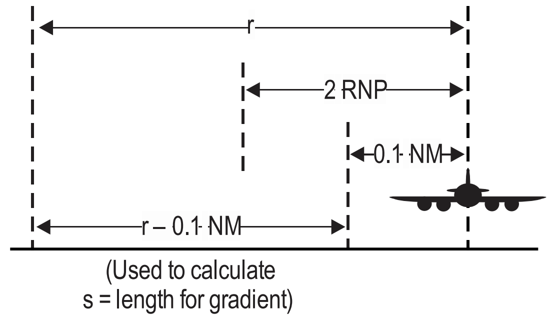
$$(OCA/H - HL) + (d_z + d_o)\tan Z - MOC$$

where:

d_o = distance measured along the arc(s), calculated for RF legs using a radius of (r – 0.1 NM); and

d_z = horizontal distance from SOC to the turning fix.

MOC applied in the formula calculating h_a equals the body geometry allowance (see section 4.4.26) for RF missed approach legs.



Note.— Use (r – 0.1 NM) radius to calculate arc length, ***s****, for gradient of surface.*

Figure 4-27. Radius for calculating track length for gradient

4.6.13 If the obstacle elevation/height penetrates the Z surface, the OCA/H must be increased or the TP moved to obtain the required clearance.

Height loss margins

Adjustments for high aerodrome elevations

4.6.14 The height loss margins in Table 4-2 shall be adjusted for airfield elevation higher than 900 m (2 953 ft). The tabulated allowances shall be increased by two per cent of the RA margin per 300 m (984 ft) airfield elevation.

Adjustments for steep VPA

4.6.15 For promulgated vertical path angles greater than 3.2 degrees, the height loss margins shall be increased by 5 per cent of the radio altimeter margin per 0.1 degree increase in glide path angle between 3.2 and 3.5 degrees.

4.6.16 Procedures with promulgated VPA greater than 3.5 degrees, or any angle when the nominal rate of descent (V_{at} for the aircraft type multiplied by the sine of the VPA) exceeds 5 m/sec (1 000 ft/min) are nonstandard and require the following:

a) increase of height loss margin (which may be aircraft type-specific);

b) the application of related operational constraints.

4.6.17 Such procedures are normally restricted to specifically approved operators and aircraft and are associated with appropriate aircraft and crew restrictions. They are not to be used to introduce noise abatement procedures.

Table 4-2. Height loss margins

The following height loss margins shall be applied to all approach and equivalent approach obstacles				
	Margin using RA		*Margin using pressure altimeter*	
Aircraft category (V_{at})	*Metres*	*Feet*	*Metres*	*Feet*
A – 169 km/h (90 kt)	13	42	40	130
B – 223 km/h (120 kt)	18	59	43	142
C – 260 km/h (140 kt)	22	71	46	150
D – 306 km/h (165 kt)	26	85	49	161

Note.— RA margins are used only for height loss adjustment.

Exceptions and adjustments

4.6.18 Values in the height loss table are calculated to account for aircraft using normal manual overshoot procedures from OCA/H on the nominal approach path. Values in the table may be adjusted for specific aircraft types where adequate flight and theoretical evidence is available, i.e., the height loss value corresponding to a probability of 1×10^{-5} (based on a missed approach rate 10^{-2}).

Margins for specific V_{at}

4.6.19 If a height loss/altimeter margin is required for a specific V_{at}, the following formulas apply (see also PANS-OPS, Volume II, Part I, Section 4, Chapter 1, Tables I-4-1-1 and I-4-1-2):

Margin = ($0.068V_{at}$ + 28.3) metres where V_{at} is in km/h; and

Margin = ($0.125V_{at}$ + 28.3) metres where V_{at} is in kt

where V_{at} is the speed at threshold based on 1.3 times stall speed in the landing configuration at maximum certificated landing mass.

Note.— The equations assume the aerodynamic and dynamic characteristics of the aircraft are directly related to the speed category. Thus, the calculated height loss/altimeter margins may not realistically represent small aircraft with V_{at} at a maximum landing mass exceeding 165 kt.

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Chapter 5

PUBLICATION AND CHARTING

5.1 INTRODUCTION

The general criteria in PANS-OPS, Volume II, Part I, Section 4, Chapter 9 and Part III, Section 5 apply as modified in this chapter. See PANS-OPS, Volume II, Part III, Section 5, Chapter 2 for specific aeronautical database publication requirements. The required navigation specification for any published procedure must be included in the State AIP on the chart in the PBN requirements box or in the GEN section.

5.2 AERONAUTICAL CHART TITLES

Charts must be titled in accordance with Annex 4 — *Aeronautical Charts*, Chapter 11, 11.6 for approach procedures.

5.3 APPROACH CHART IDENTIFICATION

The chart must be identified in accordance with Annex 4, Chapter 11, 11.6, and with PANS-OPS, Volume II, Part III, Section 5, Chapter 1, 1.4.

5.4 CHART NOTES

5.4.1 For chart notes and PBN requirements box, criteria in PANS-OPS Volume II, Part III, Section 5 apply.

5.4.2 For RNP AR APCH procedures, a note must be published on the chart that includes the specific authorization requirement.

5.5 DEPICTION

For RNP AR APCH procedures, navigation accuracy values less than 1.0 NM within initial and intermediate segments shall be charted at the waypoint where they first take effect and continue to apply until another navigation accuracy value is charted or until the final segment is reached. Navigation accuracy values associated to the final segment shall be charted within the minima box, along with the associated OCA/H. Navigation accuracy values less than 1.0 NM within missed approach segments shall be charted at the waypoint where they first take effect, starting with the MAPt, and continue to apply until another navigation accuracy is specified or until a charted accuracy value of 1.0 NM terminates the need for further charting of missed approach accuracy values. When the missed approach includes navigation accuracy values less than 1.0 NM, this shall also be stated within the PBN requirements box (e.g. missed approach RNP < 1.0) (see PANS-OPS, Volume II, Part III, Section 5, Chapter 1 and Doc 8697.)

5.6 MINIMA

5.6.1 OCA/H is published on approach charts for all RNP AR APCH procedures. An example of minima depiction is provided in PANS-OPS, Volume II, Part III, Section 5, Chapter 1, 1.4.5.

5.6.2 An OCA/H for RNP 0.3 should be published for each RNP AR approach procedure, if possible. Additional OCA/H for RNP navigation accuracy requirements between 0.1 NM and 0.3 NM may be published as applicable.

5.7 RESTRICTIONS ON PROMULGATION OF RNP AR PROCEDURES

Altimeter errors

5.7.1 Final approach vertical guidance is based on barometric altimeters and therefore procedures shall not be promulgated for use with remote altimeter setting sources.

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Appendix A

VERTICAL ERROR BUDGET
MINIMUM OBSTACLE CLEARANCE
EQUATION EXPLANATION (SI UNITS)

The MOC for the VEB is derived by combining three known standard deviation variations by the root sum square (RSS) method and multiplying by four-thirds to determine a combined four-standard deviation (4σ) value. Bias errors are then added to determine the total MOC.

The sources of variation included in the MOC for the VEB are:

a) actual navigation performance error (anpe);

b) waypoint precision error (wpr);

c) flight technical error (fte) **fixed at** 23 m;

d) altimetry system error (ase);

e) vertical angle error (vae);

f) automatic terminal information service (atis) **fixed at** 6 m.

The bias errors for the MOC are:

a) body geometry (bg) error;

b) semi-span **fixed at** 40 m; and

c) international standard atmosphere temperature deviation (isad).

The MOC equation which combines these is:

$$MOC = bg - isad + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase^2 + vae^2 + atis^2}$$

Three standard deviation formulas for RSS computations are:

The anpe: anpe = 1.225 * rnp · 1852 * tan(VPA);

The wpr: wpr = 18 * tan(VPA);

The fte: fte = 23;

The ase: ase = $-2.887 * 10^{-7} * (elev)^2 + 6.5 * 10^{-3} * (elev) + 15$;

The vae: vae = $\left(\frac{elev - LTP_{elev}}{\tan(VPA)}\right)$ $[\tan(VPA) - \tan(VPA - 0.01°)]$;

The atis: atis = 6.

Bias error computations:

The isad: isad = $(\Delta ISA_{LOW} / Lo) * \ln[1 + Lo * a / (To + Lo * h_{THR})]$

The bg bias: Straight segments fixed values: bg = 7.6

RF segments: bg = semispan * sin α

SAMPLE CALCULATIONS

Design variables

Applicable facility temperature minimum is 20°C below standard: (ΔISA = –20).

RNP is 0.14 NM: (rnp = 0.14).

AUTHORIZATION REQUIRED (AR) FIXED VALUES

Vertical fte of three standard deviations is assumed to be 23 m: (fte = 23).

atis three-standard deviation altimeter setting vertical error is assumed to 6 m: (atis = 6).

The maximum assumed bank angle is 18 degrees: (α = 18°).

Vertical path variables

VPA = 3°

FAP is 1 400 m: (fap = 1 400)

Landing threshold point elevation (LTP_{elev}): (LTP_{elev} = 360)

(RDH = 17)

Minimum aerodrome temperature (T_{min}) at 20°C below ISA: (ΔISA = –20):

$T_{min} = \Delta ISA + (15 - .0065 \cdot LTP_{elev})$
$T_{min} = -20 + (15 - 0.0065 \cdot 360)$
$T_{min} = -7.34°C$

Calculations

$$MOC = bg - isad + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase^2 + vae^2 + atis^2}$$

The anpe: anpe = 1.225 * rnp * 1852 * tan(VPA)
= 1.225 * 0.14 * 1852 * tan3°
= 16.6457

The wpr: wpr = 18 * tan(VPA)
= 18 * tan3°
= 0.9433

The fte: fte = 23

The ase: $ase = -2.887 * 10^{-7} * (elev)^2 + 6.5.10^{-3} * (elev) + 15$

$ase_{75} = -2.887 * 10^{-7} * (LTP_{elev} + 75)^2 + 6.5.10^{-3} * (LTP_{elev} + 75) + 15$
$= -2.887 * 10^{-7} * (360 + 75)^2 + 6.5.10^{-3} * (360 + 75) + 15$
= 17.7729

$ase_{FAP} = -2.887 * 10^{-7} . (FAP)^2 + 6.5.10^{-3} * (FAP) + 15$
$= -2.887 * 10^{-7} * (1400)^2 + 6.5.10^{-3} * (1400) + 15$
= 23.5341

The vae: $vae = \left(\frac{elev - LTP_{elev}}{\tan(VPA)}\right)[\tan(VPA) - \tan(VPA - 0.01°)]$

$vae_{75} = \left(\frac{75}{\tan(VPA)}\right)[\tan(VPA) - \tan(VPA - 0.01°)]$

$= \left(\frac{75}{\tan 3°}\right)[\tan 3° - \tan(3° - 0.01°)]$

= 0.2505

$vae_{FAP} = \left(\frac{FAP - LTP_{elev}}{\tan(VPA)}\right)[\tan(VPA) - \tan(VPA - 0.01°)]$
$= \left(\frac{1400 - 360}{\tan 3°}\right)[\tan 3° - \tan(3° - 0.01°)]$
= 3.4730

The atis: atis = 6

The isad: $isad = (\Delta ISA_{LOW} / Lo) * \ln[1 + Lo * a / (To + Lo * h_{THR})]$

$isad_{75}$ = (-20/-0.0065) * ln[1-0.0065*75/(288.15-0.0065*360)] = -5.2143

$isad_{FAP}$ = (-20/-0.0065) * ln[1-0.0065*1040/(288.15 – 0.0065*360)] = -73.6501

The bg: bg = semispan * sin α
= 40 * sin18°
= 12.3607

$$MOC_{75} = bg - isad_{75} + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase_{75}^2 + vae_{75}^2 + atis^2}$$

$$= 12.6307 + 5.2143 + \frac{4}{3}\sqrt{16.6457^2 + 0.9433^2 + 23^2 + 17.7729^2 + 0.2505^2 + 6^2}$$
$$= 62.9653$$

$$MOC_{fap} = bg - isad_{fap} + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase_{fap}^2 + vae_{fap}^2 + atis^2}$$
$$= 12.6307 + 73.6501 + \frac{4}{3}\sqrt{16.6457^2 + 0.9433^2 + 23^2 + 23.5341^2 + 3.4730^2 + 6^2}$$
$$= 136.2276$$

CALCULATING THE OBSTACLE ASSESSMENT SURFACE (OAS) GRADIENT

The OAS gradient is calculated by taking the difference in heights of the OAS surface at MOC_{fap} and MOC_{75}:

$$OASgradient = \frac{(FAP - LTP_{elev} - MOC_{FAP}) - (75 - MOC_{75})}{\frac{FAP - LTP_{elev} - 75}{\tan(VPA)}}$$

CALCULATING THE OAS LTP TO ORIGIN DISTANCE

The OAS origin is calculated by taking the distance from LTP of the 75-m point of the VPA and subtracting the distance from the MOC_{75} point.

$$OASorigin = \left(\frac{75 - RDH}{\tan(VPA)}\right) - \left(\frac{75 - MOC_{75}}{OASgradient}\right)$$

Using the example numbers from above:

$$OASgradient = \frac{(1400 - 360 - 136.2276) - (75 - 62.9653)}{\frac{1400 - 360 - 75}{\tan 3°}}$$

$$= 0.0484 = 4.84\%$$

$$OASorigin = \left(\frac{75 - 17}{\tan 3°}\right) - \left(\frac{75 - 62.9653}{0.0484}\right)$$

$$= 858.0551$$

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Appendix B

VERTICAL ERROR BUDGET
MINIMUM OBSTACLE CLEARANCE
EQUATION EXPLANATION (NON-SI UNITS)

The required MOC for the VEB is derived by combining known three standard deviation variations by the RSS method and multiplying by four-thirds to determine a combined four standard deviation (4σ) value. Bias errors are then added to determine the total MOC.

The sources of variation included in the MOC for the VEB are:

a) actual navigation performance error (anpe);

b) waypoint precision error (wpr);

c) flight technical error (fte) **fixed at 75 ft**;

d) altimetry system error (ase);

e) vertical angle error (vae); and

f) automatic terminal information system (atis) **fixed at 20 ft**.

The bias errors for the MOC are:

a) body geometry (bg) error;

b) semi-span **fixed at 132**;

c) international standard atmosphere temperature deviation (isad).

The MOC equation which combines these is:

$$MOC = bg - isad + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase^2 + vae^2 + atis^2}$$

Three standard deviation formulas for RSS computations:

The anpe: $anpe = 1.225 * rnp * \frac{1852}{0.3048} * \tan(VPA)$

The wpr: $wpr = 60 * \tan(VPA)$

The fte: $fte = 75$

The ase: $ase = -8.8 * 10^{-8} * (elev)^2 + 6.5 * 10^{-3} * (elev) + 50$

The vae: $vae = \left(\frac{elev - LTPelev}{\tan\theta}\right) [\tan\theta - \tan(\theta - 0.01°)]$

The atis: $atis = 20$

Bias error computations:

The isad: $isad = (\Delta ISA_{LOW} / Lo) * \ln[1 + Lo * a / (To + Lo * h_{THR})]$

The bg bias: straight segments fixed values: bg = 25

RF segments: bg = semispan · sin α

SAMPLE CALCULATIONS

Design variables

Applicable facility temperature minimum is 20°C below standard: (ΔISA = –20).
RNP is 0.14 NM: (rnp = 0.14).

AUTHORIZATION REQUIRED (AR) FIXED VALUES

Vertical fte of three standard deviations is assumed to be 75 ft: (fte = 75).

atis three standard deviation altimeter setting vertical error is assumed to be 20 ft: (atis = 20).

The maximum assumed bank angle is 18°: (α = 18°).

Vertical path variables

FAP is 4 500 ft: (FAP = 4 500)

Landing threshold point elevation (LTP_{elev} (ft)): (LTP_{elev} = 1 200)

RDH (ft): (RDH = 55)

VPA = 3°

Calculations

$$MOC = bg - isad + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase^2 + vae^2 + atis^2}$$

The anpe: $anpe = 1.225 * rnp * \frac{1852}{0.3048} . \tan(VPA)$

$= 1.225 * 0.14 * \frac{1852}{0.3048} * \tan 3°$

$= 54.6117$

The wpr: $wpr= 60 * \tan(VPA)$
$= 60 * \tan 3°$
$= 3.1445$

The fte: $fte = 75$

The ase_{250}: $ase= -8.8 .10^{-8} * (elev)^2 + 6.5 * 10^{-3} * (elev) + 50$
$ase_{250}= -8.8 *10^{-8} * (LTP_{elev} + 250)^2 + 6.5 * 10^{-3} * (LTP_{elev}+250) + 50$
$= -8.8 *10^{-8} * (1200+250)^2 + 6.5 * 10^{-3} * (1200+250) + 50$
$= 59.2400$

The ase_{FAP}: $= -8.8 * 10^{-8} * (FAP)^2 + 6.5 * 10^{-3} * (FAP) + 50$
$= -8.8 * 10^{-8} * (4500)^2 + 6.5 * 10^{-3} * (4500) + 50$
$= 77.4680$

The vae: $vae = \left(\frac{elev - LTP_{elev}}{\tan VPA}\right) [\tan(VPA) - \tan(VPA - 0.01°)]$

$vae_{FAP} = \left(\frac{FAP - LTP_{elev}}{\tan VPA}\right) [\tan(VPA) - \tan(VPA - 0.01°)]$

$= \left(\frac{4500 - 1200}{\tan 3°}\right) [\tan 3° - \tan(3° - 0.01°)]$
$= 11.0200$

$vae_{250} = \left(\frac{250}{\tan VPA}\right) [\tan(VPA) - \tan(VPA - 0.01°)]$

$= \left(\frac{250}{\tan 3°}\right) [\tan 3° - \tan(3° - 0.01°)]$

$= 0.8349$

The isad: $isad = (\Delta ISA_{LOW}/Lo) * \ln[1 + Lo * a/(To + Lo * h_{THR})]$

$isad_{FAP} = (-20/-0.00198) * \ln[1-0.00198 * 3300 / (288.15 – 0.00198 * 1200)] = -233.6329$

$isad_{250} = (-20/-0.00198) * \ln[1-0.00198 * 250 / (288.15-0.00198 * 1200)] = -17.5115$

The bg: $bg = semispan * \sin \alpha$
$= 132 * \sin 18°$
$= 40.7902$

$MOC_{250}= bg - isad_{250}+ \frac{4}{3} \sqrt{anpe^2 + wpr^2+ fte^2 + ase_{250}{}^2 + vae_{250}{}^2 + atis^2}$
$= 40.7902 +17.5115 + \frac{4}{3} \sqrt{54.6117^2 + 3.1445^2+ 75^2 + 59.2400^2 + 0.8349^2 + 20^2}$
$= 207.536$

$$MOC_{FAP} = bg - isad_{FAP} + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase_{FAP}^2 + vae_{FAP}^2 + atis^2}$$

$$= 40.7902 + 233.6329 + \frac{4}{3}\sqrt{54.6117^2 + 3.1445^2 + 75^2 + 77.4680^2 + 11.020^2 + 20^2}$$

$$= 438.483$$

CALCULATING THE OBSTACLE ASSESSMENT SURFACE (OAS) GRADIENT

The OAS gradient is calculated by taking the difference in heights of the OAS surface at MOC_{fap} and MOC_{250}:

$$OASgradient = \frac{(FAP - LTP_{elev} - MOC_{FAP}) - (250 - MOC_{250})}{\frac{FAP - LTP_{elev} - 250}{\tan(VPA)}}$$

$$= \frac{(4500 - 1200 - 438.483) - (250 - 207.536)}{\frac{4500 - 1200 - 250}{\tan(3)}}$$

$$= 0.0484 = 4.84\%$$

CALCULATING THE OAS LTP TO ORIGIN DISTANCE

The OAS origin is calculated by taking the distance from the LTP of the 250-ft point of the VPA and subtracting the distance from the MOC_{250} point.

$$OASorigin = \left(\frac{250 - RDH}{\tan(VPA)}\right) - \frac{(250 - MOC_{250})}{OASgradient}$$

$$= \left(\frac{250 - 55}{\tan(3)}\right) - \frac{(250 - 207.536)}{0.0484}$$

$$= 2843.466$$

— END —

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