Doc 9905
AN/471

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

Approved by the Secretary General
and published under his authority

First Edition — 2009

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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.

The same State, consistent with its aviation community, derived a separate set of procedure design criteria that retained many key areas of flexibility but also set specific standards in others, so as to simplify the procedure design implementation effort while retaining the means to achieve significant operational benefits. These criteria were documented in United States FAA Order 8250.52, which was initially used in that State, but was also embraced by others needing such criteria to address operational problems in their regions. ICAO has reviewed these criteria and developed equivalent criteria contained herein that was harmonized with PANS-OPS with regard to terminology, units of measurement and certain design parameters. As the concepts behind the criteria contained in this manual are relatively new, it was decided not to include the criteria in PANS-OPS at this stage.

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 from the State regulatory authority.

RNP AR procedures can provide significant operational and safety advantages over other area navigation (RNAV) procedures 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 aircraft operators and procedure designers of instrument approaches based on RNP using RNAV 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, Implementing RNP AR APCH. Similar criteria for departure procedures will be incorporated when developed.

DEFINITIONS

Aircraft-based augmentation system (ABAS). An augmentation system that augments and/or integrates the information obtained from the other GNSS elements with information available on board the aircraft.

Note.— The most common form of ABAS is receiver autonomous integrity monitoring (RAIM).

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). An instrument procedure which utilizes lateral and vertical guidance but does not meet the requirements established for precision approach and landing operations.

Area navigation (RNAV). A method of navigation which 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.

Area navigation route. An ATS route established for the use of aircraft capable of employing area navigation.

ATS surveillance service. Term used to indicate a service provided directly by means of an ATS surveillance system.

ATS surveillance system. A generic term meaning variously, ADS-B, PSR, SSR or any comparable ground-based system that enables the identification of aircraft.

Note.— A comparable ground-based system is one that has been demonstrated, by comparative assessment or other methodology, to have a level of safety and performance equal to or better than monopulse SSR.

Cyclic redundancy checking (CRC). *A mathematical algorithm applied to the digital expression of data that provides a level of assurance against loss or alteration of data.*

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

Note 1.— DA is referenced to mean sea level and DH 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".

Glide path. A flight path defined in the vertical axis that passes through the DCP/RDH on the final approach segment of an APV or PA.

Mixed navigation environment. An environment where different navigation specifications may be applied within the same airspace (e.g. RNP 10 routes and RNP 4 routes in the same airspace) or where operations using conventional navigation are allowed together with RNAV or RNP applications.

Navigation aid (NAVAID) infrastructure. Navaid infrastructure refers to space-based and or ground-based navigation aids available to meet the requirements in a navigation specification.

Navigation application. The application of a navigation specification and the supporting navaid infrastructure to routes, procedures, and/or defined airspace volume, in accordance with the intended airspace concept.

Note.— The navigation application is one element, along with communication, surveillance and ATM procedures meeting the strategic objectives in a defined airspace concept.

Navigation function. The detailed capability of the navigation system (such as the execution of leg transitions, parallel offset capabilities, holding patterns, navigation databases) required to meet the airspace concept.

Note.— Navigational functional requirements are one of the drivers for selection of a particular navigation specification. Navigation functionalities (functional requirements) for each navigation specification can be found in the Performance-Based Navigation (PBN) Manual (Doc 9613), *Volume II, Parts B and C.*

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.

Procedural control. Air traffic control service provided by using information derived from sources other than an ATS surveillance system.

RNAV operations. Aircraft operations using an area navigation system for RNAV applications. RNAV operations include the use of area navigation for operations which are not developed in accordance with the *Performance-Based Navigation (PBN) Manual (*Doc 9613).

RNAV system. A navigation system which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these. An RNAV system may be included as part of a flight management system (FMS).

RNP operations. Aircraft operations using an RNP system for RNP applications.

RNP route. An ATS route established for the use of aircraft adhering to a prescribed RNP specification.

RNP system. An area navigation system which supports on-board performance monitoring and alerting.

Satellite based augmentation system (SBAS). A wide coverage augmentation system in which the user receives augmentation from a satellite-based transmitter.

Standard instrument arrival (STAR). A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced.

Standard instrument departure (SID). A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated ATS route, at which the en-route phase of a flight commences.

ABBREVIATIONS AND ACRONYMS

AC	Advisory circular
ADS-B	Automatic dependent surveillance broadcast
AGL	Above ground level
anpe	Actual navigation performance error
APCH	Approach
APV	Approach procedure with vertical guidance
AR	Authorization required
*ase	Altimetry system error
ASI	Airspeed indicator
ATC	Air traffic control
*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
CAT	Category
CDA	Continuous descent approach
CFIT	Controlled flight into terrain
Cot	Cotangent
CNS/ATM	Communications, navigation and surveillance/air traffic management
DA/H	Decision altitude/height
DER	Departure end of runway
D_{FAP}	Distance from threshold to FAP
D_{FROP}	Distance to final approach roll-out point
DR	Descent rate
DTA	Distance of turn anticipation
FAA	Federal Aviation Administration
FAF	Final approach fix
FAP	Final approach point
FAS	Final approach segment
FCC	Flight control computer
FOSA	Flight operations safety assessment
FROP	Final approach roll-out point
ft	Feet
*fte	Flight technical error
FTP	Fictitious threshold point
GNSS	Global navigation satellite system
GP	Glide path
GPI	Ground point of intercept
GPS	Global positioning system
H	Altitude

* Lower case is used for those abbreviations and acronyms that come from the *Performance-Based Navigation (PBN) Manual* (Doc 9613).

HATh	Height above threshold
HL	Height loss
IAF	Initial approach fix
IAS	Indicated airspeed
IF	Intermediate fix
IRU	Inertial reference unit
ISA	International standard atmosphere
isad	International standard atmosphere temperature deviation
km	Kilometre
kt	Knot
LNAV	Lateral navigation
LTP	Landing threshold point
LTP_{ELEV}	Landing threshold point elevation
m	Metre
MA	Missed approach
MAS	Missed approach segment(s)
MEL	Minimum equipment list
MOC	Minimum obstacle clearance
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
PSR	Primary surveillance radar
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
RWY	Runway
SI	International system of units
SOC	Start of climb
SSR	Secondary surveillance radar
TAS	True airspeed
TCH	Threshold crossing height
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
VGSI	Visual glide slope indicator
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

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 aircraft operators and procedure designers of instrument approaches based on required navigation performance (RNP) using area navigation (RNAV) avionics systems, where authorization is required (AR).

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

1.2 APPLICATION

1.2.1 Implementation of RNP AR procedures extends beyond procedure design in that an authorization process for aircraft operators is necessary to ensure that other critical dependencies and associated airworthiness and operational procedure approvals are complete prior to implementation. Guidance on implementation and operational approval is provided in the PBN Manual.

1.2.2 The PBN Manual contains navigation specifications applicable to two RNP approach applications: RNP APCH and RNP AR APCH.

1.2.3 RNP AR APCH operations are classified as approach procedures with vertical guidance (APVs) in accordance with Annex 6 — *Operation of Aircraft*. This type of operation requires a positive vertical navigation (VNAV) guidance system for the final approach segment (FAS). Current RNP AR APCH implementations utilize a barometric vertical navigation system (BARO-VNAV) 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.

1.2.4 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.

1.2.5 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. Where an operationally acceptable solution is not available through the application of these criteria, development of detailed procedures may be needed to satisfy local conditions. Alternative design solutions may be derived which specify aircraft type or specific performance parameters, special operating conditions or limitations, crew training, operational evaluation or other requirements that can be demonstrated to provide an equivalent level of safety. Such solutions are not the subject of this manual and require a case-by-case flight operations safety assessment (FOSA) and operational approval.

1.2.6 RNP AR APCH operations utilize high levels of RNAV capability, and all aspects of the operation must meet the relevant requirements specified in the PBN Manual.

1.2.7 The safety of RNP AR APCH procedures is dependent upon the proper inter-relationship between aircraft capability, operating procedures and procedure design. Users of this manual should understand this critical difference in the design of RNP AR procedures.

1.3 AIRCRAFT QUALIFICATION

1.3.1 Aircraft qualification is integral to the process of authorization for RNP AR operations. For an RNP AR instrument flight procedure, only aircraft that have demonstrated performance, capability and functionality can be authorized to conduct RNP AR APCH operations.

1.3.2 Aircraft must meet the requirements of the RNP AR APCH navigation specification given in the PBN Manual. Aircraft manufacturers must demonstrate and document aircraft performance and capability, and any special procedures or limitations associated with the aircraft and systems as part of either an aircraft certification programme or aircraft compliance assessment.

1.3.3 The demonstration of aircraft capability allows all qualified aircraft to use the instrument flight procedure, relieving the designer of the need to consider individual aircraft types or performance capabilities.

1.3.4 As aircraft performance, integrity and functionality are demonstrated, documented and approved as part of the demonstration of RNP AR capability, the conduct of special or extensive flight trials and simulations to gather statistical evidence of the aircraft performance is not required to support the implementation of RNP AR operations.

1.4 OPERATIONAL QUALIFICATION

1.4.1 The authorization process for RNP AR APCH operations includes the approval of operating procedures and crew training in accordance with the RNP AR APCH navigation specification given in the PBN Manual.

1.4.2 Operating procedures must conform to any conditions in the aircraft RNP AR capability approval and any additional requirement such as a minimum equipment list (MEL), flight crew operations manuals, aircraft flight manuals and maintenance guidance.

1.4.3 Operating procedures must also take into account any limitations or requirements specified by the procedure designer. Specified equipment or capabilities may be required to conduct an RNP AR APCH procedure in certain cases.

1.4.4 Individual RNP AR APCH procedures are validated in accordance with the PBN Manual and other relevant guidance prior to publication. However, as variations may occur in functionality, equipment and flyability, operators are required to conduct an operational validation of each of the procedures applicable to the type of aircraft operated.

1.4.5 Prior to authorization for the conduct of RNP AR APCH operations, an operator must demonstrate to the State regulator that all appropriate elements of the RNP AR APCH operations have been appropriately addressed including:

a) determination of aircraft qualification;

b) training e.g. flight crews, dispatch;

c) MEL, continuing airworthiness;

d) requirements for operational procedures;

e) dispatch procedures;

f) maintenance procedures;

g) conditions or limitations for approval;

h) procedure operational validation for each aircraft type; and

i) conduct of a FOSA.

1.4.6 The specific considerations and issues for these areas are as described in detail in the PBN Manual.

1.5 FLIGHT OPERATIONS INFORMATION

1.5.1 The conduct of RNP AR instrument procedures requires that the aircraft operator examine its crew information, flight procedures and training to ensure that they are sufficient to enable operator qualification and operational approval.

1.5.2 Crew information, flight procedures and training must be suitable for the RNP AR APCH instrument approach procedures, aircraft type(s) or variants, crew positions, airborne systems, navaids and ground systems to be used. Training topics will be tailored to suit their application to initial qualification, recurrent qualification, requalification, command training upgrade or differences qualification, as applicable. Crew training requirements are detailed in the PBN Manual.

1.6 FLIGHT PROCEDURES

Users of this manual must be familiar with the following aspects associated with RNP AR APCH operations.

a) *RNP capability.* Crews must be aware of the aircraft RNP capability documented in the RNP AR authorization appropriate to the aircraft configuration or operational procedures (e.g. global positioning system (GPS) inoperative, use of flight director instead of autopilot).

b) *RNP availability check*. Prior to the commencement of an approach, the crew is responsible for ensuring that the appropriate RNP is selected. The highest RNP consistent with the operating conditions should be selected to reduce the possibility of alerts and consequent missed approaches. Crews will ensure prior to commencement of a procedure that the required navigation system performance is available and can be expected to be available through the conduct of the procedure. RNP should not be changed after commencement of the procedure.

c) *Radius to fix (RF) legs*. The use of RF legs provides more flexibility in the design of the procedure track. RF legs may be present in all phases of the procedure including the final segment, and the requirement for RF leg capability, if applicable, will be annotated on the approach chart. As the use of RF legs in the design of procedures is optional, capability to fly procedures incorporating RF legs must be specifically identified in the operator authorization.

d) *Minimum equipment*. Minimum equipment provisions are detailed in the PBN Manual. At some locations, the airspace or obstacle environment will require RNP capability during a missed approach from anywhere on the procedure. At these locations redundant equipment may be required.

e) *Non-standard speeds or climb gradients*. RNP AR approaches are developed based on standard approach speeds and specified a nominal climb gradient in the missed approach. Any exceptions to these standards must be indicated on the approach procedure, and the operator must ensure they can comply with any published restrictions before conducting the operation.

f) *Non-normal operations*. Crews must be competent to contain the aircraft position within tracking tolerances consistent with the selected RNP during all normal and non-normal operations. (Flight technical tolerances are specified in the navigation specifications given in the PBN Manual, Volume II, Chapter 6.)

g) *Vertical flight path tolerances*. In the FAS, crews will monitor any vertical deviation from the VNAV path to ensure that the aircraft remains within the tolerances specified in the navigation specifications given in the PBN Manual, Volume II, Chapter 6.

h) *Coupled autopilot.* Use of coupled autopilot is recommended. Operator procedures must specify the conditions for operations without autopilot.

Chapter 2

RNP AR APPROACH PROCEDURE DESIGN

2.1 UNDERLYING PRINCIPLES

RNP APCH versus RNP AR APCH

2.1.1 RNP APCH is defined as an RNP approach procedure that requires a lateral TSE of +/-1 NM in the initial, intermediate and missed approach segments (MAS) and a lateral TSE of ±0.3 NM in the FAS. Guidance on implementing RNP APCH operations can be found in the PBN Manual, Volume II, Chapter 5, Implementing RNP APCH.

2.1.2 RNP AR APCH is defined as an RNP approach procedure that requires a lateral TSE as low as ±0.1 NM on any segment of the approach procedure. RNP AR APCH procedures also require that a specific vertical accuracy be maintained as detailed in the PBN Manual, Volume II, Chapter 6. The vertical datum for RNP AR procedures is the landing threshold point (LTP). The RNP AR APCH criteria apply only to those aircraft and operators complying with specified additional certification, approval and training requirements. RNP AR APCH procedures are only 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. For the purposes of applying the criteria contained in this manual, RNP levels address obstacle protection associated with RNP values. The RNP level is used to determine the area semi-width value (in NM) of a protection area associated with a segment of an instrument procedure.

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

2.2.1 An OCA/H is published for RNP AR procedures on the chart; however, for procedures involving an MAS with RNP values less than RNP 1.0, DA/H is published instead, and the appropriate notation is entered on the chart. In this case, the approval process ensures that the missed approach is not executed before the along-track point where the nominal DA/H occurs.

DA/H lower limit — aerodrome environment

A lower limit is applied to OCA/H as follows:

a) 75 m (246 ft) provided that the inner approach, inner transitional and balked landing surfaces of Annex 14 — *Aerodromes*, Volume I, Chapter 4, have been assessed and have not been penetrated; and

b) 90 m (295 ft) in all other cases.

Procedure complexity and OCA/H values below 75 m (246 ft)

2.2.3 If an OCH of 75 m (246 ft) is obtained using a straight-in approach, the procedure should not be further complicated by adding RF turns or reducing RNP solely to obtain lower OCH values.

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 guidance and DA/H are based on pressure altimeter;

b) procedure is flown using flight director or autopilot;

c) aircraft dimensions are considered in certification (no additional procedure design action is required);

d) early go-around or missed approach is safeguarded by the certification and approval process; and

e) aircraft are appropriately certificated and approved by the appropriate authority for RNP AR operations.

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 primary area is defined as 2 × RNP. There are no buffer or secondary areas. Table 2-1 lists RNP values applicable to the specific instrument procedure segments.

Table 2-1. RNP values

Segment	*RNP AR*		
	Maximum	*Standard*	*Minimum*
Arrival	2	2	1.0
Initial	1	1	0.1
Intermediate	1	1	0.1
Final	0.5	0.3	0.1
Missed approach	1.0	1.0	0.1*
*See section 4.6 for limitations associated with MAS minimum values.			

2.6 VERTICAL PROTECTION

2.6.1 In the final approach and MAS, obstacle clearance is provided by two obstacle assessment surfaces (OAS):

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

b) a horizontal surface based on a transition distance (TrD) (see 4.6.9), and a missed approach (Z) surface.

2.6.2 The certification, approval and training processes are designed to ensure barometric altimeter and crew performance are adequate to remain within this vertical profile.

Chapter 3

GENERAL CRITERIA

3.1 AIRCRAFT SPEED CATEGORIES

3.1.1 Aircraft performance differences have a direct effect on the airspace and visibility required for manoeuvres such as circling approach, turning missed approach, final approach descent and manoeuvering to land (including base and procedure turns). 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 landing configuration which is to be taken into consideration shall be defined by the operator or by the airplane manufacturer.

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) indicated airspeed (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

3.1.4 The criterion taken into consideration for the classification of aeroplanes by categories is the 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_{so}) multiplied by 1.23. If both V_{so} and V_{slg} are available, the higher resulting speed at threshold (V_{at}) is used. The ranges of speeds (IAS) in Tables 3-1 a) and 3-1 b) are to be used in calculating procedures. For conversion of these speeds to TAS, see 3.1.7.

Restriction on aircraft category and IAS

3.1.5 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. True airspeed (TAS) should be calculated using the procedure speeds given in Tables 3-1 a) and 3-1 b).

Permanent change of category (maximum landing mass)

3.1.6 An operator may impose a permanent, lower landing mass, and use of this mass for determining V_{at} if approved by the State of the Operator. The category defined for a given aeroplane shall be a permanent value and thus independent of changing day-to-day operations.

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

Segment		*IAS by aircraft category (CAT)*				
		CAT A	*CAT B*	*CAT C*	*CAT D*	*CAT E*
Initial, intermediate		280	335	445	465	467
Final		185	240	295	345	As specified
Missed approach		205	280	445	490	As specified
Minimum airspeed restriction	Initial	204	259	389	389	As specified
	Final	185	222	259	306	As specified
	Intermediate	204	259	333	333	As specified
	Missed	185	241	306	343	As specified

Table 3-1 b). IAS (kt)

Segment		*IAS by aircraft category (CAT)*				
		CAT A	*CAT B*	*CAT C*	*CAT D*	*CAT E*
Initial, intermediate		150	180	240	250	250
Final		100	130	160	185	As specified
Missed approach		110	150	240	265	As specified
Minimum airspeed restriction	Initial	110	140	210	210	As specified
	Final	100	120	140	165	As specified
	Intermediate	110	140	180	180	As specified
	Missed	100	130	165	185	As specified

Note.— The speeds given in Table 3-1 b) are converted and rounded to the nearest multiple of five for operational reasons and from the standpoint of operational safety are considered to be equivalent.

Calculating TAS

3.1.7 IAS to TAS conversion for RNP AR procedures uses 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
H = altitude (ft or m, as appropriate)

The above equations are incorporated in a Microsoft Excel spreadsheet, which is available together with the electronic version of the manual on the ICAO public website (www.icao.int) under “Publications”.

3.2 CALCULATING TURN RADIUS AND BANK ANGLE

Speeds for turn calculations

3.2.1 For RNP AR procedures, the turn radius for fly-by and RF turns is calculated using a speed V = TAS + an assumed tailwind.

3.2.2 Determine the TAS for the turn using formulas in 3.1.7, 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 fly-by turns

3.2.4 The turn radius applied at fly-by fixes is based on a standard bank angle of 18 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) (international system of units (SI)) or Table 3-1 b) (non-SI units), using the highest altitude allowed in the turn, calculate the TAS using the appropriate formulas in 3.1.7. For initial and intermediate segments, use the minimum altitude for the fix prior to the turn fix. Use the tailwind component (TWC) from Table 3-2 a) (SI units) or Table 3-2 b) (non-SI units) for the highest altitude within the turn. (For turns initiated at an altitude located between values in the table, a new TWC may be interpolated for that turn. If an interpolated wind value is ever used below 150 m (492 ft), then the 0 ft value for wind begins with 28 km/h (15 kt.))

3.2.5 For the MAS, use the altitude based on a seven per cent gradient with origin at OCA/H – HL (height loss: nominally 15 m (49 ft)).

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.

Table 3-2 a). TWC and altitude (SI units)

TWC (km/h) for turn calculations	
Turn height above aerodrome (m)	*Standard tailwind component (kph)*
100	40
500	92
1 000	100
1 500	130
2 000	157
2 500	185
3 000	220
≥3 500	242

3.2.7 Select the appropriate TWC from Table 3-2 a) or 3-2 b) 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;
α = bank angle

or

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

where

V = (TAS + wind speed) in kt;
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)

Table 3-2 b). TWC and altitude (non-SI units)

TWC (kt) for turn calculations	
Turn height above aerodrome (ft)	*Standard tailwind component (kt)*
500	25
1 000	38
1 500	50
2 000	50
2 500	50
3 000	50
3 500	55
4 000	60
4 500	65
5 000	70
5 500	75
6 000	80
6 500	85
7 000	90
7 500	95
8 000	100
8 500	105
9 000	110
9 500	115
10 000	120
10 500	125
≥11 000	130

Turn radii based on non-standard bank angles

3.2.8 The standard design bank angle is 18 degrees. Lower or higher bank angles are allowed for smooth transitions, maintaining stabilized approaches, lower minima or to achieve specific leg lengths. Non-standard bank angles must fall in the window of values listed in Table 3-3.

Table 3-3. Bank angle window

Lowest above ground level (AGL) height in RF segment	*Maximum bank angle (degrees)*
<150 m (492 ft)*	≤3
≥150 m (492 ft)*	≤20
* Height above threshold	

3.2.9 These criteria apply to construction at or below FL 190. Where turns above FL 190 are required, a bank angle of five degrees should be used. If five degrees results in a distance of turn anticipation (DTA) value greater than 20 NM, then:

r = 37 tan(0.5 * track change in degrees) km

r = 20 tan(0.5 * track change in degrees) NM

Note.— Aircraft using these procedures may be from States using SI units 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 low values of RNP (RNP 0.1 with a semi-width of only 370 m) and should be considered in turn boundary construction.

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 for the fastest aircraft speed category for which the procedure is designed, calculated in accordance with 3.2.4

A = turn angle

Note 1.— These criteria differ from the formulas in Doc 8168 — Procedures for Air Navigation Services — Aircraft Operations (PANS-OPS)*, Volume II, 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.

Calculation of bank angle for specific RF leg radius

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

SI units:

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

Non-SI units:

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

where

W = tailwind speed
r = turn radius

3.2.12 To ensure that the maximum number of aircraft can fly the procedure, the required radius must result in a bank angle requirement within the window specified in Table 3-3.

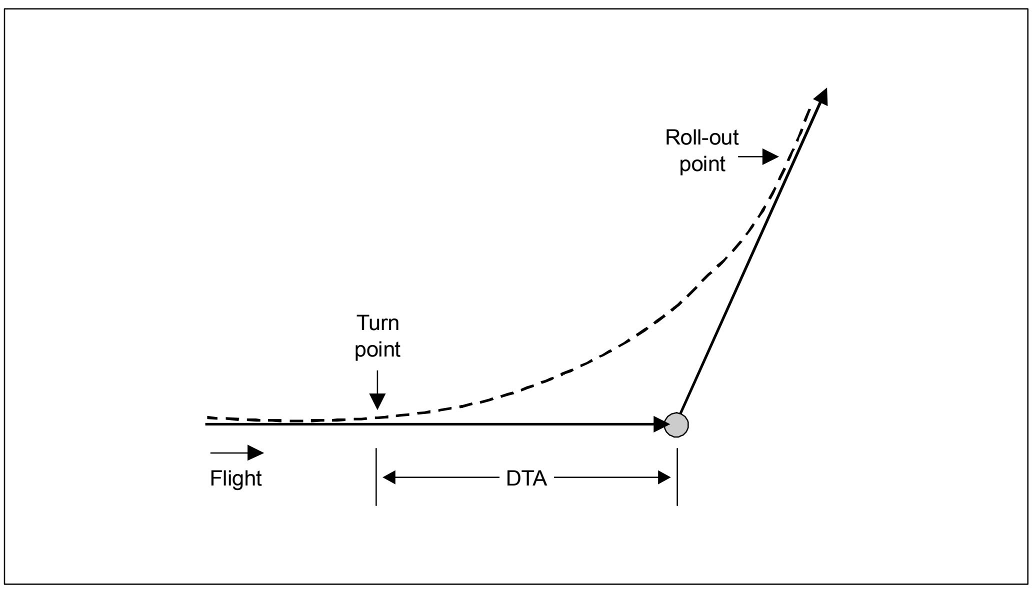

Figure 3-1. Distance of turn anticipation (DTA)

Chapter 4

PROCEDURE CONSTRUCTION

4.1 GENERAL PRINCIPLES

Segments and legs

4.1.1 The arrival, initial and intermediate segments provide a smooth transition from the en-route environment to the FAS. Descent to glide path (GP) 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 (ARINC leg type) (TF or RF)) to satisfy obstruction and operational requirements in initial, intermediate, final and MAS. Generally, TF legs are considered first, but RF legs may be used in lieu of TF-TF turns for turn path control, procedure simplification, or improved flyability.

Fixes

Fix identification

4.1.2 The fixes used are those in the general criteria. Each fix shall be identified as specified in Annex 15 — *Aeronautical Information Services*.

Stepdown fixes

4.1.3 Stepdown fixes are not permitted in RNP AR procedures.

Restrictions on promulgation of RNP AR procedures

Altimeter errors

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

Visual segment surface

4.1.5 The visual segment surface must be clear of obstacles in order to publish RNP AR procedures.

Frame of reference

4.1.6 Positions of obstacles are related to a conventional x, y, z coordinate system with its origin at 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 right angles to the x-axis. The z-axis is vertical, heights above threshold being positive.

RNP segment width

4.1.7 RNP values are specified in increments of a hundredth (0.01) of a NM. Segment width is defined as 4 × RNP; segment half-width (semi-width) is defined as 2 × RNP (see Figure 4-2). Standard RNP values for instrument procedures are listed in Table 4-1.

4.1.8 The standard RNP values listed in Table 4-1 should be applied unless a lower value is required to achieve the required ground track or lowest OCA/H. The lowest RNP values are listed in the "Minimum" column of Table 4-1.

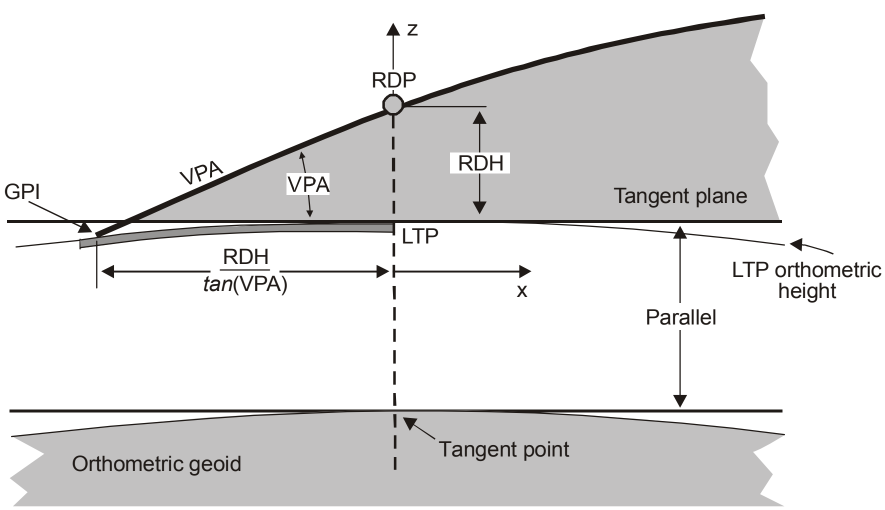

Figure 4-1. Coordinate system baseline

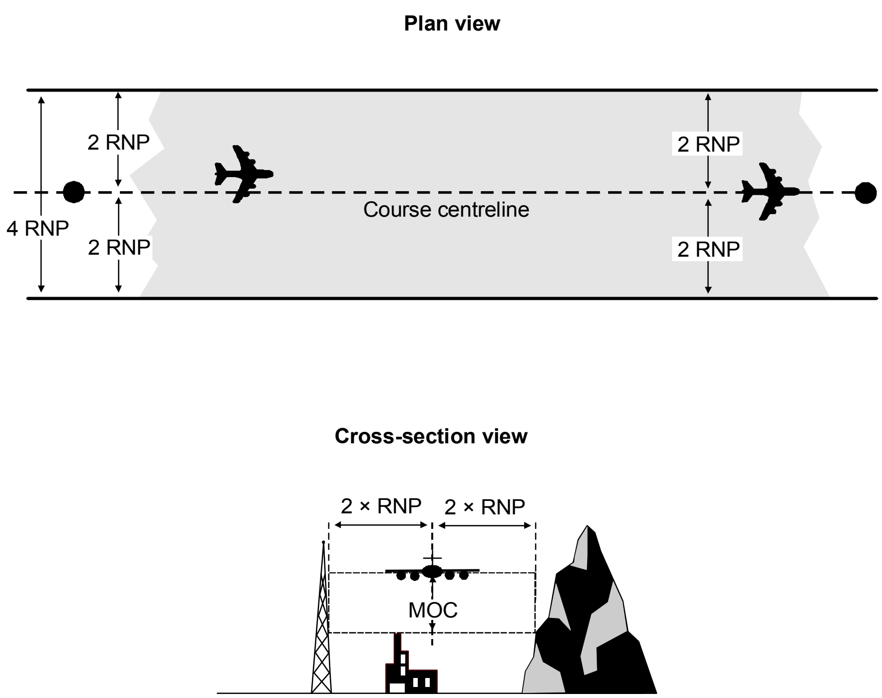

Figure 4-2. RNP segment widths

Table 4-1. RNP values

Segment	*RNP VALUES*		
	Maximum	*Standard*	*Minimum*
Initial	1	1	0.1
Intermediate	1	1	0.1
Final	0.5	0.3	0.1
Missed approach	1	1	0.1*

* Used only with the provisions for minimum, straight final segment as specified in the missed approach section. Refer to section 4.6.

RNP 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 2 × RNP (+DTA, as appropriate, for fly-by turn constructions). Paragraph 4.1.7 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 (RNP values)

4.1.10 Changes in RNP values must be completed upon the aircraft reaching the fix; therefore, the area within ±1 RNP of the fix must be evaluated for both segments. RNP reduction is illustrated in Figure 4-3, RNP increase is illustrated in Figure 4-4, and RNP changes involving RF legs are illustrated in Figure 4-5.

TF 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 are normally linked by fly-by fixes.

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 4.1.13). 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 3.2.4. Construct the turning flight path tangent to the inbound and outbound legs. The centre will be located on the bisector (see Figures 4-6 and 4-7).

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 4-7).

The evaluation for the succeeding segment begins at a distance of 1 RNP before the turn fix (see Figure 4-6) or at 1 RNP before the angle bisector line (see Figure 4-7), whichever is encountered first.

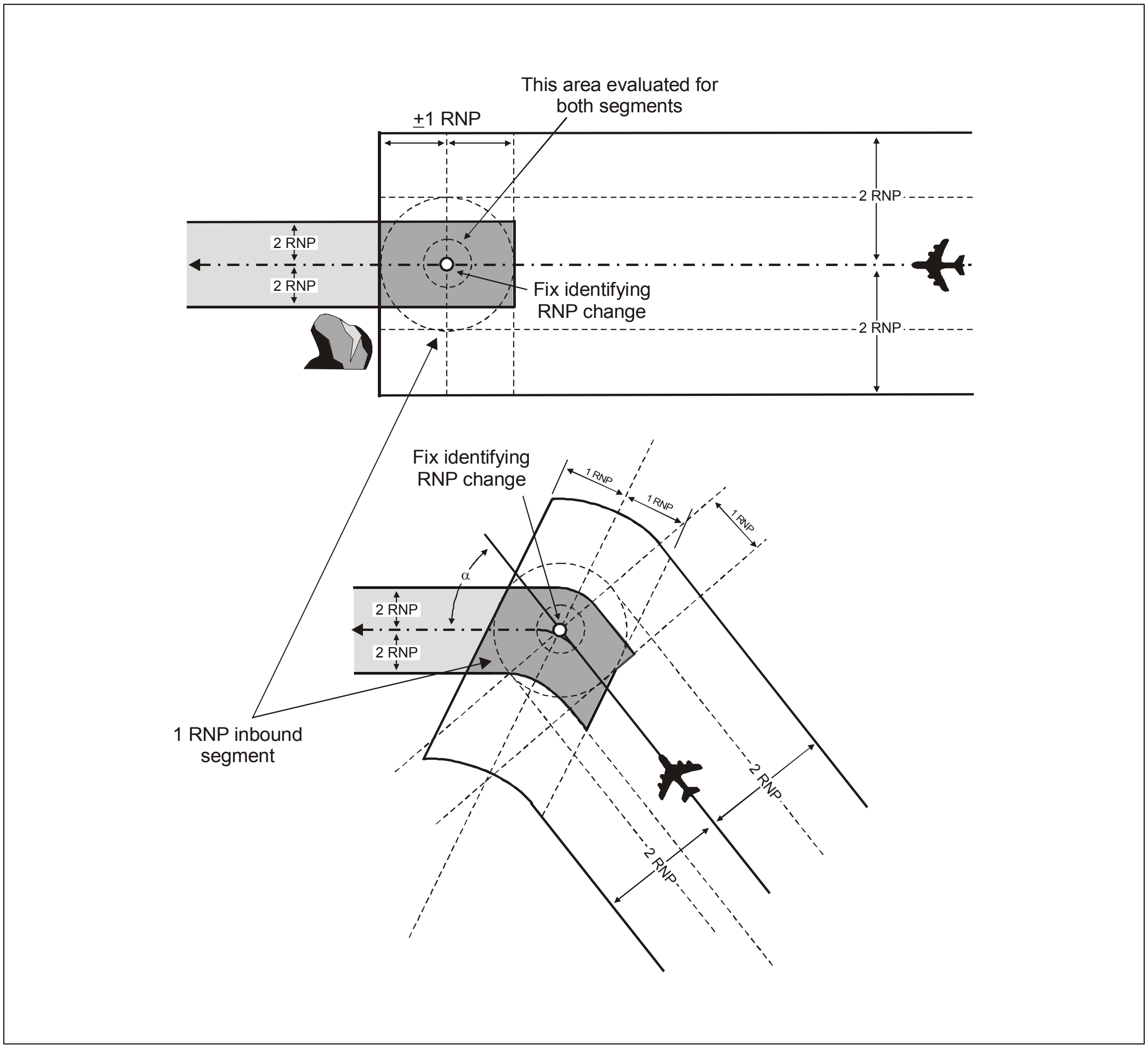

Figure 4-3. RNP reduction (straight and turning segment)

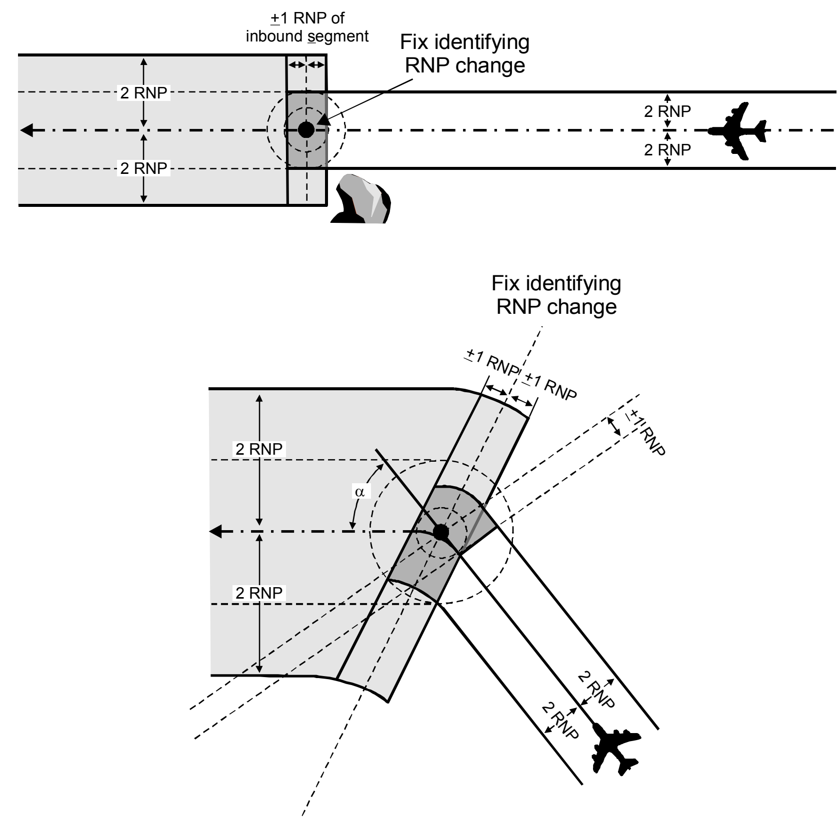

Figure 4-4. RNP increase (straight and turning segments)

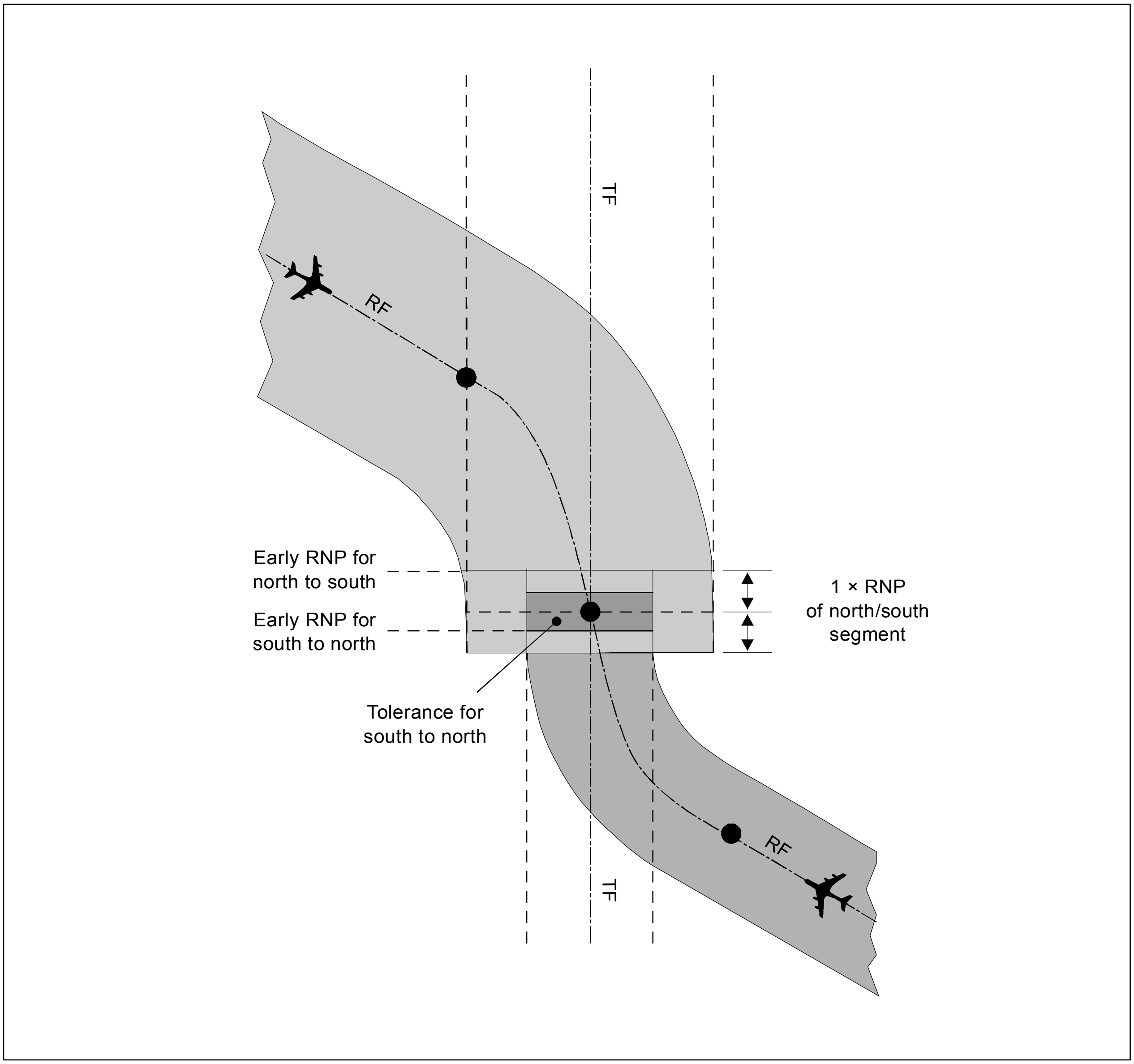

Figure 4-5. Changing RNP values

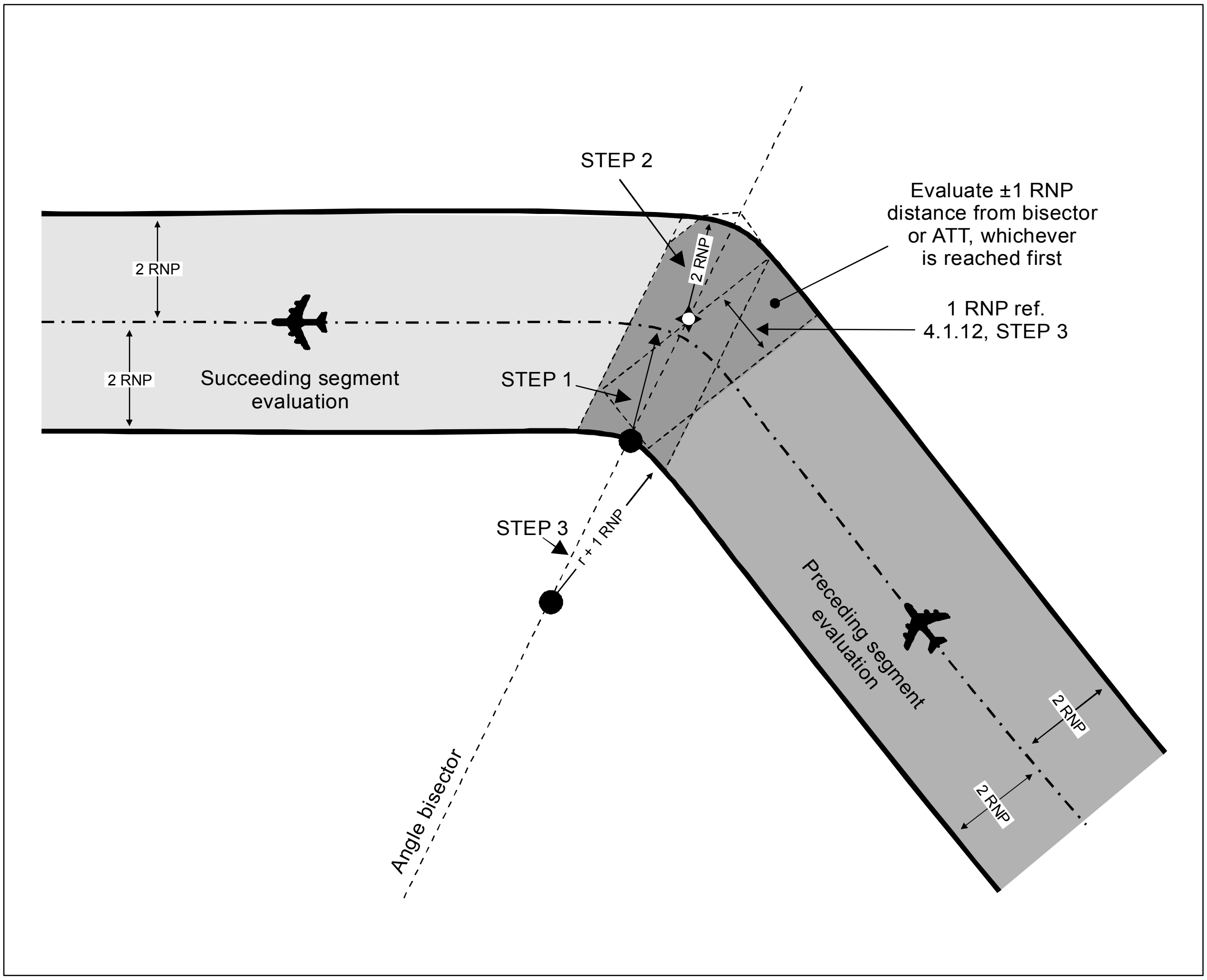

Figure 4-6. Small turn at fly-by fix

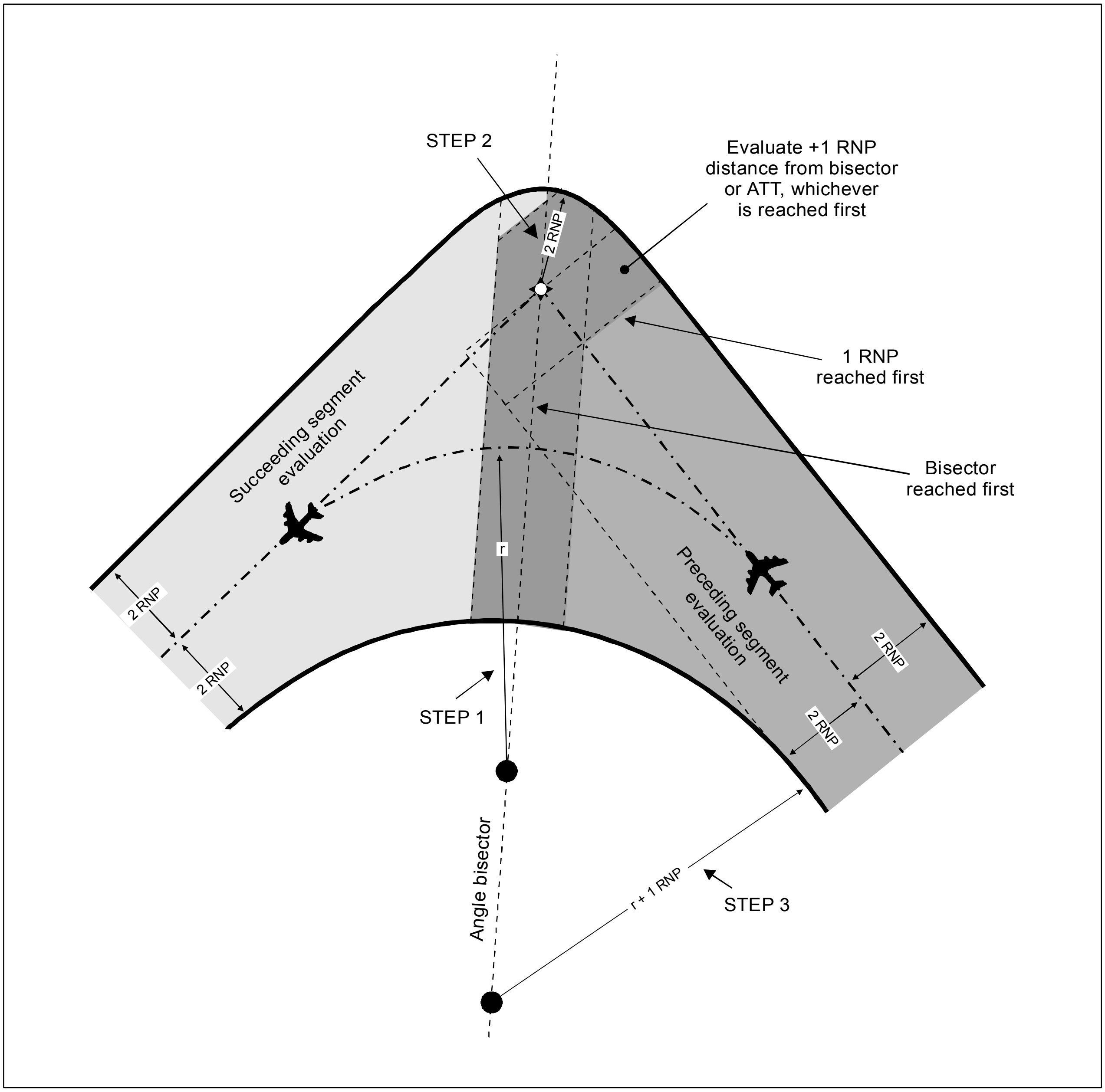

Figure 4-7. Large turn at fly-by fix

RF turns

RF leg construction

4.1.13 An RF leg may be used to accommodate a track change where obstructions prevent the design of a fly-by turn or to accommodate other operational requirements. RF legs provide a repeatable, fixed-radius ground track in a turn.

4.1.14 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 overspecify the turn. However, this is resolved by the data coder selecting the parameters required for the specific navigation system. (See Figure 4-8.)

4.1.15 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 3.2.8 to verify the bank angle associated with R is within the Table 3-3 specified 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 * 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 * 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 stair case as illustrated in Figure 4-9 a) for approach and Figure 4-9 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 – 1 × RNP).

Calculation of descent gradients

4.1.16 Descent gradients are calculated between the nominal fix positions. For RF segments, the distance used is the arc distance between the nominal fix positions.

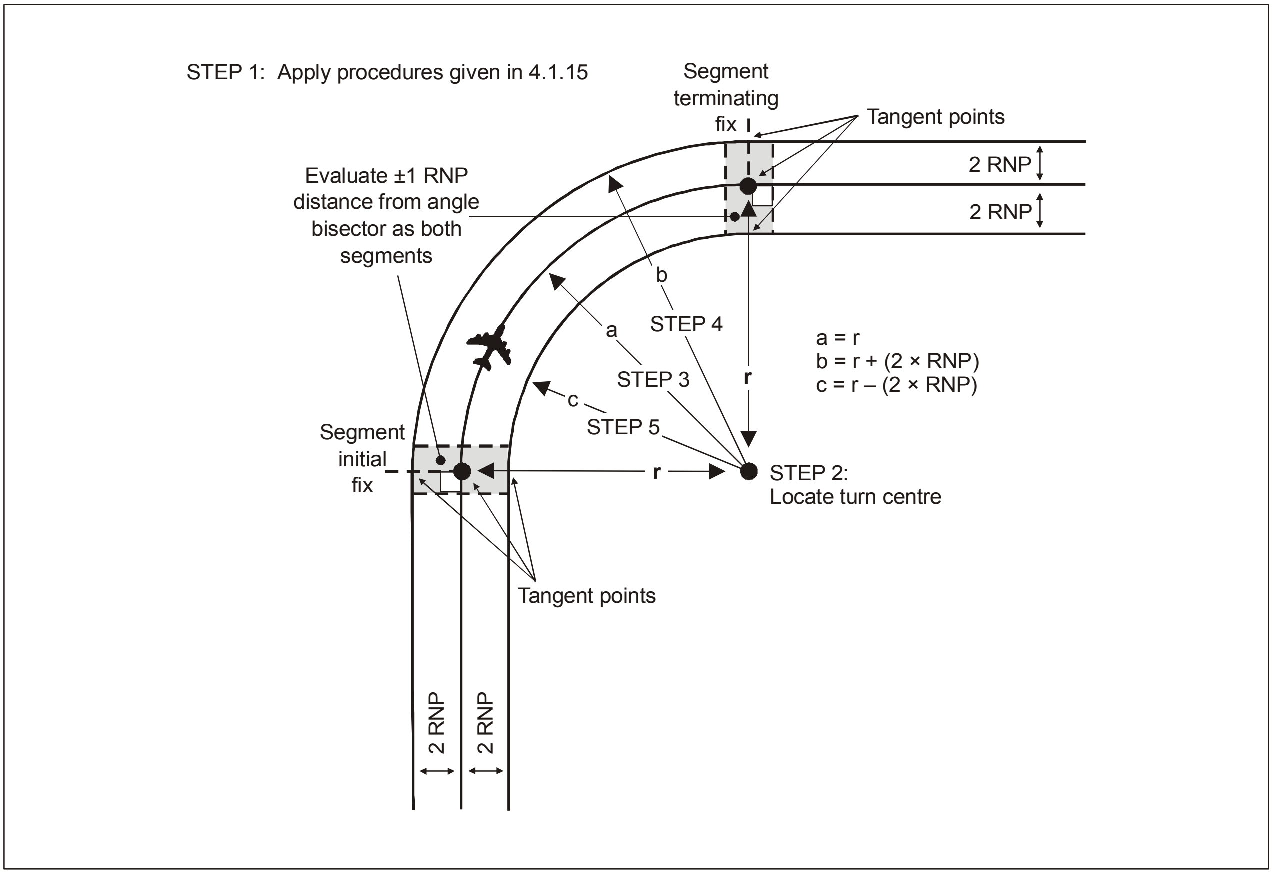

Figure 4-8. RF turn construction

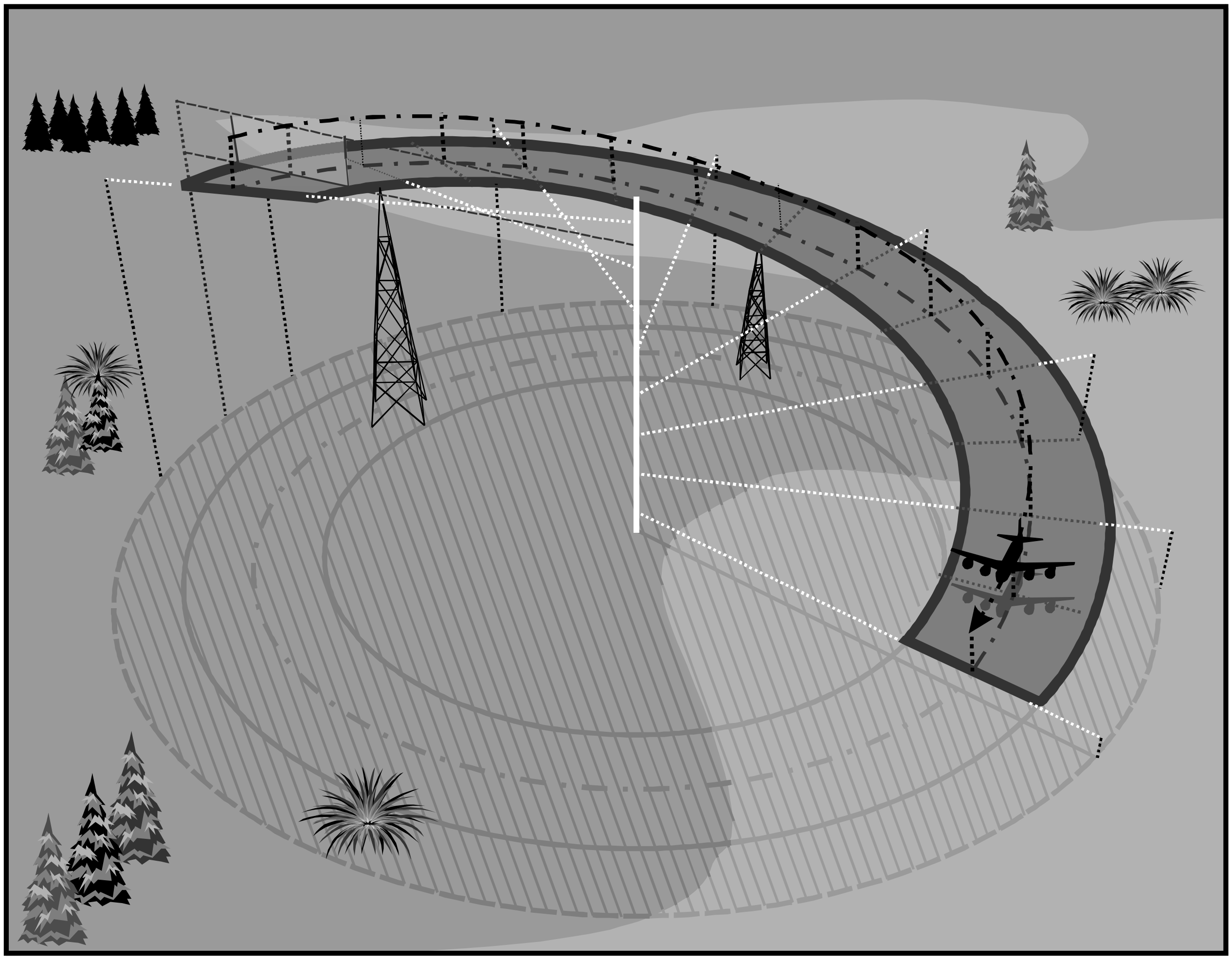

Figure 4-9 a). Obstacle clearance surface (OCS) for RF approach segments

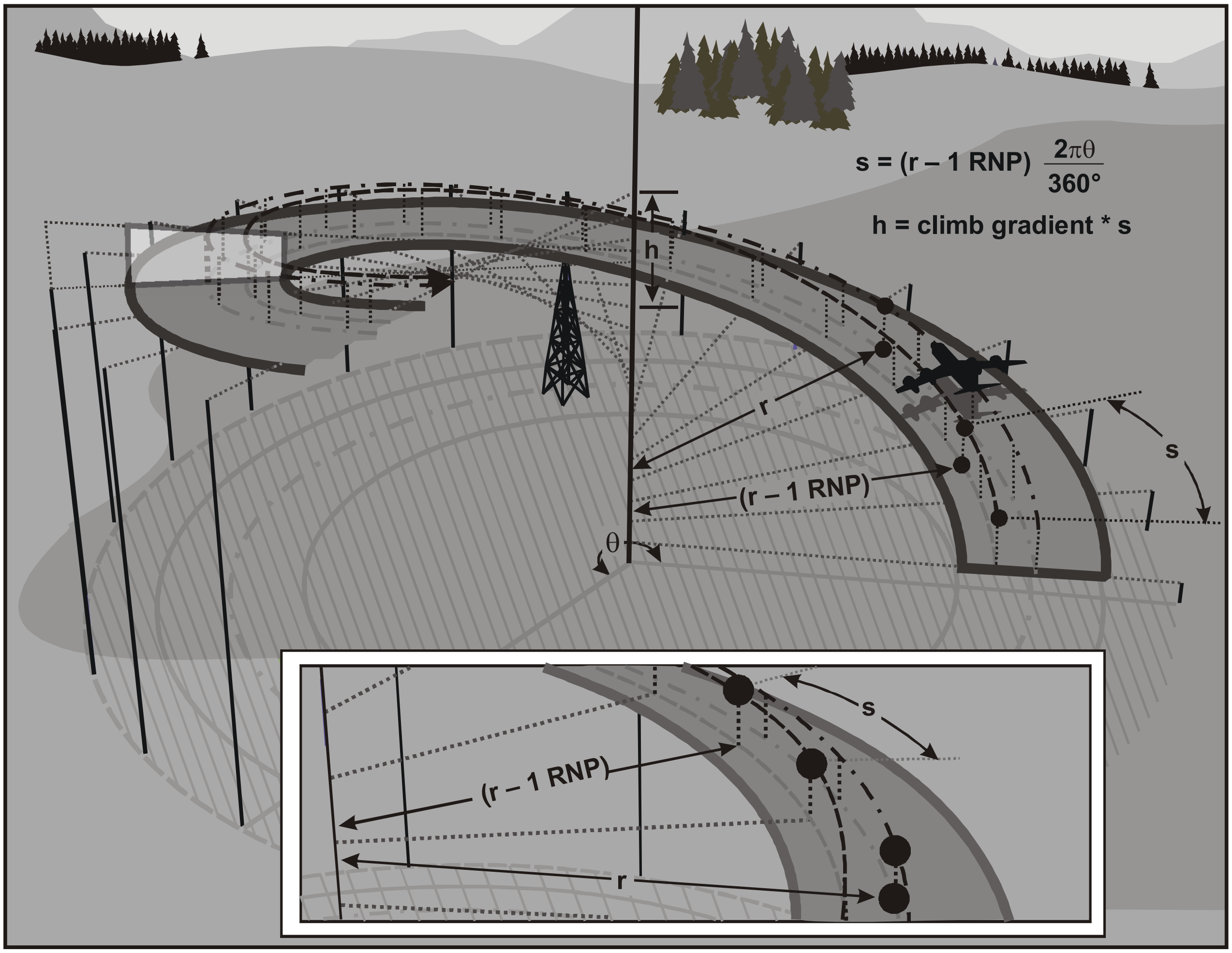

Figure 4-9 b). OCS for RF missed approach segments (MAS)

Mountainous terrain

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

4.2 INITIAL APPROACH SEGMENT

Lateral accuracy value

4.2.1 In the initial approach segment the maximum and the optimum lateral accuracy value is 1.0 NM. The minimum value 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 and to take account of DTA where fly-by turns are required.

4.2.3 Minimum straight segment (any segment) length is 2 × RNP (+DTA, as appropriate, for fly-by turn construction). Paragraph 4.1.10 applies where the lateral accuracy value changes occur (changes 1 × RNP prior to the fix).

4.2.4 The maximum initial segment length (total of all component segments) is 50 NM.

Alignment

4.2.5 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 RNP APCH T- or Y-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 or a Y.

4.2.6 RNAV enables the geometry of approach procedure design to be very flexible. The “Y” 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 4-10 for examples.

4.2.7 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 and Y configurations, offset initial approach fixes (IAFs) are located such that a course change of 70 to 90 degrees is required at the 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 intermediate fix (IF) is 70 degrees or more.

Lateral initial segments

4.2.8 The lateral initial segments are based on course differences of 70 to 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 110 degrees.

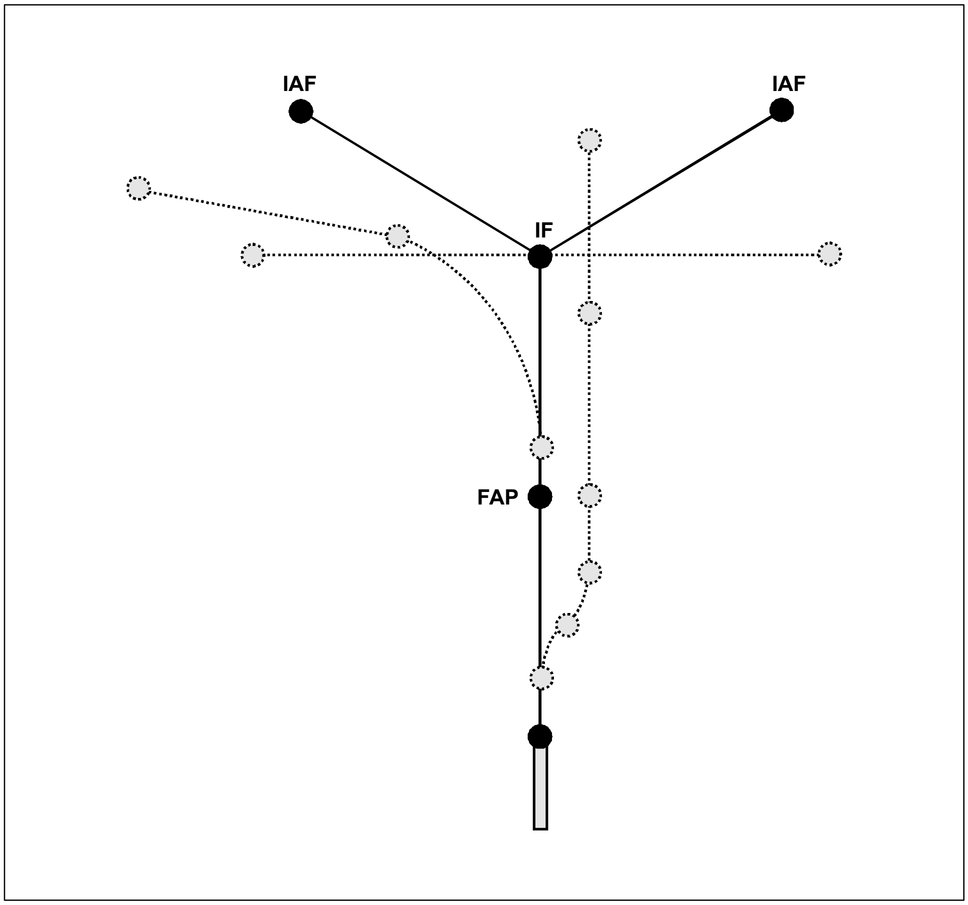

Figure 4-10. Application of basic Y and basic T

Central initial segment

4.2.9 The central initial segment may commence at the IF. It is normally aligned with the intermediate segment. Its capture region is 70 to 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. For turns greater than 110 degrees at the IAFs, sector 1 or 2 entries should be used.

Restricted initial segments

4.2.10 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 IAF to enable entry to the procedure via a procedure turn.

4.3 HOLDING

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

Descent gradient

4.3.2 See Table 4-2 for standard and maximum descent values.

Minimum altitudes

4.3.3 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

4.3.4 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.

4.4 INTERMEDIATE APPROACH SEGMENT

4.4.1 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.

Table 4-2. Descent gradient constraints

Segment	*Descent gradient*	
	Standard	*Maximum*
Arrival	4% (2.4°)	8% (4.7°)
Initial	4% (2.4°)	8% (4.7°)
Intermediate	≤2.5% (1.4°)	Equal to final segment gradient
Final	5.2% (3°)	See Table 4-3

Lateral accuracy value

4.4.2 In the intermediate approach segment, the maximum and optimum lateral accuracy value is 1.0 NM. The minimum value is 0.1 NM.

Length

4.4.3 Segments should be designed with sufficient length to allow the required descent to be as close to the OPTIMUM gradient as possible and accommodate the DTA where fly-by turns are required. Minimum straight segment (any segment) length is: 2 × RNP (+DTA, as appropriate, for fly-by turn constructions). Paragraph 4.1.10 applies where the lateral accuracy value changes occur (RNP value changes 1 RNP prior to fix).

Alignment

4.4.4 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

4.4.5 The optimum descent gradient in the intermediate segment is 2.5 per cent (1.4 degrees). The maximum descent gradient is the same as the maximum final approach gradient. If a descent angle higher than standard is used, the evaluation should ensure that sufficient flexibility is provided for the continuous descent approach (CDA) technique.

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

4.4.7 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).

Table 4-3. Maximum VPA

Aircraft Category	*VPA θ*	*Gradient %*	*Ft/NM*
A < 150 km/h (80 kt)	6.4	11.2	682
150 km/h ≤ A < 167 km/h (80 kt ≤ A < 90 kt)	5.7	9.9	606
B	4.2	7.3	446
C	3.6	6.3	382
D	3.1	5.4	329

Minimum altitude/height

4.4.8 The minimum altitude/height is the height of the highest obstacle within the intermediate approach segment area plus the MOC of 150 m (492 ft).

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

Procedure altitudes/heights

4.4.10 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)

4.4.11 When establishing the intermediate segment minimum altitude (vertical path angle (VPA) intercept altitude), the difference between the 150 m (492 ft) intermediate MOC value and the MOC value provided by the VEB OAS where it reaches the height of the intermediate segment controlling obstruction should be considered.

4.4.12 If the VEB MOC at the height of the controlling obstruction exceeds the intermediate segment MOC, then the VEB MOC value should be applied (see Figures 4-11 and 4-12).

4.4.13 If the VEB is less than the MOC for the intermediate segment at the FAP, the intermediate MOC should be extended into the final segment until intersecting the VEB surface.

Note.— If the minimum altitude has to be raised because of obstacles in the intermediate segment, the FAP must be moved. The VEB must be recalculated and a new minimum altitude derived.

4.5 FAS

4.5.1 FAS lateral guidance is based on RNP. Vertical guidance is based on BARO-VNAV avionics. The FAS OAS (VEB) is based on limiting the vertical error performance of BARO-VNAV avionic systems to stated limits.

Lateral accuracy value

4.5.2 In the FAS the maximum lateral accuracy value is 0.5 NM, the optimum value is 0.3 NM and the minimum value 0.1 NM. The segment should be evaluated for 0.3 NM. A lower than optimum value should only be used if:

a) 0.3 NM results in a DA/H greater than 90 m (295 ft) above LTP; and

b) a significant operational advantage can be obtained.

4.5.3 In these cases, the minimum that may be used is 0.1 NM. Where approaches with RNP values less than 0.3 are published, OCA/H should also be published for RNP 0.3.

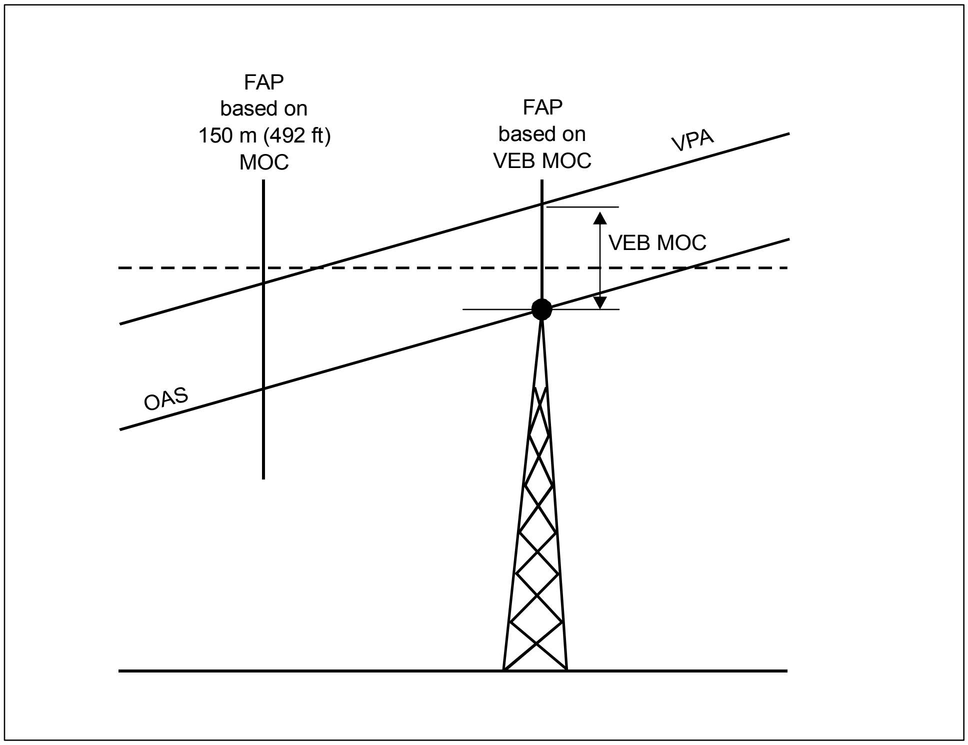

Figure 4-11. Intermediate segment MOC 1

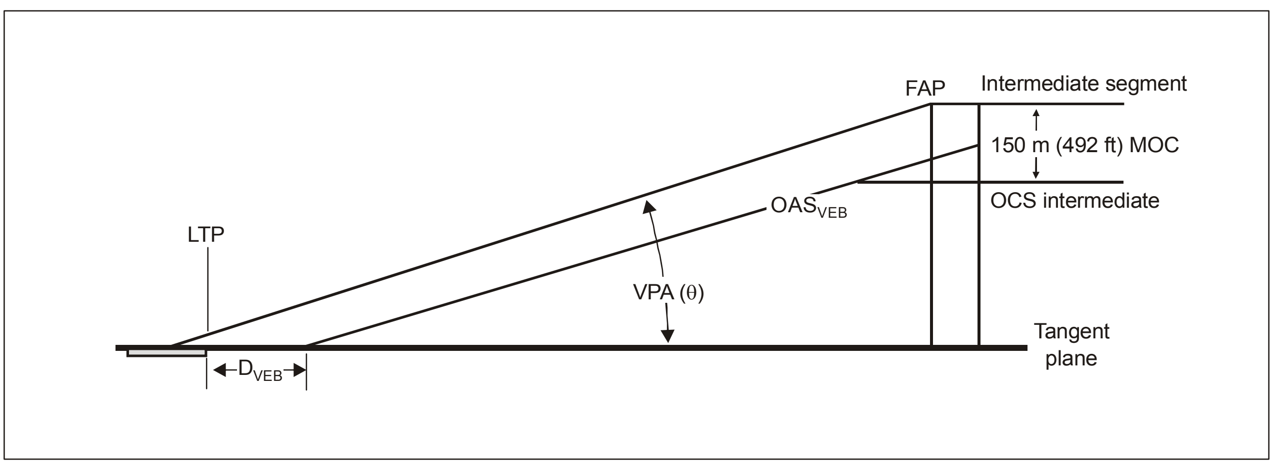

Figure 4-12. Intermediate segment MOC 2

Length

4.5.4 No maximum or minimum is specified. However, the length must accommodate the descent required and must provide a stabilized segment prior to OCA/H.

Alignment

Straight-in approaches

4.5.5 The optimum final approach alignment is a TF segment straight in from FAP to LTP on the extended runway centreline (see Figure 4-13). If necessary, the TF track may be offset by up to five degrees. Where the track is offset, it must cross the extended runway centreline at least 450 m (1 476 ft) before the LTP.

Location of FAP

4.5.6 The FAP is a point on the reciprocal of the true final approach course where the VPA extending from RDH above the LTP (fictitious threshold point (FTP) if offset) intersects the intermediate segment altitude.

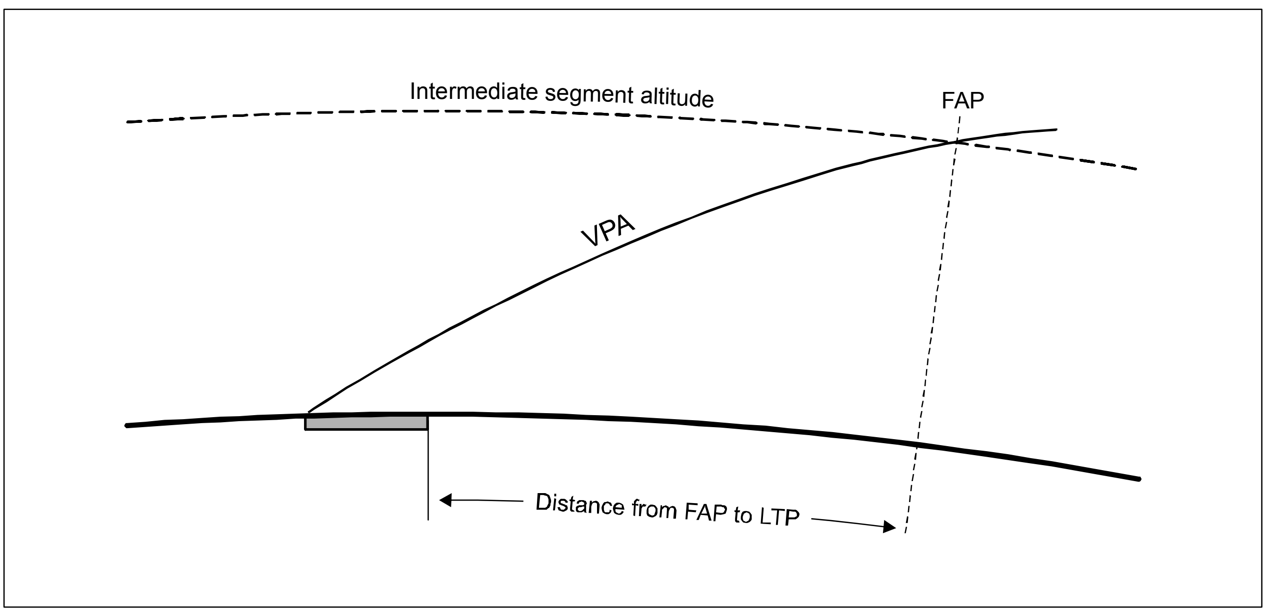

Figure 4-13. FAP to LTP distance

4.5.7 In all cases, the FAP shall be identified as a named fix. The latitude and longitude of the FAP is calculated geodetically from the LTP 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.

4.5.8 Where the final approach consists of a single TF leg, a Microsoft Excel spreadsheet, which is available together with the electronic version of the manual on the ICAO public website (www.icao.int) under "Publications", is provided to calculate D_{FAP} (distance from LTP to FAP) and the WGS-84 latitude and longitude of the FAP (see Figures 4-14 a) and 4-14 b)).

Calculation of FAP-LTP distance

4.5.9 The FAP to LTP distance can be calculated as follows:

$$d = \frac{r_e * \ln\left(\frac{r_e + a}{r_e + b + RDH}\right)}{\tan(VPA)}$$

or

$$d = r_e * \ln[(r_e + a)/(r_e + b + RDH)]/\tan(VPA)$$

where

d = FAP to LTP distance (m or ft, as appropriate)
r_e = (mean earth radius) 6367435.67964 (m) or 20 890 537 (ft), as appropriate
RDH = reference datum height (m or ft, as appropriate)
a = FAP altitude (m or ft, as appropriate)
b = LTP elevation (m or ft, as appropriate)

The calculations are geoidal (rather than ellipsoidal) since the VPA is a pressure gradient determined by the barometric altimeter and is therefore relative to the geoid. The VPA maintains a gradient relative to the earth and follows an arcing path as illustrated in Figure 4-13.

FAP calculator

4.5.10 An FAP calculator is available together with the electronic version of the manual on the ICAO public website (www.icao.int) under "Publications".

Turns in the FAS

4.5.11 A final segment may be designed using an RF leg segment when obstacles or operational requirements prevent a straight-in approach from the FAP to the LTP. Fly-by turns are not allowed. The along-track geodetic distance from the LTP (FTP if offset) to the point the GP intercepts the intermediate segment minimum altitude (D_{FAP}) should be determined and D_{FAP} calculated.

FAP
Calculations

Min Intermediate Segment Alt (a):	500.00	m
LTP MSL Elevation (b):	20.00	m
RDH:	15.00	m
Vertical Path Angle (VPA):	3.00°	
Distance from LTP to FAP (D):	**8,872.36**	m
	4.79 NM	
LTP/FTP Latitude:	036° 30' 00.00"	N
LTP/FTP Longitude:	095° 54' 00.00"	W
True RWY Bearing/True Course:	15.00	
FAP Latitude:	**36° 25' 21.962"**	**N**
FAP Longitude:	**95° 55' 32.181"**	**W**

Latitude/Longitude valid for straight segment only

VEB
OAS Origin & Gradient

	Min Intermediate Segment Altitude:	762.00	m
	LTP Elevation:	16.00	m
	Vertical Path Angle:	3.00	°
-165.00	RDH:	17.00	m
	RNP Value:	0.30	NM
	8 ISA:	-12.44	°
	Straight In Segment		
	(*Wingspan =<80 m*) **LTP to Origin:**	**1042.86**	m
	OAS Gradient :	**0.049845**	
	RF Turn Segment | Bank angle:	**18.00°**	
	(*Wingspan =<80 m*) **LTP to Origin:**	**1138.37**	m
	OAS Gradient :	**0.049845**	

SI UNITS
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VPA
Temperature Limits

Vertical Path Angle:	3.00°	
Max Vertical Path Angle:	3.50°	
FAP Elevation:	762.00 m	
LTP Elevation:	400.00 m	
ACT:	2.44°C	
Min Vertical Path Angle	**2.99°**	
NA Below	**2.44°C**	**36.39°F**
NA Above	**45.46°C**	**113.84°F**
NA Below (2.5°)	**-38.87°C**	**-37.96°F**

VEB MOC

Vertical Path Angle	3.00°	
LTP MSL Elevation	16.00	m
RDH	17.00	m
Tangent of VPA	**0.052408**	
OAS Gradient	**0.049845**	
OAS Origin Distance *(measured along-track from LTP)*	762.00	m
Obstacle Distance *(measured along-track from LTP)*	3,048.00	m
VEB MOC *(at obstacle)*	**63**	m
OAS_{HGT} *(at obstacle)*	**113**	m

Figure 4-14 a). VEB and FAP calculators (SI units)

FAP Calculations

Min Intermediate Segment Alt (a):	5,000.00 ft
LTP MSL Elevation (b):	321.00 ft
RDH:	52.50 ft
Vertical Path Angle (VPA):	3.00°
Distance from LTP to FAP (D):	**88,267.53** ft 14.53 NM
LTP/FTP Latitude:	088° 00' 00.00" N
LTP/FTP Longitude:	167° 55' 48.50" W
True RWY Bearing/True Course:	150.00
FAP Latitude:	**88° 12' 16.420" N**
FAP Longitude:	**171° 46' 37.176" W**

Latitude/Longitude valid for straight segment only

VEB OAS Origin & Gradient

Min Intermediate Segment Altitude:	4500.00	ft
LTP Elevation:	1200.00	ft
Vertical Path Angle:	3.00°	
RDH:	55.00	ft
RNP Value:	0.14	NM
ISA:	-20.00°	
Straight In Segment		
(***Wingspan =<262***) **LTP to Origin:**	**2537.39**	ft
OAS Gradient :	**0.048172**	
RF Turn Segment | Bank angle:	**18.00°**	
(***Wingspan =<262***) **LTP to Origin:**	**2865.18**	ft
OAS Gradient :	**0.048172**	

NON SI UNITS
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VPA Temperature Limits

Vertical Path Angle:	3.00°	
Max Vertical Path Angle:	3.50°	
FAP Elevation:	4500.00 ft	
LTP Elevation:	1200.00 ft	
ACT:	-10.00°C	
Min Vertical Path Angle	**2.84°**	
NA Below	**-10.00°C**	**14.00°F**
NA Above	**47.25°C**	**117.05°F**
NA Below (2.5°)	**-39.32°C**	**-38.78°F**

VEB MOC

Vertical Path Angle	3.00°	
LTP MSL Elevation	1,200.00	ft
RDH	55.00	ft
Tangent of VPA	**0.052408**	
OAS Gradient	**0.048172**	
OAS Origin Distance *(measured along-track from LTP)*	3,811.84	ft
Obstacle Distance *(measured along-track from LTP)*	29,763.55	ft
VEB MOC *(at obstacle)*	**365**	ft
OAS_{HGT} *(at obstacle)*	**1250**	ft

Figure 4-14 b). VEB and FAP calculators (non-SI units)

4.5.12 The leg (TF or RF) on which the FAP is located is determined by comparing this distance with the total length of the FAS.

Requirement for straight segment prior to OCH

4.5.13 Procedures that incorporate an RF leg in the final segment shall establish the aircraft at a final approach roll-out point (FROP) aligned with the runway centreline prior to the greater of:

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

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

Non-SI units: $D_{492} = \dfrac{492 - RDH}{\tan(VPA)}$

b) a minimum distance before OCA/H is calculated as in 4.5.14 (see Figures 4-15 and 4-16).

4.5.14 TAS based on the IAS for the fastest aircraft category for which the procedure is designed at ISA + 15^{o} C at aerodrome elevation, plus a 15-kt tailwind for a time of:

a) 15 seconds where the missed approach is based on RNP 1.0 or greater:

SI units: $D_{15sec} = \dfrac{HATh - RDH}{\tan(VPA)} + (V_{TAS} + 27.78) * 4.167$

Non-SI units: $D_{15sec} = \dfrac{HATh - RDH}{\tan(VPA)} + (V_{TAS} + 15) * 25.317$

b) 50 seconds where the missed approach RNP is less than 1.0 or where the missed approach is based on RNP APCH:

SI units: $D_{50sec} = \dfrac{HATh - RDH}{\tan(VPA)} + (V_{TAS} + 27.78) * 13.89$

Non-SI units: $D_{50sec} = \dfrac{HATh - RDH}{\tan(VPA)} + (V_{TAS} + 15) * 84.39$

Note.— The HATh is the height above threshold of the OCH or DH, as appropriate.

Identification of FAP within an RF segment

4.5.15 Where the FAP must be located within an RF segment, the segment must be broken into two segments, each having the same radius and turn centre, with the FAP coincident with the initial fix of the second segment. Determine the flight track distance (D_{FAP}) from LTP to FAP under the formula in 4.5.9. The length of the RF leg ($LENGTH_{RF}$) from the FROP to FAP can be calculated by subtracting distance to the final approach roll-out point (D_{FROP}) from D_{FAP}.

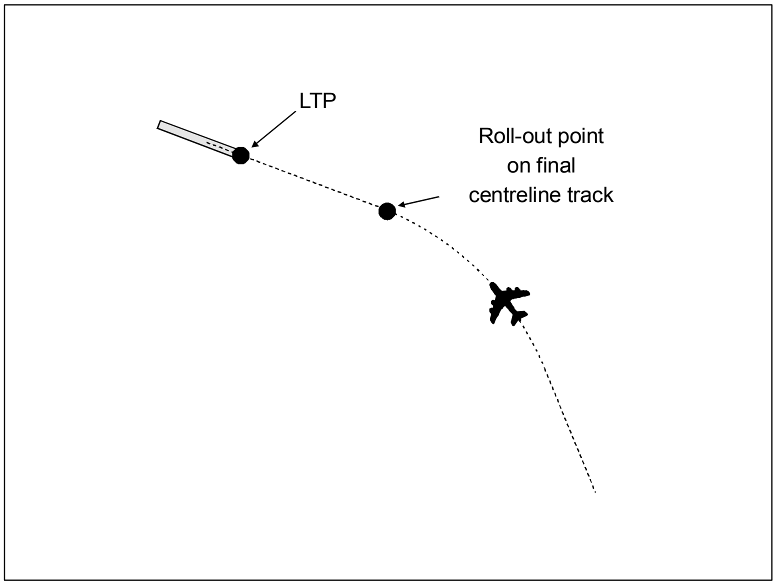

Figure 4-15. FROP

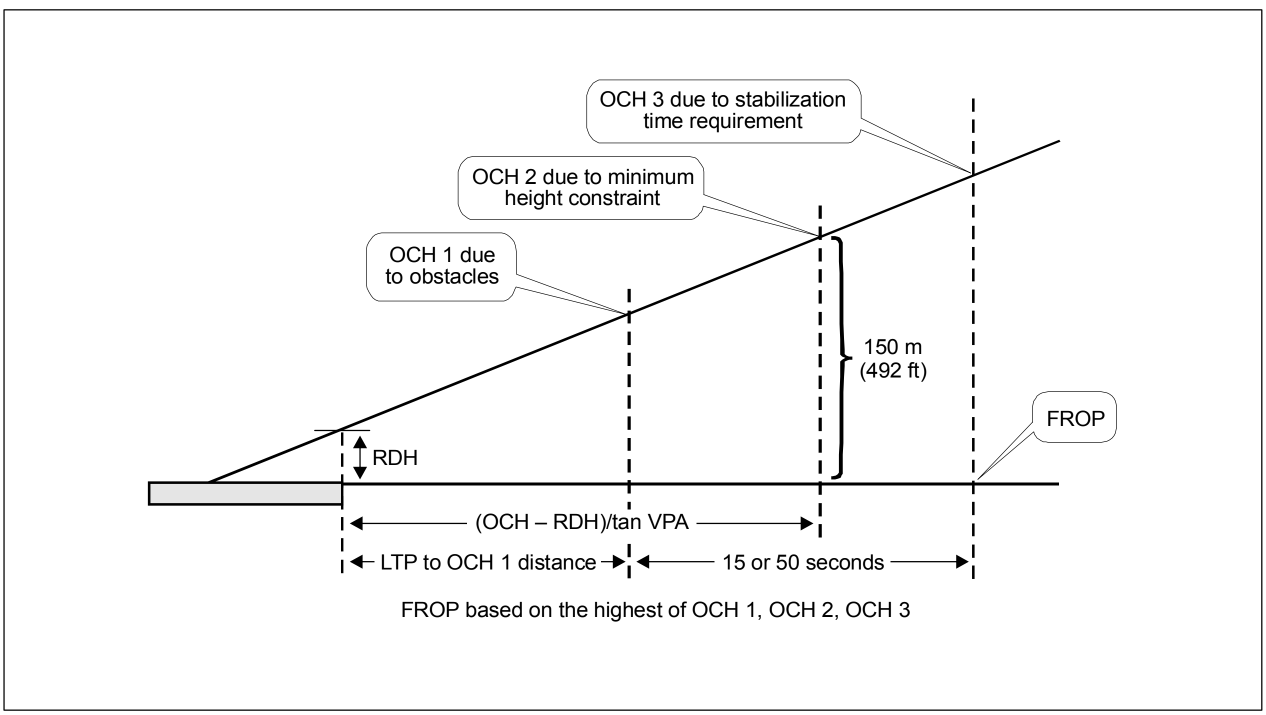

Figure 4-16. Constraints on OCH and FROP

4.5.16 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

4.5.17 This method may be used for calculating WGS-84 latitude and longitude (see Figure 4-17). 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 4.5.9.

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.

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

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

$Y = r – r * \cos A$

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

A = turn angle

4.5.19 The turn altitude is determined by projecting the glide path from RDH out to the IAF along the fix-to-fix flight track. The turn altitude is the altitude of the GP at the fix or the minimum fix altitude, whichever is higher.

System limitation based on radio altimeter (RA) height

4.5.20 The flight control computers (FCCs) in some aircraft limit bank angles when the aircraft is below 122 m (400 ft) radio altitude. If an obstacle or terrain in any portion of the turn area is higher than the altitude of the nominal approach track perpendicular to the obstacle or terrain minus 122 m (400 ft), (obstacle elevation greater than nominal track altitude – 122 m (400 ft)), then the FCC bank angle limitation of five degrees should be used in the turn calculation.

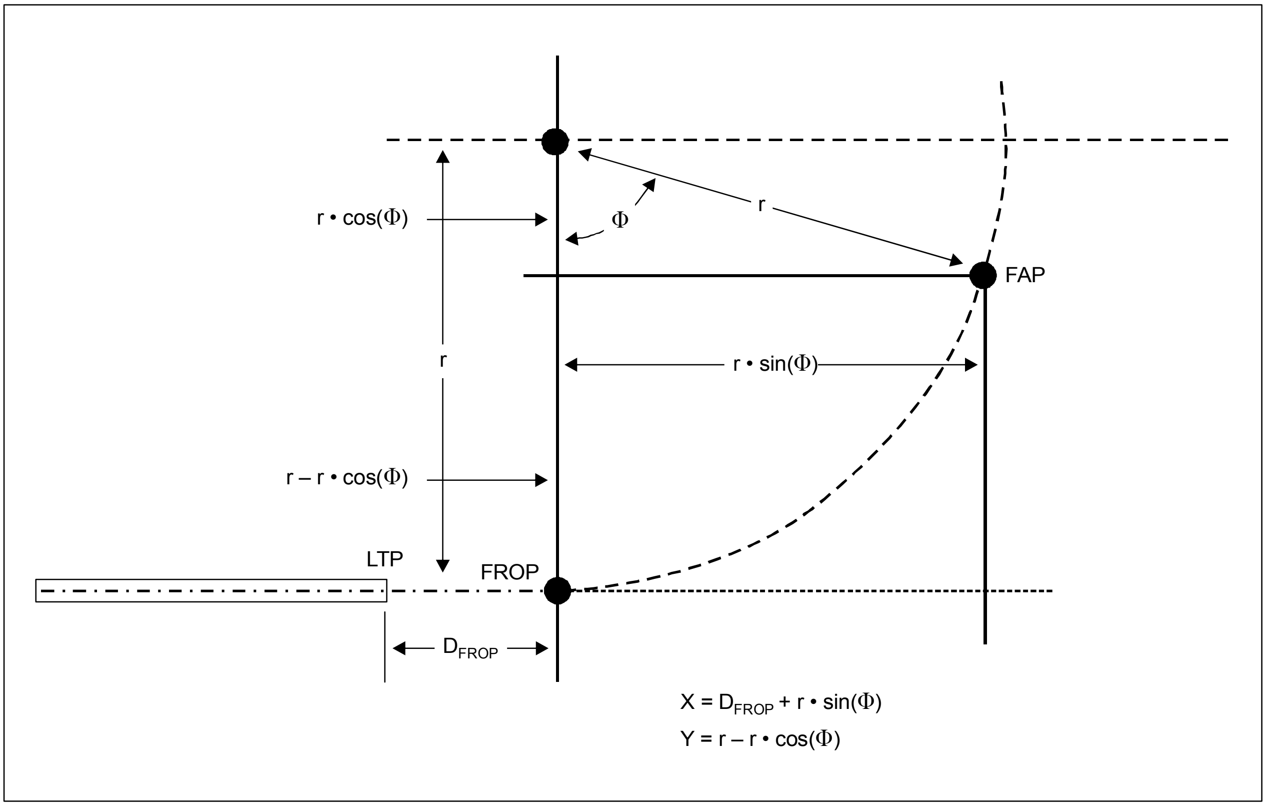

Figure 4-17. FAP within an RF leg

VPA requirements

4.5.21 The minimum standard design VPA is 3 degrees. VPAs higher than 3 degrees shall be used only:

a) where obstacles prevent use of 3 degrees, or

b) when cold temperatures reduce the effective VPA below a minimum value of 2.75 degrees.

4.5.22 Table 4-3 lists the highest allowable VPA by aircraft category. If the required VPA is greater than the maximum for an aircraft category, OCA/H for that category should not be published.

4.5.23 The GP angle should not result in a descent rate (DR) greater than a nominal 300 m/min (1 000 ft/min) for aircraft served by the procedure.

RDH values and recommended ranges for aircraft categories

4.5.24 RDH values and recommended ranges of values appropriate for aircraft categories A to D. RNP AR procedures serving the same runway should share common RDH and GP angle values. If an ILS serves the runway, the ILS RDH and GP angle values should be used to define the VPA. If there is no ILS, but a visual glide slope indicator (VGSI) system with a suitable RDH and GP angle serves the runway, the VGSI RDH and VPA equal to the GP angle should be used. Otherwise, an appropriate RDH value from Table 4-4 should be selected, with a three-degree VPA.

Note.— A note must be published on the approach chart indicating when the VGSI angle is more than 0.2 degrees from the VPA or when the VGSI RDH differs from the procedure RDH by more than 1 m (3 ft), e.g. PAPI not coincident with VPA.

Effect of temperature on VPA

4.5.25 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 standard ISA associated with airport elevation. The high temperature limit attempts to prevent exceeding a DR of 300 m/min (1 000 ft/min). 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.

$$ISA_{airport}C° \text{ (SI units) } = 15 - \left(\frac{0.00198 * Airport_{elev}}{0.3048}\right)$$

$$ISA_{airport}C° \text{ (non-SI units) } = 15 - \left(0.00198 * Airport_{elev}\right)$$

Table 4-4. RDH requirements

Aircraft Category	*Recommended RDH ±5 ft*	*Remarks*
A	12 m (40 ft)	Many runways less than 1 800 m (6 000 ft) long with reduced widths and/or restricted weight bearing would normally prohibit landings by larger aircraft.
B	14 m (45 ft)	Regional airport with limited air carrier service.
C, D	15 m (50 ft)	Primary runways not normally used by aircraft with aircraft reference point-to-wheel heights exceeding 6 m (20 ft).
E	17 m (55 ft)	Most primary runways at major airports.

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 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

4.5.26 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 4-18.)

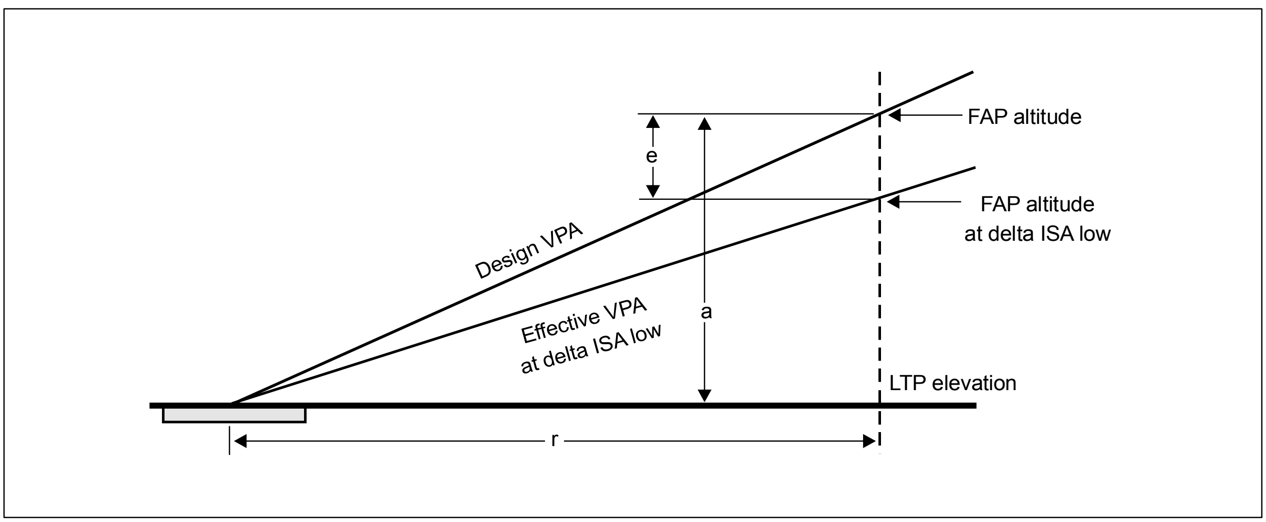

Figure 4-18. Effective VPA cold temperature

Low temperature limit

4.5.27 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 GP for the aircraft.

4.5.27.1 If the temperature history for the location indicates the low temperature limitation is frequently encountered during established busy recovery times, consideration should be given to raising the GP angle to the lowest angle (within the limits of Table 4-3) that will make the approach more frequently usable.

4.5.27.1.1 The minimum VPA is the larger of 2.5 degrees, or

$$Min_{VPA} = \arctan\left(\frac{a+e}{r}\right)$$

where

a = FAP altitude – LTP elevation (m or ft, as appropriate)

e (Si units) = ΔISA_{LOW} * [(0.19 * 0.3048) + (0.0038 * a)] + (0.032 * a) + (4.9 * 0.3048), or

e (non-Si units) = ΔISA_{LOW} * [0.19 + (0.0038 * a)] + (0.032 * a) + 4.9

$$r = \frac{a}{\tan(VPA)}$$

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

$$\Delta ISA_{LOW}\text{ (SI units)} = \frac{-el-(0.032*a)-(4.9*0.3048)}{(0.19*0.3048)+(0.0038*a)}$$

$$\Delta ISA_{LOW}\text{ (non-SI units)} = \frac{-el-(0.032*a)-4.9}{0.19+(0.0038*a)}$$

where

el = FAP altitude – b

b = r * tan(2.5°) + LTP elevation

$$r = \frac{a}{\tan(VPA)}$$

a = FAP altitude – LTP elevation (m or ft, as appropriate)

4.5.27.1.3 Determine the published low temperature limitation “NA below” for the procedure using the ΔISA_{LOW} derived from the equation in 4.5.27.1.2 in the following formula:

NA below = ISA + ΔISA_{LOW}

Note.— If the temperature history for the location indicates the low temperature limitation is frequently encountered during established busy recovery times, consider raising the VPA to the lowest angle that will make the approach usable more often.

Calculation of maximum effective VPA

4.5.28 The maximum effective VPA 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 increased angle from the origin of the VPA at threshold level (see Figure 4-19).

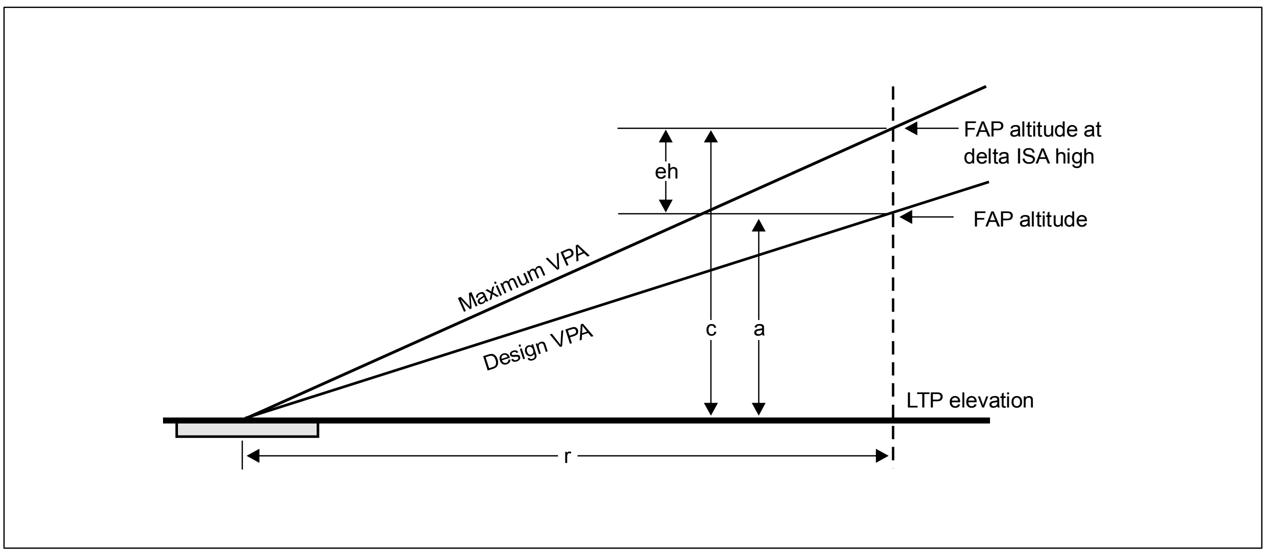

Figure 4-19. Effective VPA hot temperature

4.5.28.1 To accomplish this, determine the maximum ΔISA_{High} (above ISA) that will produce the maximum allowed VPA using one of the following formulas:

$$\Delta ISA_{High}\text{ (SI units)} = \frac{eh - (0.032 * a) - (4.9 * 0.3048)}{(0.19 * 0.3048) + (0.0038 * a)}$$

$$\Delta ISA_{High}\text{ (non-SI units)} = \frac{eh - (0.032 * a) - 4.9}{0.19 + (0.0038 * a)}$$

where

eh = c – FAP altitude

c = r * tan (α) + LTP elevation

α = maximum allowed VPA

a = FAP altitude – LTP elevation

$$r = \frac{a}{\tan(VPA)}$$

4.5.28.2 The maximum effective VPA angle is 1.13 times the Table 4-3 maximum design value for the fastest published approach category. If the calculated effective VPA exceeds this, then the published maximum temperature must be restricted to a lower value. Determine NA_{above} with the following formula:

$$NA_{above} = ISA + \Delta ISA_{High}$$

VEB

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

Final approach OAS

4.5.30 The distance of the final approach OAS origin from LTP (D_{VEB}) and its slope are defined by the VEB. Two Microsoft Excel spreadsheets (see Figures 4-20 a) and 4-20 b)) that perform VEB calculations are available together with the electronic version of the manual on the ICAO public website (www.icao.int) under “Publications”.

Note.— In case of RNP reduction in segments where the VEB is applied, the maximum RNP value shall be used in VEB calculation.

FAP
Calculations

Min Intermediate Segment Alt (a):	500.00	m
LTP MSL Elevation (b):	20.00	m
RDH:	15.00	m
Vertical Path Angle (VPA):	3.00°	
Distance from LTP to FAP (D):	**8,872.36**	m
	4.79 NM	
LTP/FTP Latitude:	036° 30' 00.00"	N
LTP/FTP Longitude:	095° 54' 00.00"	W
True RWY Bearing/True Course:	15.00	
FAP Latitude:	**36° 25' 21.962"**	**N**
FAP Longitude:	**95° 55' 32.181"**	**W**

Latitude/Longitude valid for straight segment only

VEB
OAS Origin & Gradient

Min Intermediate Segment Altitude:	762.00	m
LTP Elevation:	16.00	m
Vertical Path Angle:	3.00	°
-165.00 RDH:	17.00	m
RNP Value:	0.30	NM
Ξ ISA:	-12.44	°
Straight In Segment		
(*Wingspan =<80 m*) **LTP to Origin:**	**1042.86**	m
OAS Gradient :	**0.049845**	
RF Turn Segment | Bank angle:	**18.00°**	
(*Wingspan =<80 m*) **LTP to Origin:**	**1138.37**	m
OAS Gradient :	**0.049845**	

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VPA
Temperature Limits

Vertical Path Angle:	3.00°	
Max Vertical Path Angle:	3.50°	
FAP Elevation:	762.00 m	
LTP Elevation:	400.00 m	
ACT:	2.44°C	
Min Vertical Path Angle	**2.99°**	
NA Below	**2.44°C**	**36.39°F**
NA Above	**45.46°C**	**113.84°F**
NA Below (2.5°)	**-38.87°C**	**-37.96°F**

VEB MOC

Vertical Path Angle	3.00°	
LTP MSL Elevation	16.00	m
RDH	17.00	m
Tangent of VPA	**0.052408**	
OAS Gradient	**0.049845**	
OAS Origin Distance *(measured along-track from LTP)*	762.00	m
Obstacle Distance *(measured along-track from LTP)*	3,048.00	m
VEB MOC *(at obstacle)*	**63**	m
OAS_{HGT} *(at obstacle)*	**113**	m

Figure 4-20 a). VEB spreadsheet (SI units)

FAP
Calculations

Min Intermediate Segment Alt (a):	5,000.00	ft
LTP MSL Elevation (b):	321.00	ft
RDH:	52.50	ft
Vertical Path Angle (VPA):	3.00°	
Distance from LTP to FAP (D):	**88,267.53**	ft
	14.53 NM	
LTP/FTP Latitude:	088° 00' 00.00" N	
LTP/FTP Longitude:	167° 55' 48.50" W	
True RWY Bearing/True Course:	150.00	
FAP Latitude:	**88° 12' 16.420" N**	
FAP Longitude:	**171° 46' 37.176" W**	

Latitude/Longitude valid for straight segment only

VEB
OAS Origin & Gradient

Min Intermediate Segment Altitude:	4500.00	ft
LTP Elevation:	1200.00	ft
Vertical Path Angle:	3.00°	
RDH:	55.00	ft
RNP Value:	0.14	NM
□ ISA:	-20.00°	

Straight In Segment

(*Wingspan =<262*) **LTP to Origin:**	**2537.39**	ft
OAS Gradient :	**0.048172**	
RF Turn Segment | Bank angle:	**18.00°**	
(*Wingspan =<262*) **LTP to Origin:**	**2865.18**	ft
OAS Gradient :	**0.048172**	

NON SI UNITS
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VPA
Temperature Limits

Vertical Path Angle:	3.00°	
Max Vertical Path Angle:	3.50°	
FAP Elevation:	4500.00 ft	
LTP Elevation:	1200.00 ft	
ACT:	-10.00°C	
Min Vertical Path Angle	**2.84°**	
NA Below	**-10.00°C**	**14.00°F**
NA Above	**47.25°C**	**117.05°F**
NA Below (2.5°)	**-39.32°C**	**-38.78°F**

VEB MOC

Vertical Path Angle	3.00°	
LTP MSL Elevation	1,200.00	ft
RDH	55.00	ft
Tangent of VPA	**0.052408**	
OAS Gradient	**0.048172**	
OAS Origin Distance *(measured along-track from LTP)*	3,811.84	ft
Obstacle Distance *(measured along-track from LTP)*	29,763.55	ft
VEB MOC *(at obstacle)*	**365**	ft
OAS_{HGT} *(at obstacle)*	**1250**	ft

Figure 4-20 b). VEB spreadsheet (Non-SI units)

4.5.31 The height of the OAS at any distance “x” from the LTP can be calculated as follows:

$$OAS_{HGT} = (r_e + LTP)e^f - r_e - LTP$$

where

$$f = \frac{(x - D_{VEB}) * OAS_{gradient}}{r_e}$$

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

x = distance from LTP to obstacle (m or ft, as appropriate)

D_{VEB} = distance from LTP to the LTP level intercept of the VEB OAS (m or ft, as appropriate)

r_e = (mean earth radius) 6367435.67964 (m) or 20 890 537 (ft), as appropriate

$OAS_{gradient}$ = value as derived from Appendix 1 or 2, as appropriate

Note.— D_{VEB} and tan final approach OAS are both obtained from Appendix 1 (SI units) or Appendix 2 (non-SI units).

Adjustment for aircraft body geometry (bg)

4.5.32 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 (25 ft) for all aircraft. Additional adjustment for bg during a bank is calculated as follows:

bg = 40 * sin(bank angle) m; or

bg = 132 * sin(bank angle) ft

The optimum bank angle equals 18 degrees; however, other bank angles may be applied for specific aircraft. The adjustment 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 4-21.

Interaction of VPA with VEB

4.5.33 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. To determine the OAS height and VEB MOC (at obstacle), use the following formulas:

$$OAS_{Hgt(Obs)} = (r_e + LTP_{elev}) \bullet e^p - r_e - LTP_{elev}$$

$$VEB_{MOC} = e^q \bullet (r_e + LTP_{elev} + RDH) - r_e - OAS_{Hgt(Obs)}$$

where

r_e = (mean earth radius) 6367435.67964 (m) or 20 890 537 (ft), as appropriate

LTP_{elev} = LTP elevation (m or ft, as appropriate)

OBS_x = distance from LTP to obstacle (m or ft, as appropriate)

D_{origin} = distance from LTP to OAS origin (m or ft, as appropriate)

OAS_{grad} = OAS gradient, as derived from Appendix 1 or 2 (m or ft, as appropriate)

$$p = \frac{OBS_x - D_{origin}}{r_e \bullet \left(\frac{1}{OAS_{grad}} \right)}$$

$$q = \frac{OBS_x \bullet \tan(VPA)}{r_e}$$

4.6 MISSED APPROACH SEGMENT (MAS)

4.6.1 The MAS begins at the point of the OCA/H on the VPA and terminates at the point at which a new approach, holding or return to en-route flight is initiated.

General principles

4.6.2 The considerations of missed approach design options follow this order:

a) Standard missed approach using RNP 1.0;

b) RNAV missed approach using RNP APCH. Reversion to RNP APCH is used only if a significant operational advantage is achieved; and

c) Use of levels less than RNP 1.0. (See Figure 4-22.)

4.6.3 The missed approach OAS (Z) is 2.5 per cent with provision for additional gradients of up to 5 per cent 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 must also be made available.

4.6.4 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.

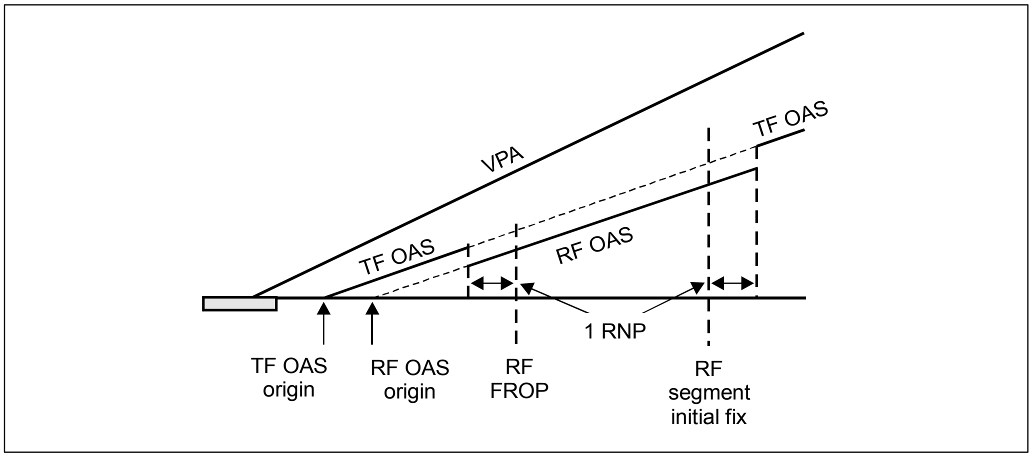


Figure 4-21. OAS adjustment for TF and RF legs

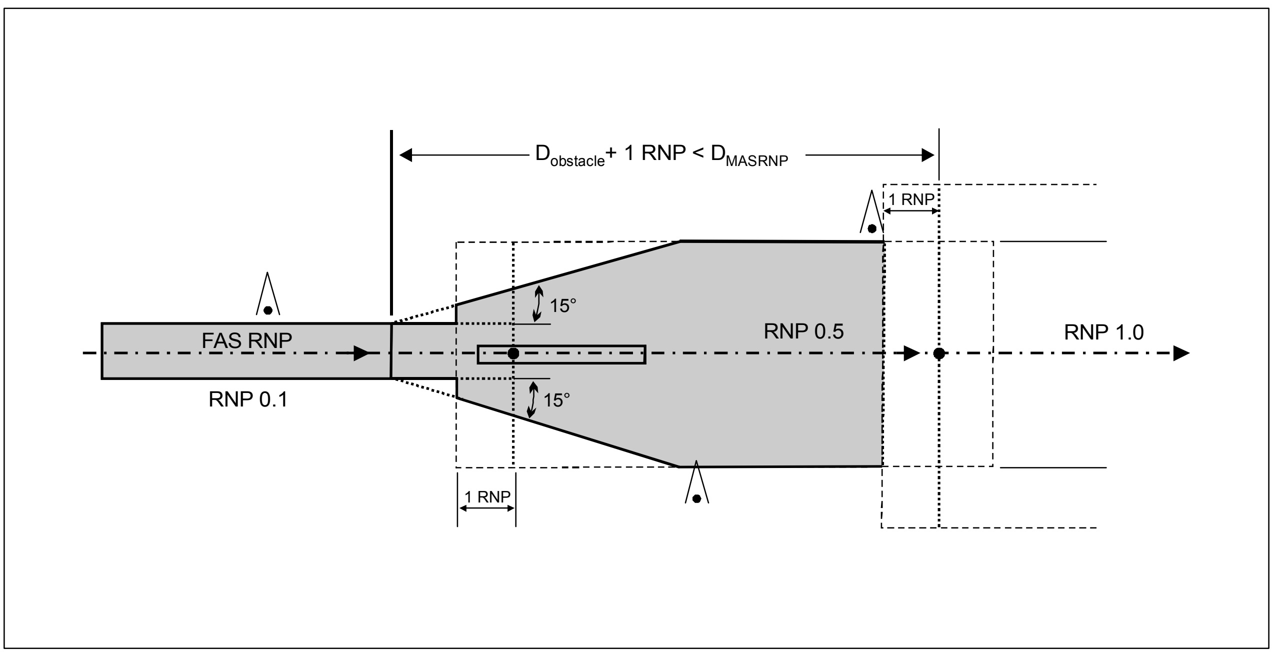


Figure 4-22. Maximum extension of RNP < 1.0 in the missed approach

4.6.5 For missed approaches using levels less than RNP 1.0 (see Figure 4-22), the following constraints apply:

a) Aircraft are required to follow the designed missed approach track regardless of the point from which the go-around is initiated;

b) Extension of final approach levels less than RNP 1.0 into the MAS is limited (see 4.6.17);

c) For RNP levels less than RNP 1, turns are not allowed below 150 m (492 ft) AGL;

d) Missed approach levels less than RNP 1.0 may limit the population of aircraft that can fly the procedure and should be implemented only where necessary. If applied, a charting note is required; and

e) A DA/H is specified and a note is added to the approach chart cautioning against early transition to a missed approach RNP for guidance.

Lateral accuracy values for missed approach

4.6.6 The standard MAS splays from the FAS width at OCA/H or DA/H, as appropriate, at 15 degrees relative to course centreline, to a width of ±2 NM (RNP 1.0). (See Figure 4-23.)

4.6.7 Turns are not allowed until the splay is complete. If turns are required before D_{splay}, consider another construction technique, e.g. reducing the MAS lateral accuracy (RNP) values below 1.0.

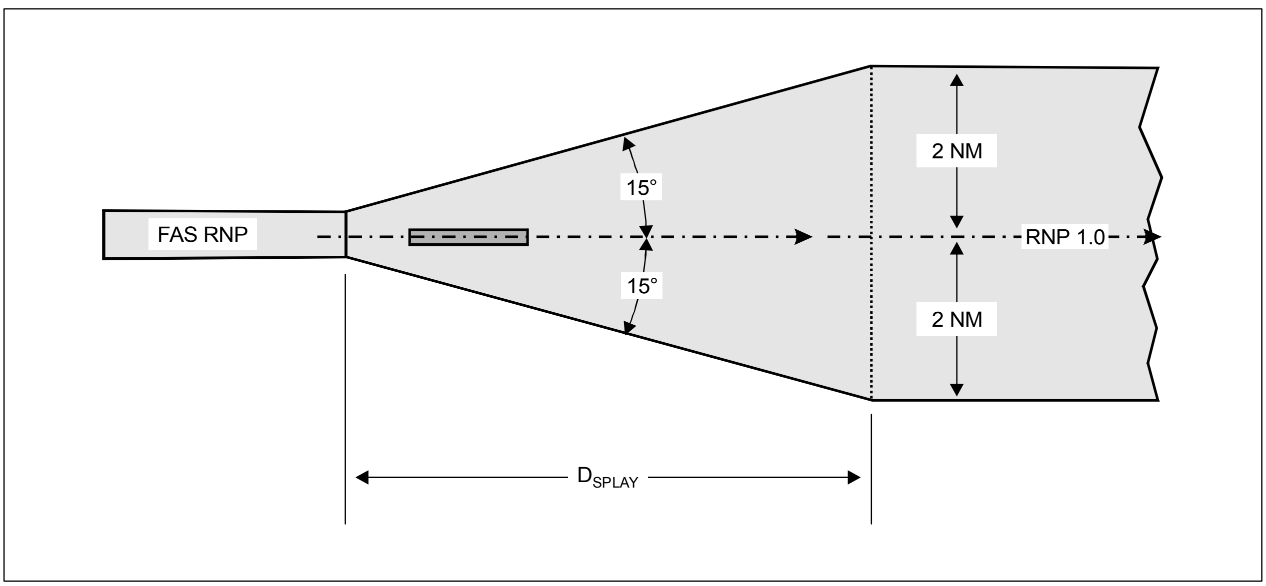


Figure 4-23. Missed approach splay

Missed approach OAS (Z surface).

4.6.8 See Figures 4-24, 4-25 and 4-26 for illustration of the following process.

Calculation of the start of climb (SOC)

Range of the SOC

4.6.9 The range of the start of climb (SOC) relative to LTP is:

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

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 = vertical path reference 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, calculated at aerodrome elevation and ISA + 15 plus a 19 km/h (10 kt) tailwind

anpe = 1.225 × RNP (99.7 per cent along-track error)

wpr = 18.3 m (60 ft) (99.7 per cent waypoint resolution 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.

Height of the SOC

4.6.10 The height of the SOC above LTP 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

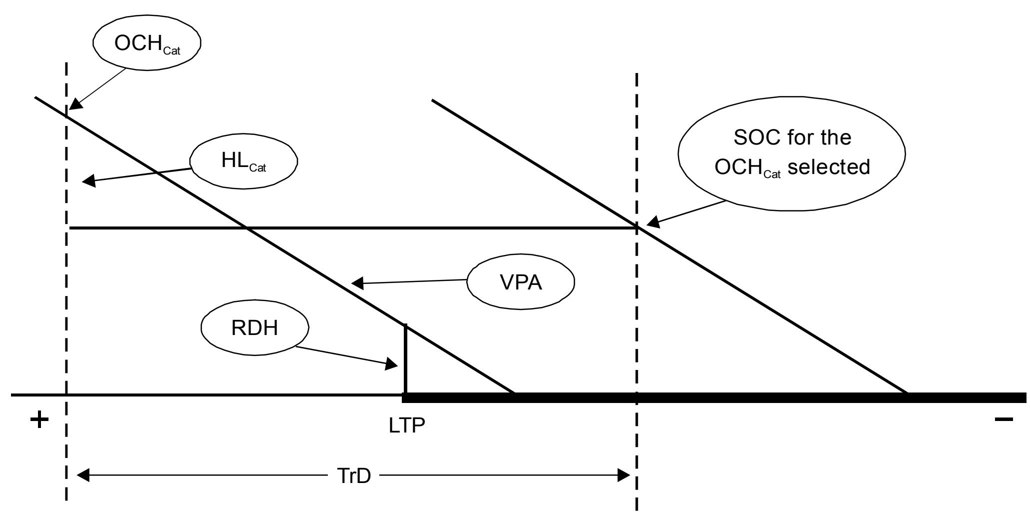
Gradient

4.6.11 A nominal missed approach climb surface gradient (tan Z) of 2.5 per cent is specified by the procedure. Additional gradients of up to 5 per cent may also be specified as described in 4.6.2. These may be used 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.

Permitted leg types

4.6.12 The missed approach route is a series of segments. The following leg types are permitted: TF and RF.

4.6.13 Additionally, if the RF leg RNP value is <1.0, the RF leg length must comply with the requirements of 4.6.17 relating to “Missed approach RNP < 1.0 and promulgation of the maximum DA/H”.



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

Figure 4-24. Determination of SOC

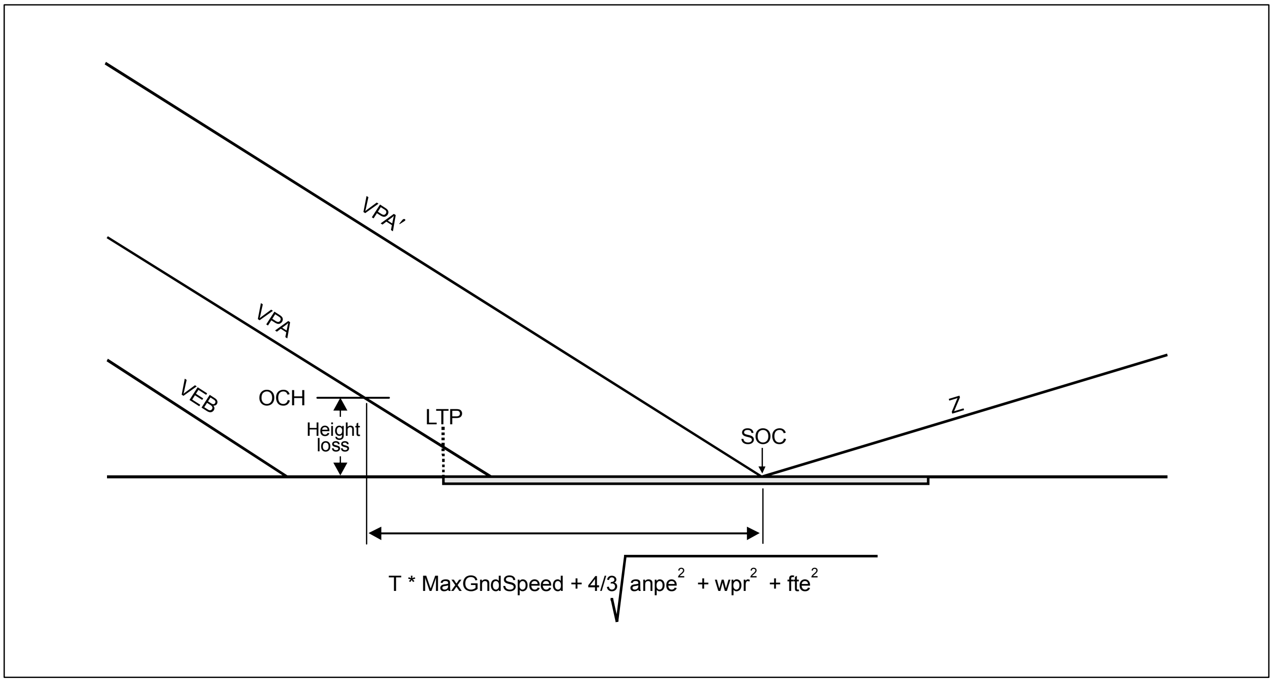


Figure 4-25. Missed approach surface (Z)

Turning missed approach

4.6.14 The number and magnitude of turns add complexity to a procedure; therefore, their use should be limited. Where turns are required in the missed approach, the FAS track should continue to be maintained to the departure end of runway (DER) (or the equivalent in an offset procedure). The first turn must not occur before the DER unless the missed approach RNP is less than RNP 1.0.

4.6.15 If the missed approach level is less than RNP 1.0, missed approach RF 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 DER.

4.6.16 In certain circumstances, neither a reduced RNP nor an RF turn can overcome a straight-ahead missed approach obstacle. In these circumstances, the RNP procedure can be terminated and a standard global navigation satellite system (GNSS) RNP APCH missed approach constructed. In this case, the area splay for the Z surface begins 1 RNP (final approach) prior to the longitudinal location of the OCA/H on the VPA, or 75 m (250 ft) on the VPA, whichever is higher, and splays at 15 degrees on each side.

Note.— A heading to altitude (ARINC leg type) (VA) leg based on a GNSS missed approach (RNP APCH) can provide better clearance margin from a straight ahead missed approach obstacle than either RF or fly-by turns.

Missed approach RNP < 1.0 and promulgation of the DA/H (see Figure 4-25)

4.6.17 Where the OCA/H is defined by missed approach obstacles, the missed approach RNP value may be limited until past the obstruction. The largest RNP value (of FAS RNP or MAS RNP <1.0) that clears the obstruction should be used. However, the DA/H is promulgated rather than OCA/H and is limited to 75 m (246 ft), (90 m (295 ft)) or higher. The chart must be annotated that "Transition to missed approach RNP for lateral guidance must not be initiated prior to the along-track position of the DA/H".

Maximum length of RNP < 1.0 in the missed approach

4.6.18 The maximum distance (D_{MASRNP}) that a lateral accuracy value <1.0 NM may be extended into the missed approach measured from the point where the DA/H intersects the VPA is:

D_{MASRNP} = (RNP missed approach – RNP final approach)*cot inertial reference unit (IRU) splay

where

for NM measure, cot IRU Splay = TAS/8 kt

for km measure, cot IRU Splay = TAS/14.816 km/h

TAS = initial missed approach speed for the aircraft category for the aerodrome elevation at ISA + 15

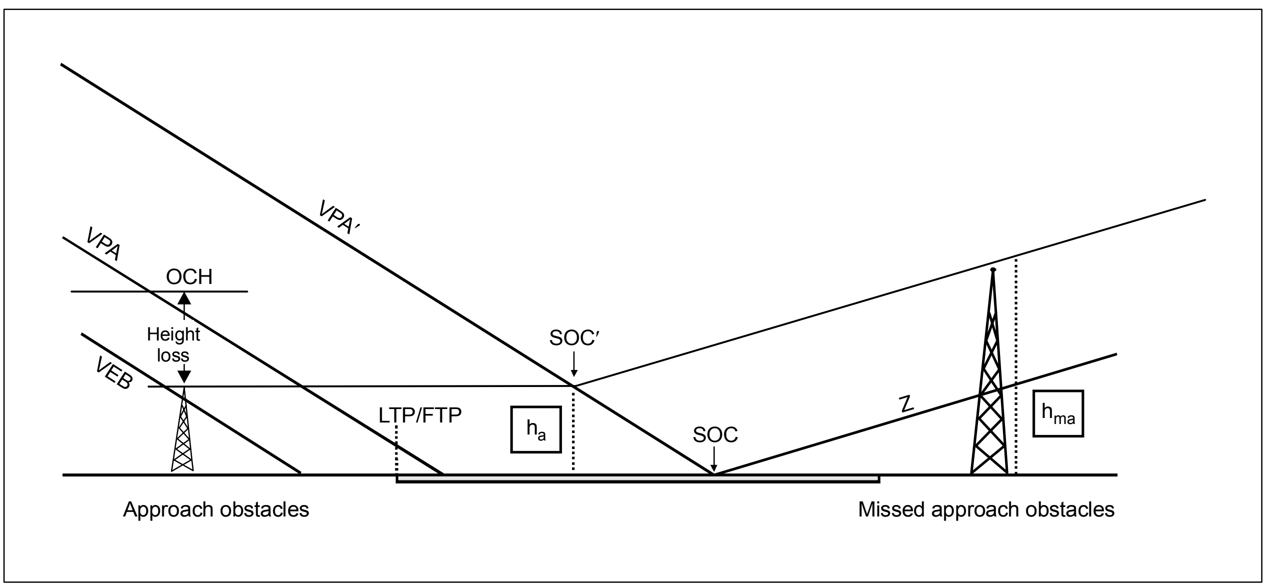


Figure 4-26. Missed approach obstacle after SOC

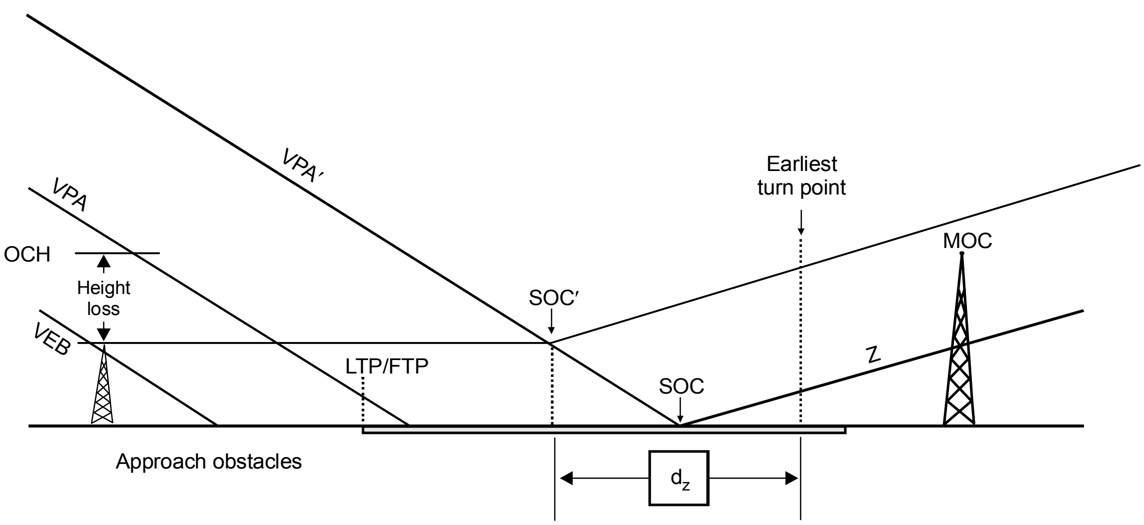
Note.— The specification of a DA/H and a distance ensures that an eight degrees per hour IRU drift rate does not exceed the extended final approach RNP boundary.

Turn restriction with RNP <1.0 in the missed approach

4.6.19 Where turns are necessary, the turn initiation must occur after passing 150 m (492 ft) AGL and at least $D_{MASturn}$ after DA/H. When possible, the turn should not occur until after DER.

4.7 DETERMINATION OF OCA/H

4.7.1 OCA/H calculation involves a set of OAS. If the OAS is penetrated, the aircraft category-related height loss allowance is added to the height of the highest approach obstacle or the equivalent height of the largest missed approach OAS penetration, whichever is greater. This value becomes the OCA/H (see Figures 4-26 and 4-27).



Note.— d_o = d_z + shortest distance from obstacle to line K – K′

Figure 4-27. Turning missed approach

Accountable obstacles

4.7.2 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 between the FAP and the SOC.

- Missed approach obstacles are those after the SOC.

4.7.3 However, in some cases this categorization of obstacles may produce an excessive penalty for certain missed approach obstacles. Where desired by the appropriate authority, missed approach obstacles may be defined as those above a plane surface parallel to the plane of the VPA and with origin at the SOC, i.e., obstacle height greater than (XSOC + x)tan VPA, where XSOC is the distance from LTP to the SOC.

OCH calculation

4.7.4 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.

4.7.5 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

X_Z = X coordinate of the point where $Z_X = Z_{LTP}$ (origin of the missed approach surface).

4.7.6 MOC is 0 m/(0 ft) for a straight missed approach and RF turns; 30 m/(98 ft) for turns up to 15 degrees; 50 m/(164 ft) for turns greater than 15 degrees.

Straight missed approach

4.7.7 Determine OCH for the procedure by adding the height loss allowance defined in Table 4-5, to the height of the highest approach obstacle (real or equivalent).

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

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

4.7.8 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 4-26 and 4-27)

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.

4.7.9 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

4.7.10 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 – 1RNP. (See Figures 4-9 b) and 4-28).

4.7.11 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.

4.7.12 Obstacle elevation/height shall be less than

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

where

d_o = is the distance measured along the arc(s), calculated for RF legs using a radius of (r – 1RNP),

d_z = horizontal distance from SOC to the turning fix.

MOC applied in the formula calculating h_a is 0 for RF missed approach legs.

4.7.13 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

4.7.14 The height loss margins in Table 4-5 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

4.7.15 Procedures involving VPAs greater than 3.5 degrees or any angle when the nominal rate of descent (V_{at} for the aircraft type x´ 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) adjustment of the origin of the missed approach surface;

c) adjustment of the slope of the W surface;

d) re-survey of obstacles; and

e) the application of related operational constraints.

4.7.16 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 as a means to introduce noise abatement procedures.

Table 4-5. 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.

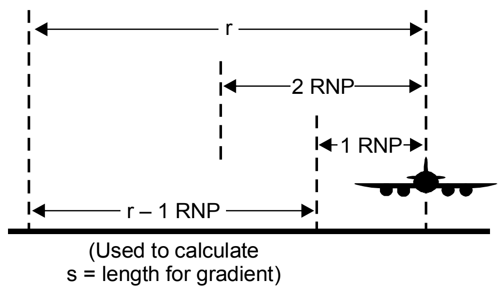


Figure 4-28. Radius for calculating track length for gradient

Exceptions and adjustments

4.7.17 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}

4.7.18 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

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 maximum landing mass exceeding 165 kt.

Missed approach turns — restrictions

4.7.19 Where missed approach turns are necessary, the earliest point in the turn initiation area must be located after a distance equivalent to 150 m (492 ft) AGL relative to a 2.5 per cent gradient or specified climb gradient, if higher, with its origin at the SOC.

Chapter 5

PUBLICATION AND CHARTING

5.1 INTRODUCTION

The general criteria in PANS-OPS, Volume II, Part I, Section 3, Chapter 5, Published Information for Departure Procedures; Part I, Section 4, Chapter 9, Charting/AIP; and Part III, Section 5, Publication, 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 or in the GEN section.

5.2 AERONAUTICAL CHART TITLES

Charts must be titled in accordance with Annex 4 — *Aeronautical Charts*, 2.2.

5.3 CHART IDENTIFICATION

5.3.1 The chart must be identified in accordance with Annex 4, 11.6, and must include the word RNAV.

5.3.2 RNP approach charts depicting procedures that meet the RNP AR APCH navigation specification criteria must include the term RNAV ($_{\text{RNP}}$) in the identification.

Note.— The text in parentheses (in 5.3.2) does not form part of the ATC clearance.

5.4 CHART NOTES

5.4.1 RNAV-related requirements concerning equipment, operation, or navigation functionality must be charted as a note.

a) examples of additional equipment requirement notes:

“dual GNSS required” or “IRU required”;

b) example of specific navigation functionality requirement note:

“RF required”.

5.4.2 For RNP AR APCH procedures, the following specific notes may be required:

a) a note must be published on the chart that includes the specific authorization requirement; and

b) for RNP AR APCH procedures with missed approach RNP less than 1.0, the following note is required: "Transition to missed approach RNP for lateral guidance must not be initiated prior to the along-track position of DA/H".

5.5 DEPICTION

RF legs

5.5.1 Any RF requirement must be charted. The RF requirement note may be charted with the applicable leg, or as a specific note with reference to the applicable leg. If RF is a common requirement within a given chart, then a general note should be used as indicated in 5.4.

5.5.2 Different required RNP levels on different initial segment legs must be charted with a note. The required note may be charted with the applicable leg or as a procedure note with reference to the applicable leg. If the same RNP value applies to all initial and intermediate segments, then a general note should be used as indicated in 5.4.

5.6 MINIMA

5.6.1 OCA/H is published an approach charts for all RNP AR APCH procedures with one exception: for RNP AR APCH procedures involving a MAS with RNP values less than RNP 1.0, a DA/H shall be published. An example of minima depiction is provided in PANS-OPS, Volume II, Part 1, Section 4, Chapter 9.

5.6.2 An OCA/H or DA/H for RNP 0.3 must be published for each RNP AR approach procedure. Additional OCA/H or DA/H for values between RNP 0.1 and 0.3 may be published as applicable.

Appendix 1

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

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

MOC: 75 m when the approach surfaces are not penetrated (see Annex 14, Vol. I, Chapter 4)
90 m when the approach surfaces are penetrated (see Annex 14, Vol. I, Chapter 4)

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

- Actual navigation performance error (anpe)
- Waypoint precision error (wpr)
- Flight technical error (fte) **fixed at** 23 m
- Altimetry system error (ase)
- Vertical angle error (vae)
- Automatic terminal information system (atis) **fixed at** 6 m

The bias errors for the MOC are:

- Body geometry (bg) error
- Semi-span **fixed at** 40 m
- International standard atmosphere temperature deviation (isad)

The MOC equation which combines these is:

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

Three standard deviation formulas for RSS computations are:

The anpe: $\mathrm{anpe} = 1.225 \cdot \mathrm{rnp} \cdot 1852 \cdot \tan(\mathrm{VPA})$

The wpr: $\mathrm{wpr} = 18 \cdot \tan(\mathrm{VPA})$

The fte: $\mathrm{fte} = 23$

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

The vae: $\mathrm{vae} = \left(\dfrac{\mathrm{elev} - \mathrm{LTP}_{\mathrm{elev}}}{\tan(\mathrm{VPA})}\right)\left[\tan(\mathrm{VPA}) - \tan(\mathrm{VPA} - 0.01^\circ)\right]$

The atis: $\mathrm{atis} = 6$

Bias error computations:

The isad: $\text{isad} = \dfrac{(\text{elev} - \text{LTP}_{\text{elev}}) \cdot \Delta\text{ISA}}{288 + \Delta\text{ISA} - 0.5 \cdot 0.0065 \cdot \text{elev}}$

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)

Required navigational performance (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)

Automatic terminal information service (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

Vertical path angle (VPA): VPA = 3°

Final approach point (FAP) is 1 400 m: (fap = 1 400)

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

Reference datum height (RDH): (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

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

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: $ase = -2.887 \cdot 10^{-7} \cdot (elev)^2 + 6.5 \cdot 10^{-3} \cdot (elev) + 15$

$$\begin{aligned} ase_{75} &= -2.887 \cdot 10^{-7} \cdot (LTP_{elev} + 75)^2 + 6.5 \cdot 10^{-3} \cdot (LTP_{elev} + 75) + 15 \\ &= -2.887 \cdot 10^{-7} \cdot (360 + 75)^2 + 6.5 \cdot 10^{-3} \cdot (360 + 75) + 15 \\ &= 17.7729 \end{aligned}$$

$$\begin{aligned} ase_{FAP} &= -2.887 \cdot 10^{-7} \cdot (FAP)^2 + 6.5 \cdot 10^{-3} \cdot (FAP) + 15 \\ &= -2.887 \cdot 10^{-7} \cdot (1400)^2 + 6.5 \cdot 10^{-3} \cdot (1400) + 15 \\ &= 23.5341 \end{aligned}$$

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

$$\begin{aligned} vae_{75} &= \left(\frac{75}{\tan(VPA)} \right) \left[\tan(VPA) - \tan(VPA - 0.01°) \right] \\ &= \left(\frac{75}{\tan 3°} \right) \left[\tan 3° - \tan(3° - 0.01°) \right] \\ &= .2505 \end{aligned}$$

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

The atis: atis = 6

The isad: $isad = \frac{(elev - LTP_{elev}) \cdot \Delta ISA}{288 + \Delta ISA - 0.5 \cdot 0.0065 \cdot elev}$

$$\begin{aligned} isad_{75} &= \frac{75 \cdot (\Delta ISA)}{288 + \Delta ISA - 0.5 \cdot 0.0065 \cdot (LTP_{elev} + 75)} \\ &= \frac{75 \cdot (-20)}{288 - 20 - 0.5 \cdot 0.0065 \cdot (360 + 75)} \\ &= -5.6267 \end{aligned}$$

$$\begin{aligned} isad_{FAP} &= \frac{(elev - LTP_{elev}) \cdot (\Delta ISA)}{288 + \Delta ISA - 0.5 \cdot 0.0065 \cdot (FAP)} \\ &= \frac{(1400 - 360) \cdot (-20)}{288 - 20 - 0.5 \cdot 0.0065 \cdot (1400)} \\ &= -78.9524 \end{aligned}$$

The bg: $$\begin{aligned} bg &= semispan \cdot \sin\alpha \\ &= 40 \cdot \sin 18^\circ \\ &= 12.3607 \end{aligned}$$

$$\begin{aligned} MOC_{75} &= bg - isad_{75} + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase_{76}{}^2 + vae_{76}{}^2 + atis^2} \\ &= 12.6307 + 5.6267 + \frac{4}{3}\sqrt{16.6457^2 + 0.9433^2 + 23^2 + 17.7729^2 + 0.2505^2 + 6^2} \\ &= 63.3777 \end{aligned}$$

$$\begin{aligned} MOC_{fap} &= bg - isad_{fap} + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase_{fap}{}^2 + vae_{fap}{}^2 + atis^2} \\ &= 12.6307 + 78.9524 + \frac{4}{3}\sqrt{16.6457^2 + 0.9433^2 + 23^2 + 23.5341^2 + 3.4730^2 + 6^2} \\ &= 141.3599 \end{aligned}$$

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}:

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

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:

$$\begin{aligned} OASgradient &= \frac{(1400 - 360 - 14.3599) - (75 - 63.3777)}{\dfrac{1400 - 360 - 75}{\tan 3^\circ}} \\ &= 0.0481726\ (4.817\%) \end{aligned}$$

$$\begin{aligned} OASorigin &= \left(\frac{75 - 17}{\tan 3^\circ}\right) - \left(\frac{75 - 63.3777}{0.0481726}\right) \\ &= 865.4422 \end{aligned}$$

Appendix 2

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

The required minimum obstacle clearance (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.

MOC: 250 ft when the approach surfaces are not penetrated (see Annex 14, Vol. I, Chapter 4)
300 ft when the approach surfaces are penetrated (see Annex 14, Vol. I, Chapter 4)

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

- Actual navigation performance error (anpe)
- Waypoint precision error (wpr)
- Flight technical error (fte) **fixed at 75 ft**
- Altimetry system error (ase)
- Vertical angle error (vae)
- Automatic terminal information system (atis) **fixed at 20 ft**

The bias errors for the MOC are:

- Body geometry (bg) error
- Semi-span **fixed at 132**
- International standard atmosphere temperature deviation (isad)

The MOC equation which combines these is:

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

Three standard deviation formulas for RSS computations:

The anpe: $\mathrm{anpe} = 1.225 \cdot \mathrm{rnp} \cdot \dfrac{1852}{0.3048} \cdot \tan \mathrm{VPA}$

The wpr: $\mathrm{wpr} = 60 \cdot \tan \mathrm{VPA}$

The fte: fte = 75

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

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

The atis: atis = 20

Bias error computations:

The isad: $$isad = \frac{(elev - LTP_{elev}) \cdot \Delta ISA}{288 + \Delta ISA - 0.5 \cdot 0.00198 \cdot elev}$$

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)
Required navigational performance (RNP) is .14 NM: (rnp = 0.14)

AUTHORIZATION REQUIRED (AR) FIXED VALUES

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

Automatic terminal information service (atis) two standard deviation altimeter setting vertical error is assumed to be 20 ft: (atis = 20)

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

Vertical path variables

Final approach point (FAP) is 4 500 ft: (FAP = 4 500)

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

Reference datum height (RDH (ft)): (RDH = 55)

Vertical path angle (VPA): (VPA = 3°)

Calculations

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

The anpe: $$\begin{aligned} anpe &= 1.225 \cdot rnp \cdot \frac{1852}{0.3048} \cdot \tan VPA \\ &= 1.225 \cdot 0.14 \cdot \frac{1852}{0.3048} \cdot \tan 3° \\ &= 54.6117 \end{aligned}$$

The wpr: $$\begin{aligned} wpr &= 60 \cdot \tan VPA \\ &= 60 \cdot \tan 3° \\ &= 3.1445 \end{aligned}$$

The fte: fte = 75

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

$$\begin{aligned} ase_{250} &= -8.8 \cdot 10^{-8} \cdot (LTP_{elev} + 250)^2 + 6.5 \cdot 10^{-3} \cdot (LTP_{elev} + 250) + 50 \\ &= -8.8 \cdot 10^{-8} \cdot (1200 + 250)^2 + 6.5 \cdot 10^{-3} \cdot (1200 + 250) + 50 \\ &= 59.2400 \end{aligned}$$

$$\begin{aligned} ase_{FAP} &= -8.8 \cdot 10^{-8} \cdot (FAP)^2 + 6.5 \cdot 10^{-3} \cdot (FAP) + 50 \\ &= -8.8 \cdot 10^{-8} \cdot (4500)^2 + 6.5 \cdot 10^{-3} \cdot (4500) + 50 \\ &= 77.4680 \end{aligned}$$

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

$$\begin{aligned} vae_{FAP} &= \left(\frac{FAP - LTP_{elev}}{\tan VPA} \right) [\tan VPA - \tan(VPA - 0.01°)] \\ &= \left(\frac{4500 - 1200}{\tan 3°} \right) [\tan 3° - \tan(3° - 0.01°)] \\ &= 11.0200 \end{aligned}$$

$$\begin{aligned} vae_{250} &= \left(\frac{250}{\tan VPA} \right) [\tan VPA - \tan(VPA - 0.01°)] \\ &= \left(\frac{250}{\tan 3°} \right) [\tan 3° - \tan(3° - 0.01°)] \\ &= .8349 \end{aligned}$$

The isad: $isad = \frac{(elev - LTP_{elev}) \cdot \Delta ISA}{288 + \Delta ISA - 0.5 \cdot 0.00198 \cdot elev}$

$$\begin{aligned} isad_{FAP} &= \frac{(FAP - LTP_{elev}) \cdot \Delta ISA}{288 + \Delta ISA - 0.5 \cdot 0.00198 \cdot (FAP)} \\ &= \frac{(4500 - 1200) \cdot (-20)}{288 - 20 - 0.5 \cdot 0.00198 \cdot (4500)} \\ &= -250.432 \end{aligned}$$

$$\begin{aligned} isad_{250} &= \frac{250 \cdot \Delta ISA}{288 + \Delta ISA - 0.5 \cdot 0.00198 \cdot (LTP_{elev} + 250)} \\ &= \frac{250 \cdot (-20)}{288 - 20 - 0.5 \cdot 0.00198 \cdot (1200 + 250)} \\ &= -18.7572 \end{aligned}$$

The bg:
$$\begin{aligned} bg &= semispan \cdot \sin \phi \\ &= 132 \cdot \sin 18° \\ &= 40.7902 \end{aligned}$$

$$MOC_{250} = bg - isad_{250} + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase_{250}{}^2 + vae_{250}{}^2 + atis^2}$$
$$= 40.7902 + 18.7572 + \frac{4}{3}\sqrt{54.6117^2 + 3.1445^2 + 75^2 + 59.2400^2 + 0.8349^2 + 20^2}$$
$$= 208.782$$

$$MOC_{FAP} = bg - isad_{FAP} + \frac{4}{3}\sqrt{anpe^2 + wpr^2 + fte^2 + ase_{FAP}{}^2 + vae_{FAP}{}^2 + atis^2}$$
$$= 40.7902 + 250.432 + \frac{4}{3}\sqrt{54.6117^2 + 3.1445^2 + 75^2 + 77.4680^2 + 11.020^2 + 20^2}$$
$$= 455.282$$

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}:

$$\text{OAS gradient} = \frac{(fap - ltpelev - MOC_{FAP}) - (250 - MOC_{250})}{\dfrac{FAP - LTP_{elev} - 250}{\tan VPA}}$$

$$= \frac{(4500 - 1200 - 455.282) - (250 - 208.782)}{\dfrac{4500 - 1200 - 250}{\tan(3)}}$$

$$= 0.04817\ (4.817\%)$$

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.

$$\text{OASorigin} = \left(\frac{250 - RDH}{\tan VPA}\right) - \frac{(250 - MOC_{250})}{\text{OASgradient}}$$
$$= \left(\frac{250 - 55}{\tan(3)}\right) - \frac{(250 - 208.782)}{0.04817}$$
$$= 2865.179$$

— END —