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.

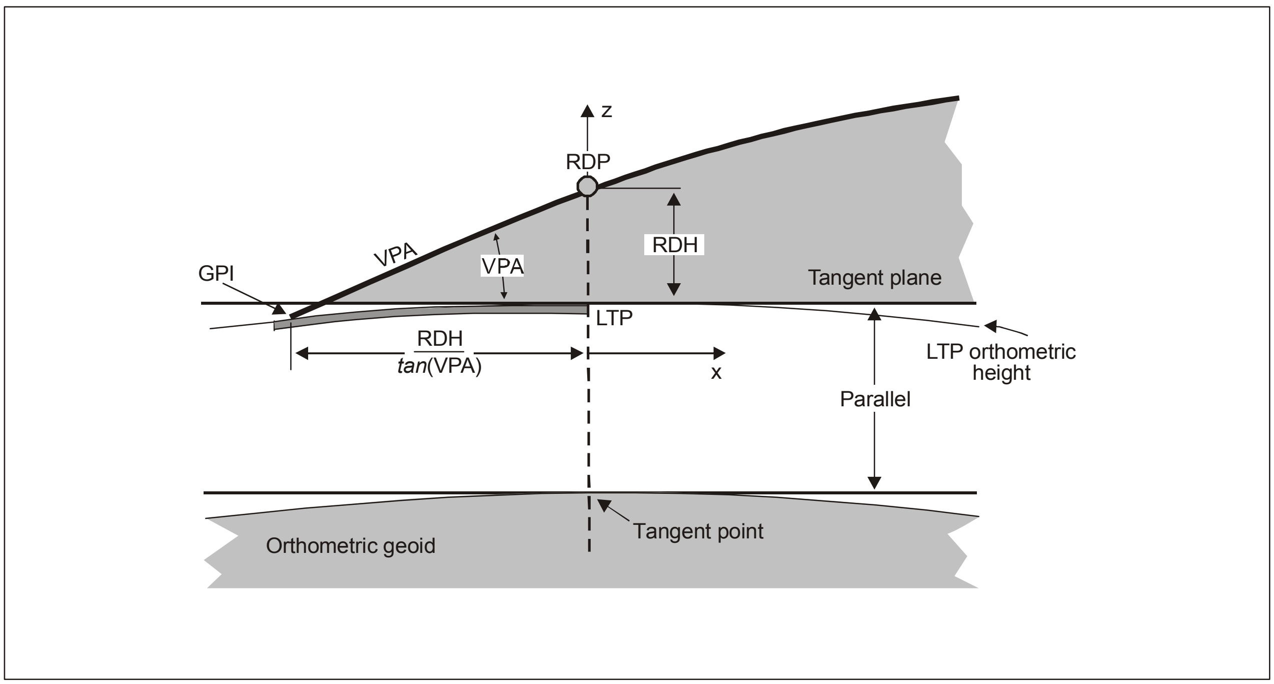

Figure 4-1. Coordinate system baseline

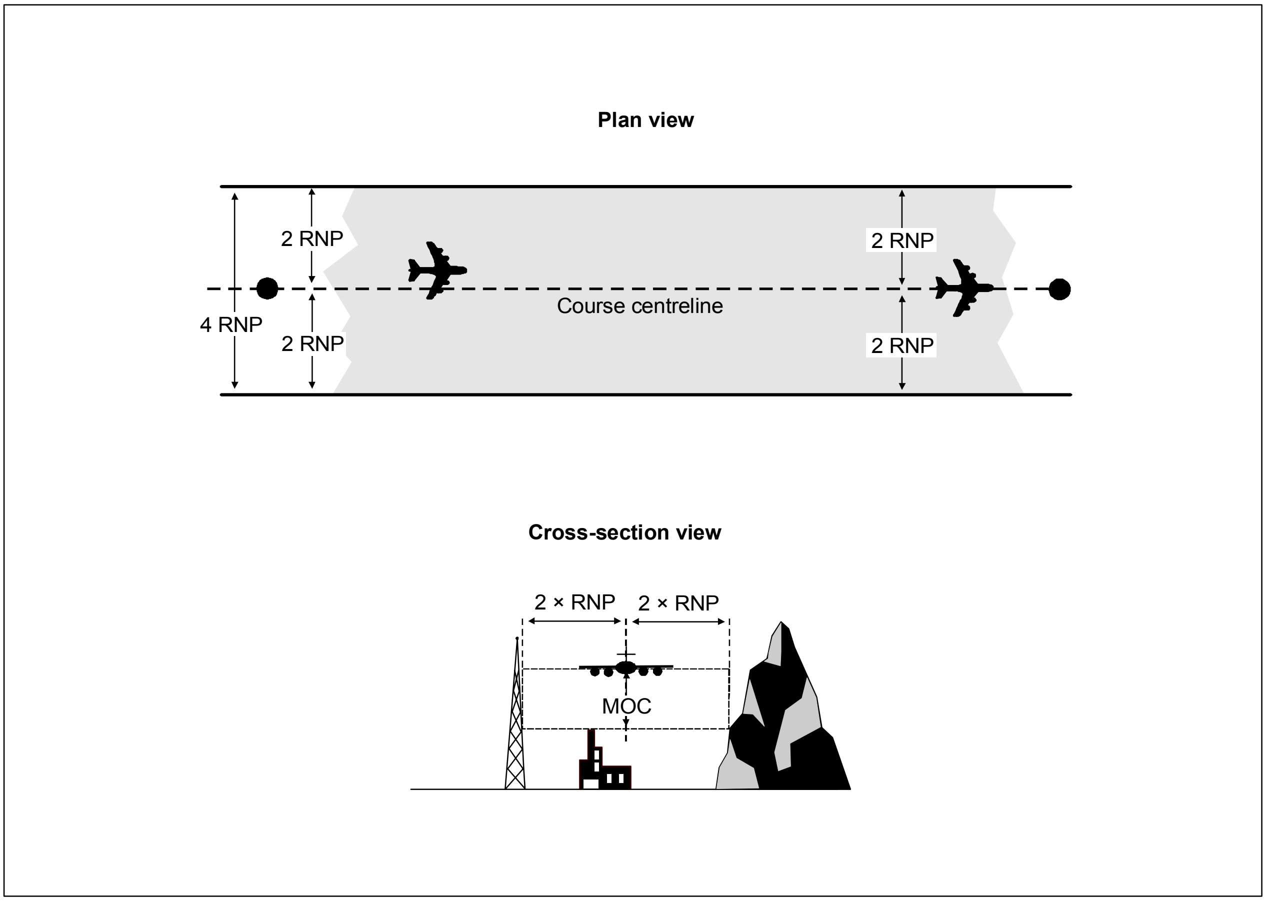

Figure 4-2. RNP segment widths

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.

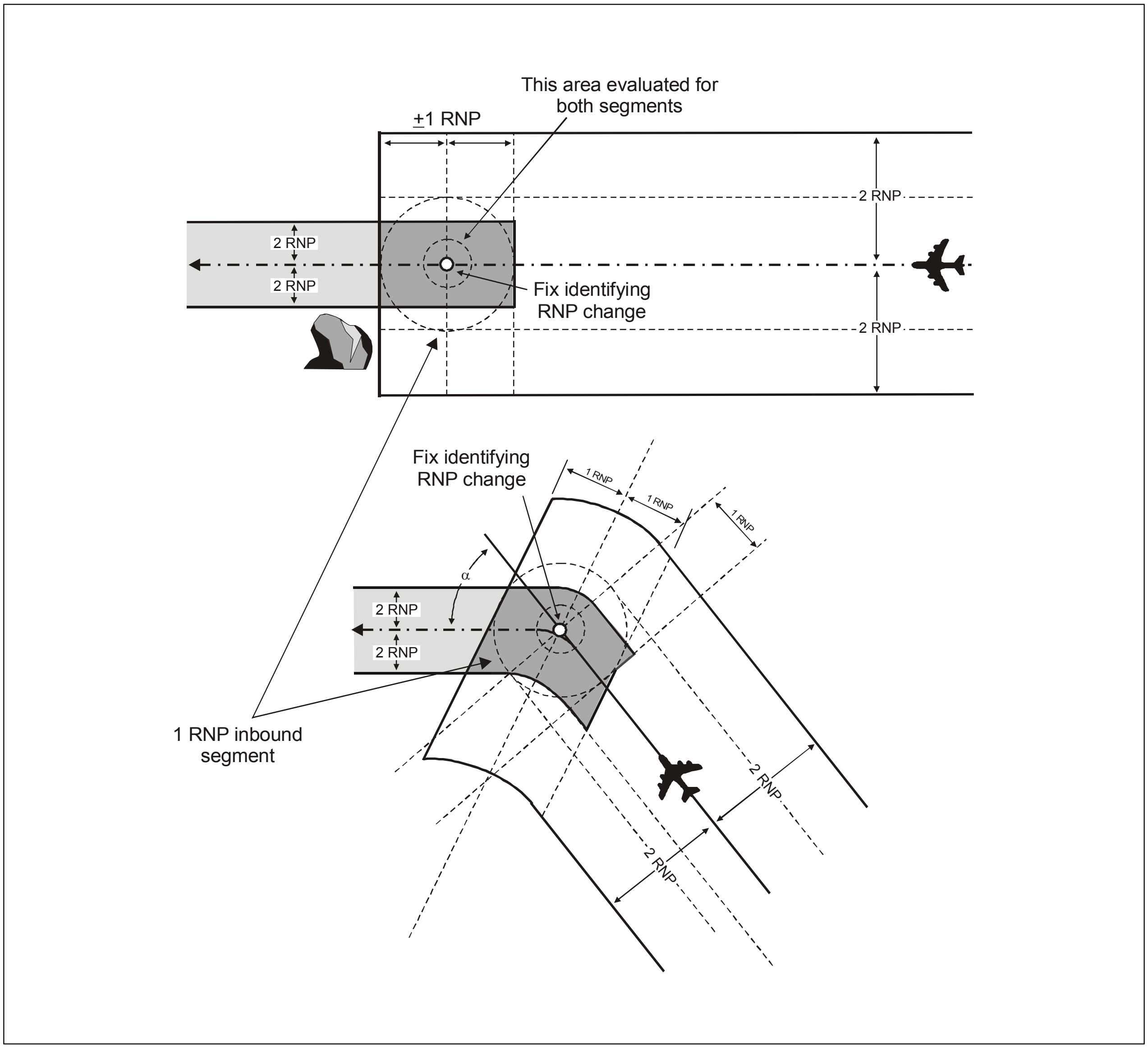

Figure 4-3. RNP reduction (straight and turning segment)

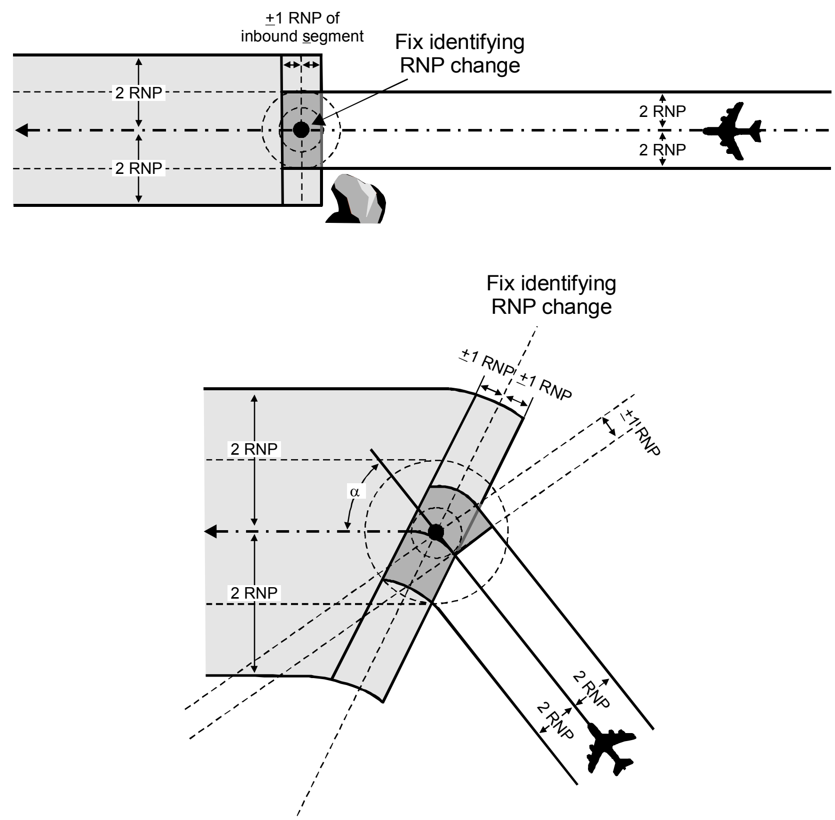

Figure 4-4. RNP increase (straight and turning segments)

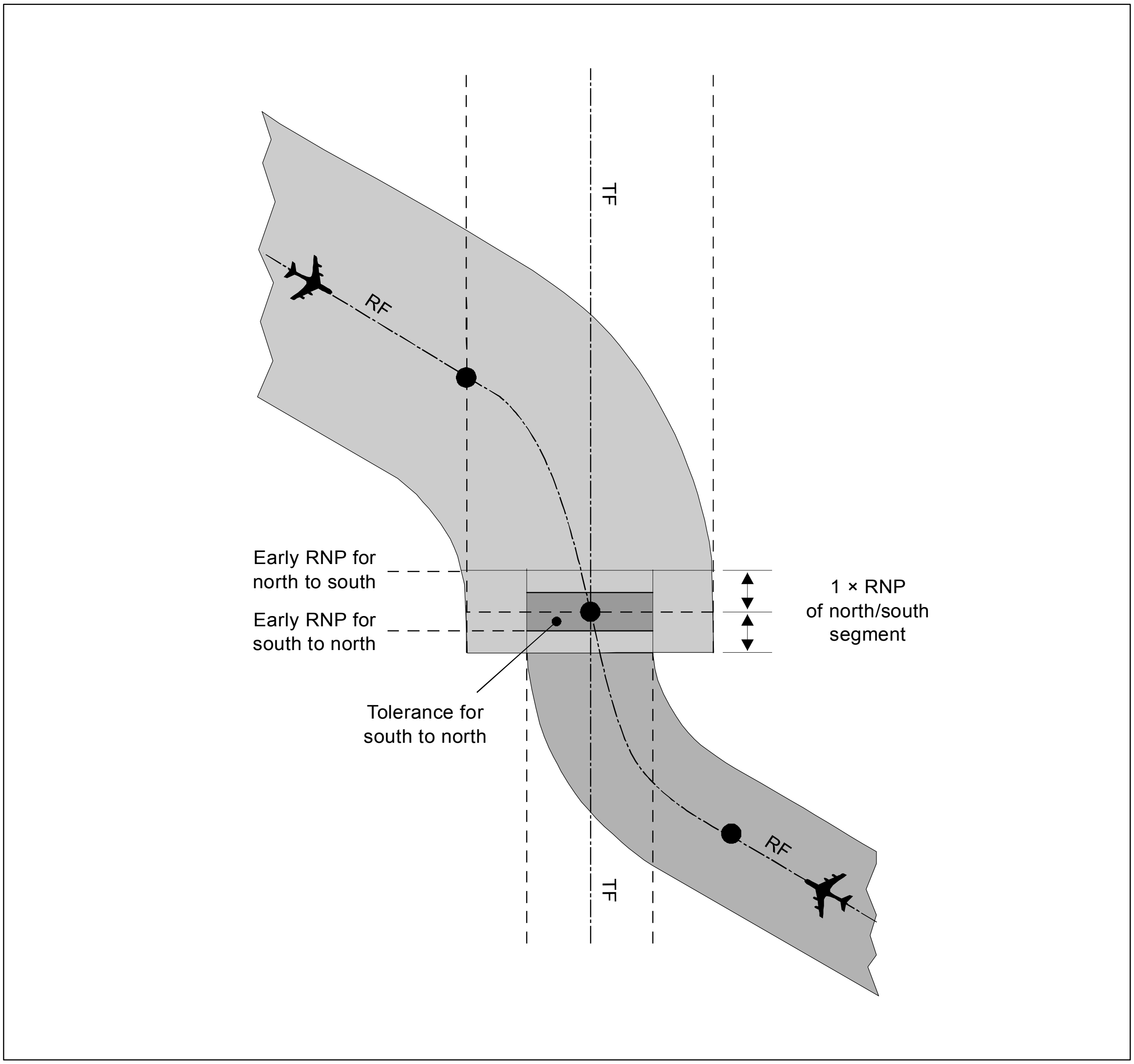

Figure 4-5. Changing RNP values

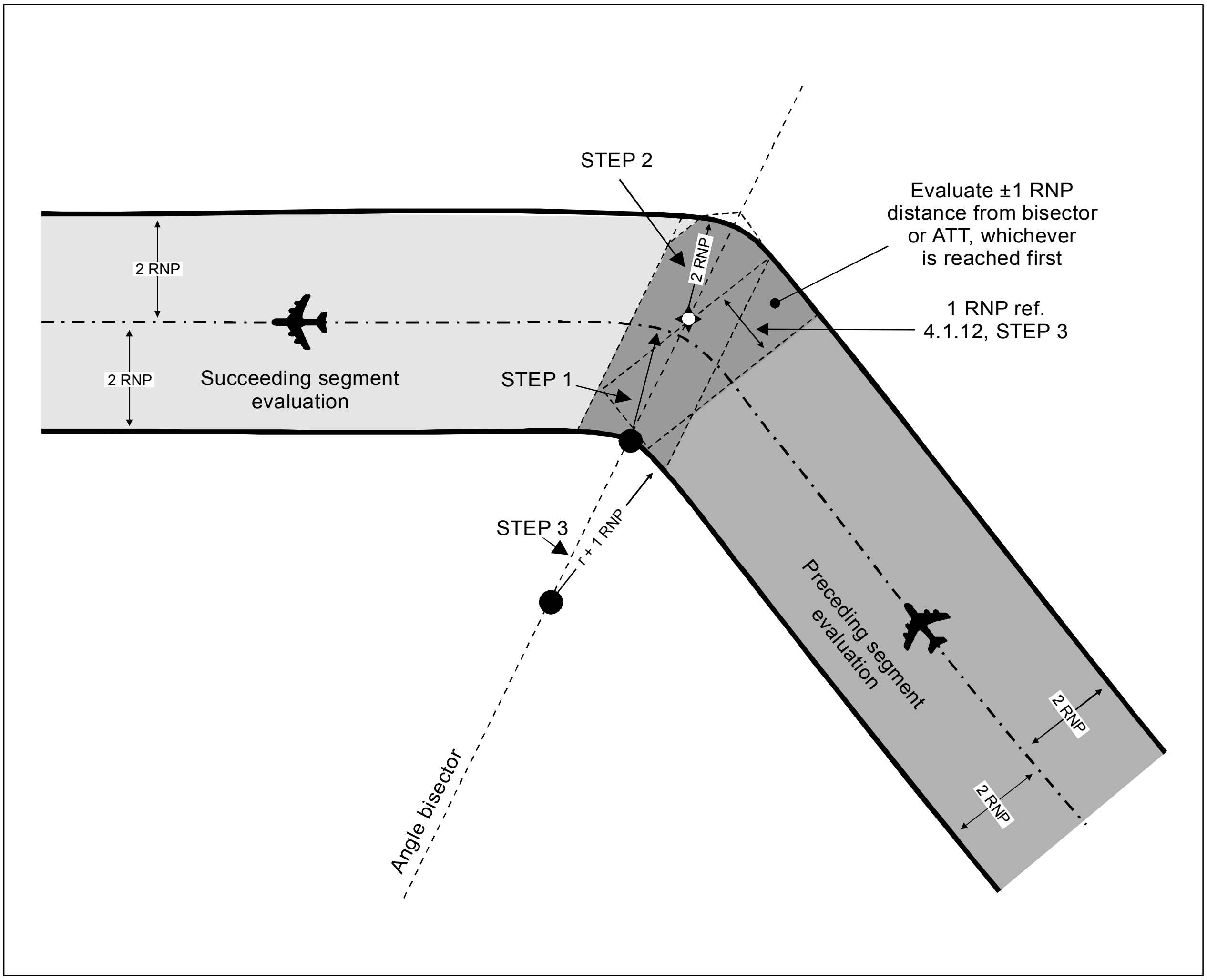

Figure 4-6. Small turn at fly-by fix

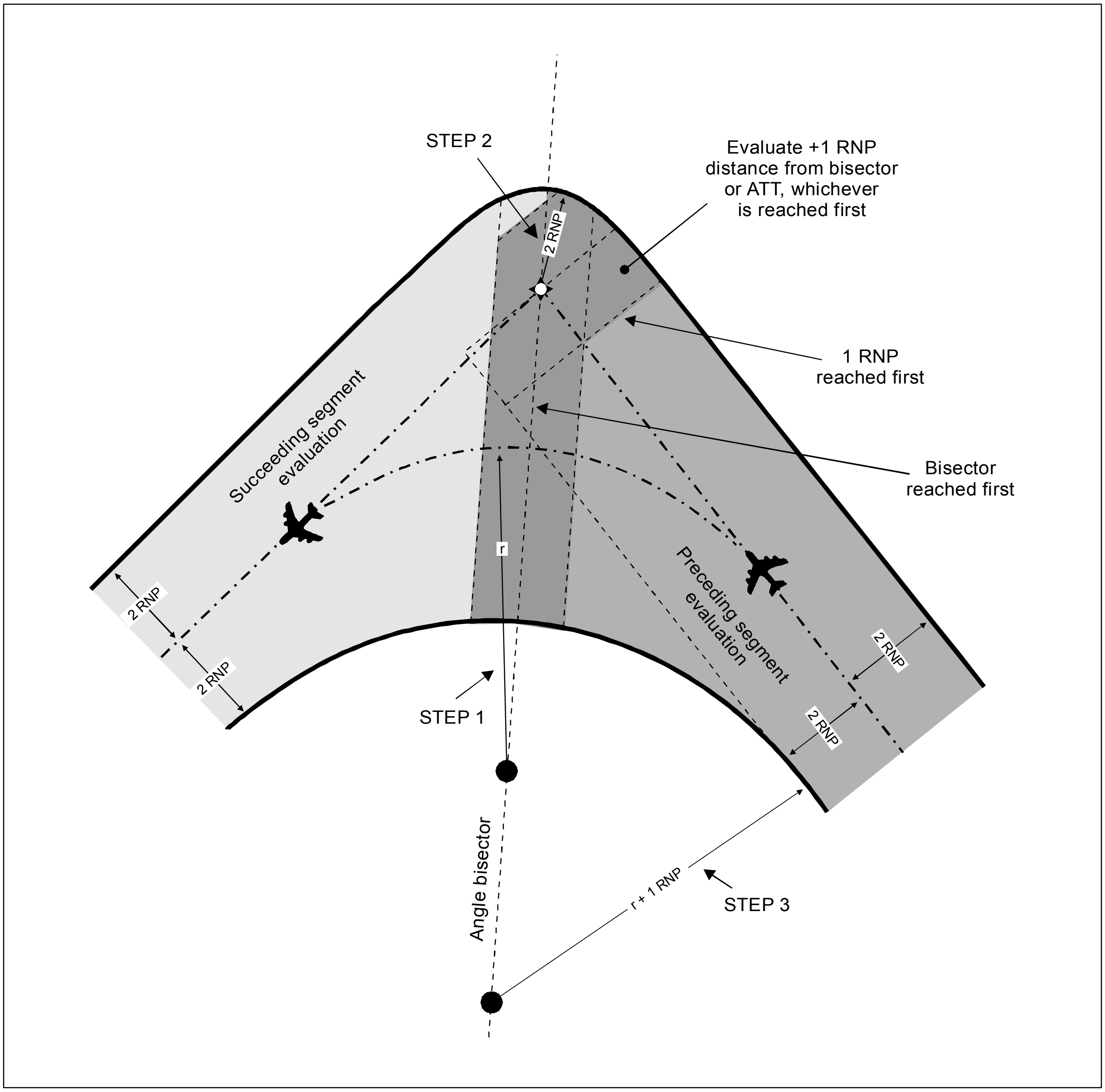

Figure 4-7. Large turn at fly-by fix

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.

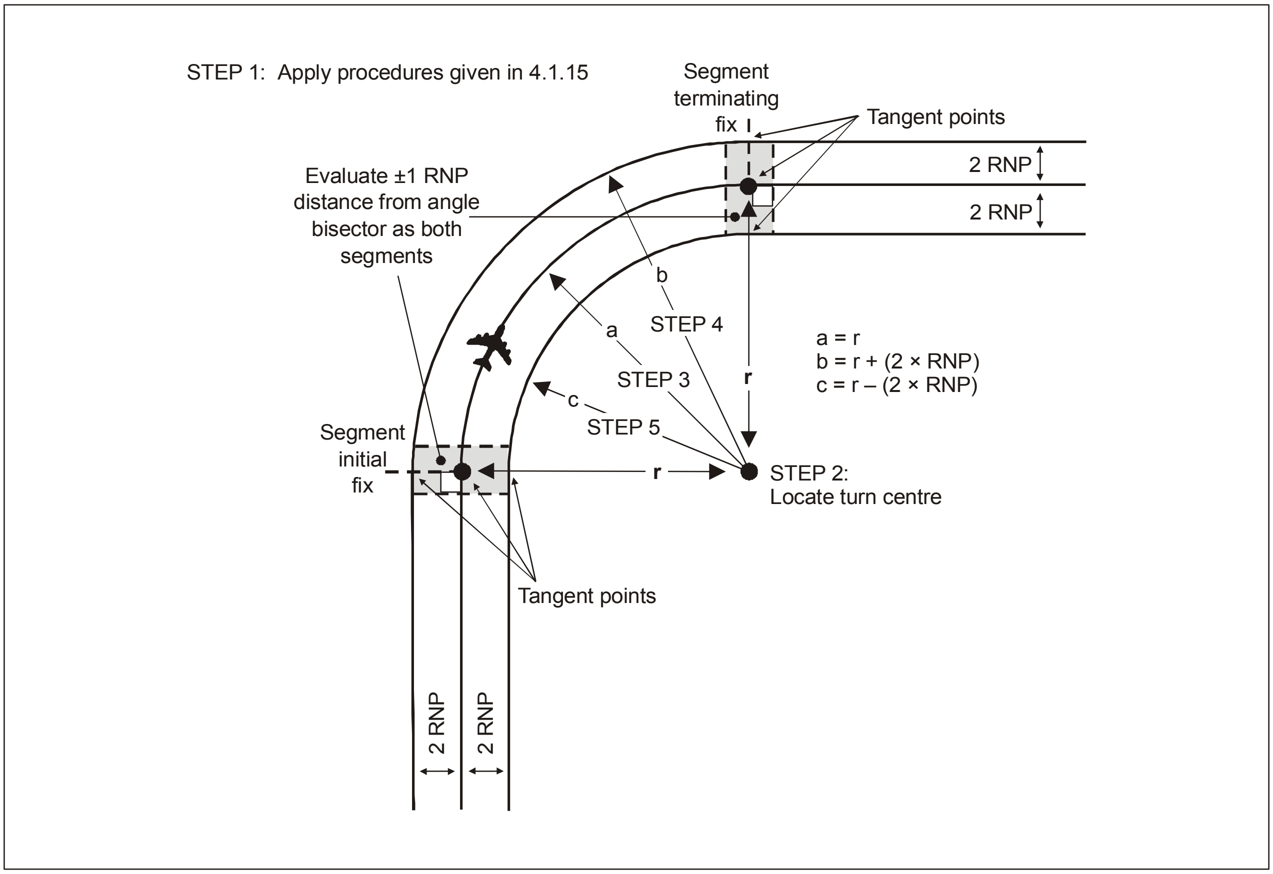

Figure 4-8. RF turn construction

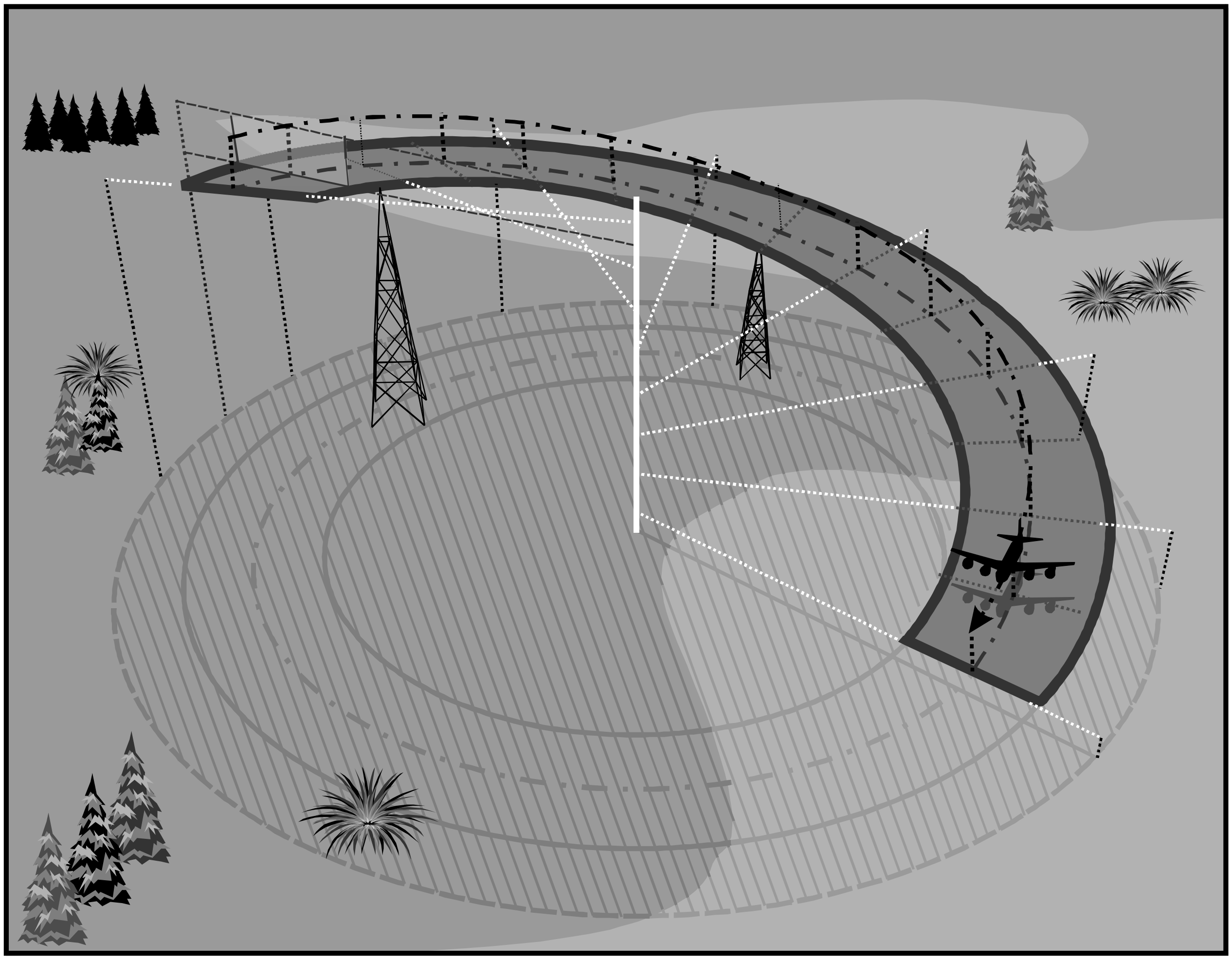

Figure 4-9 a). Obstacle clearance surface (OCS) for RF approach segments

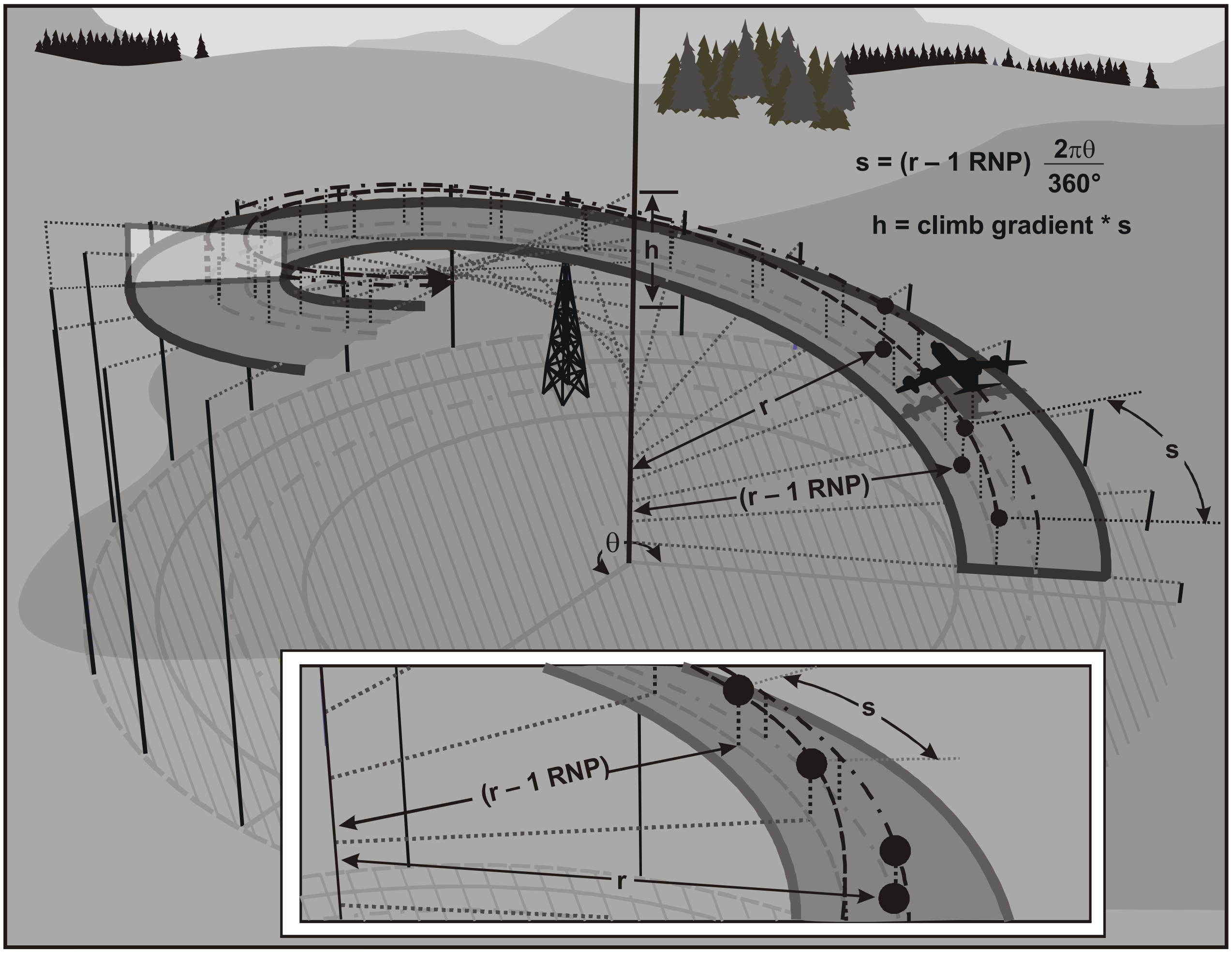

Figure 4-9 b). OCS for RF missed approach segments (MAS)

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.

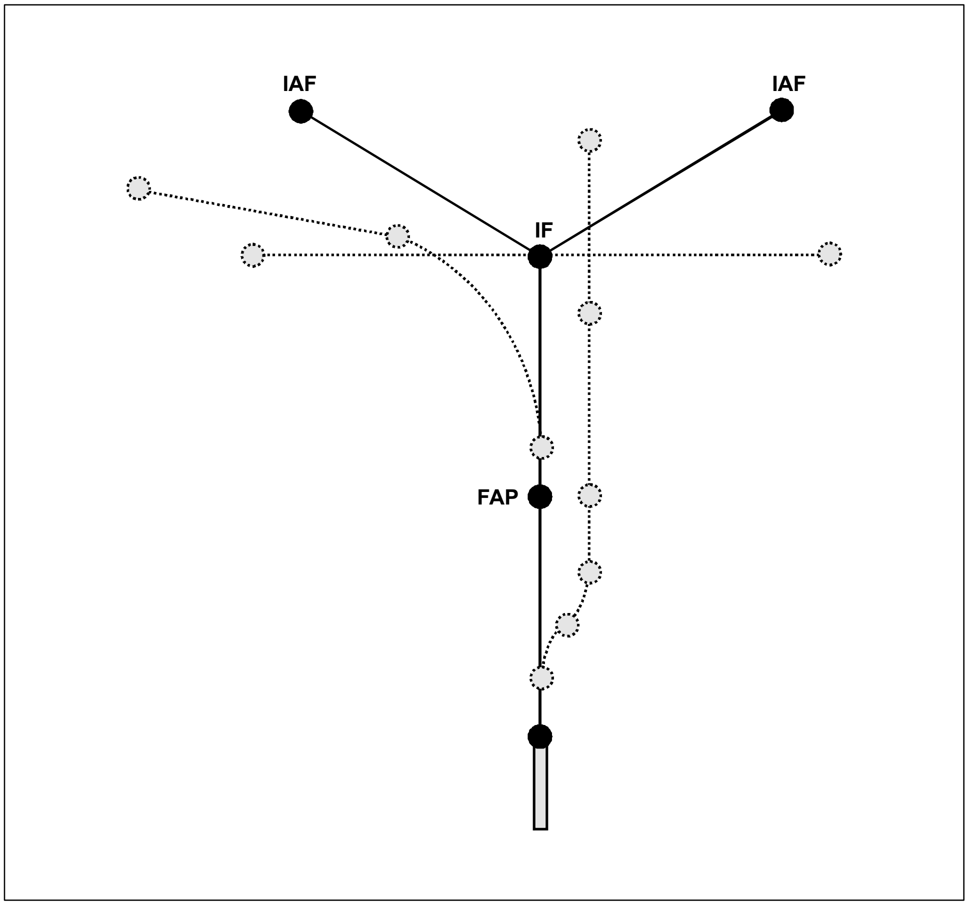

Figure 4-10. Application of basic Y and basic T

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.

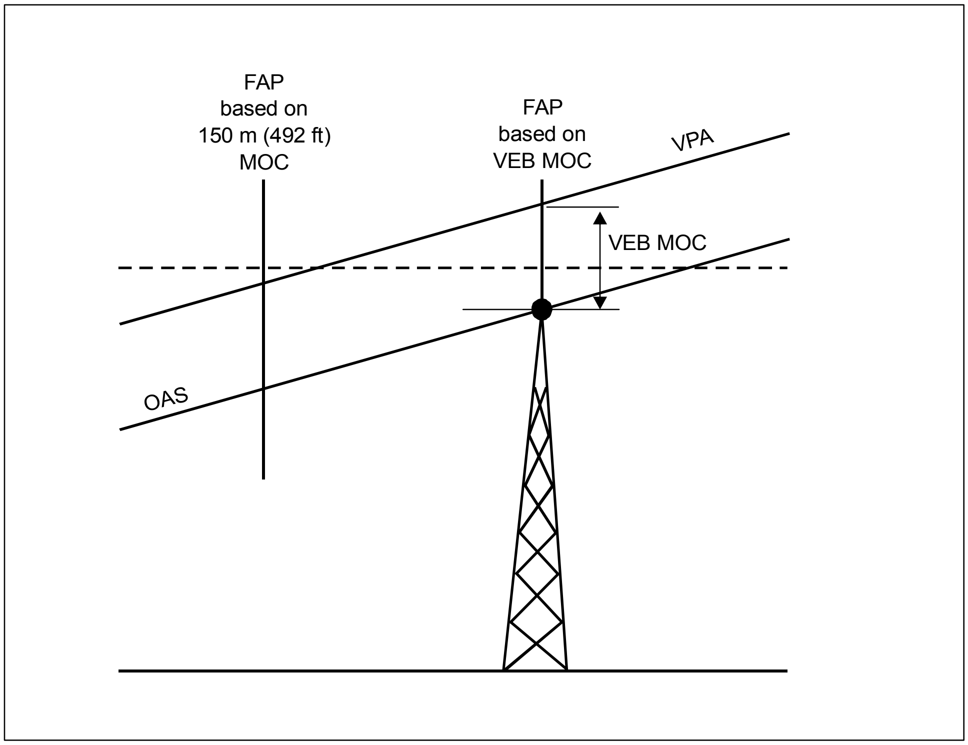

Figure 4-11. Intermediate segment MOC 1

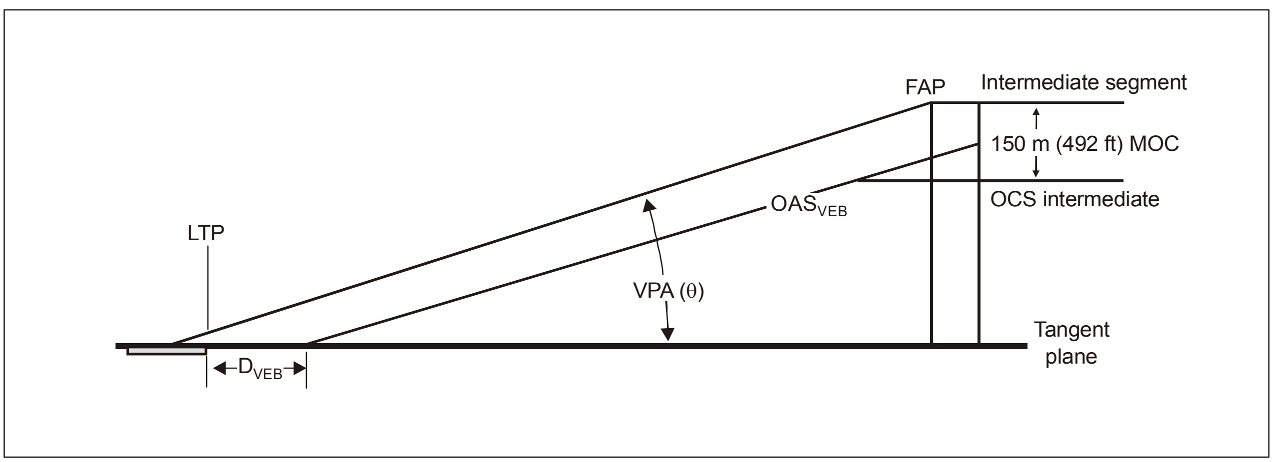

Figure 4-12. Intermediate segment MOC 2

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.

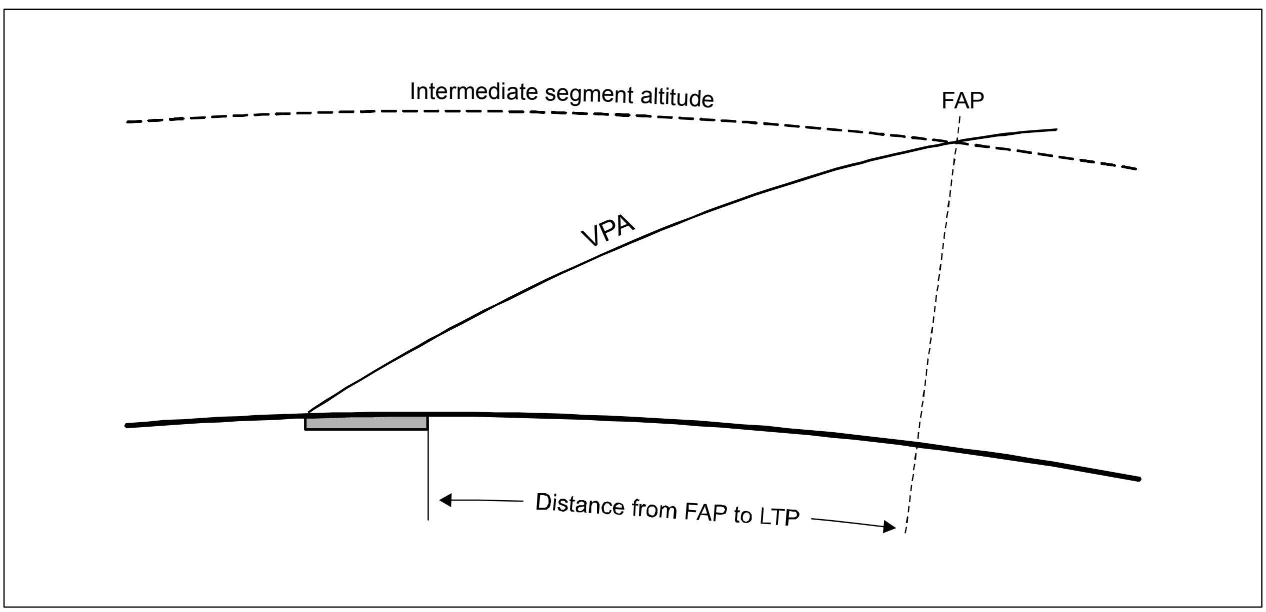

Figure 4-13. FAP to LTP distance

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
V e r s i o n 2.2
3/17/09

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

NON SI UNITS
Version 2.2
3/17/09

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**	

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: $$D_{150} = \frac{150 - RDH}{\tan(VPA)}$$

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

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

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

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

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

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}.

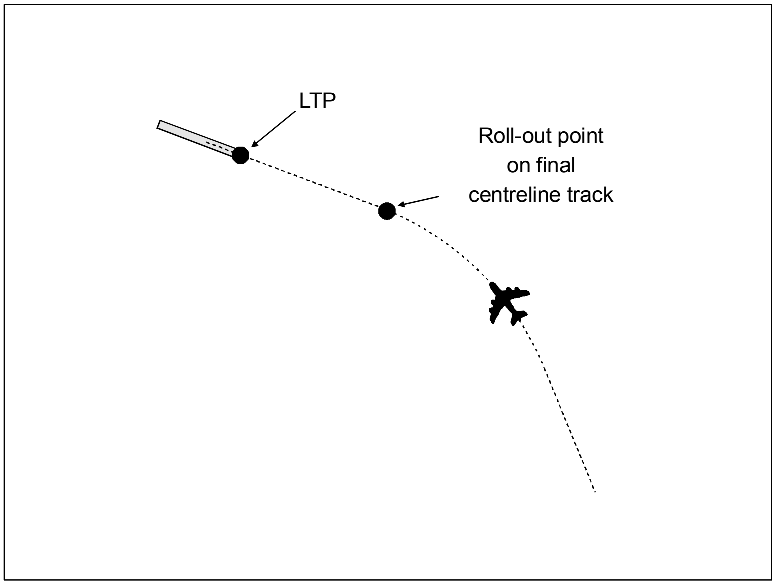

Figure 4-15. FROP

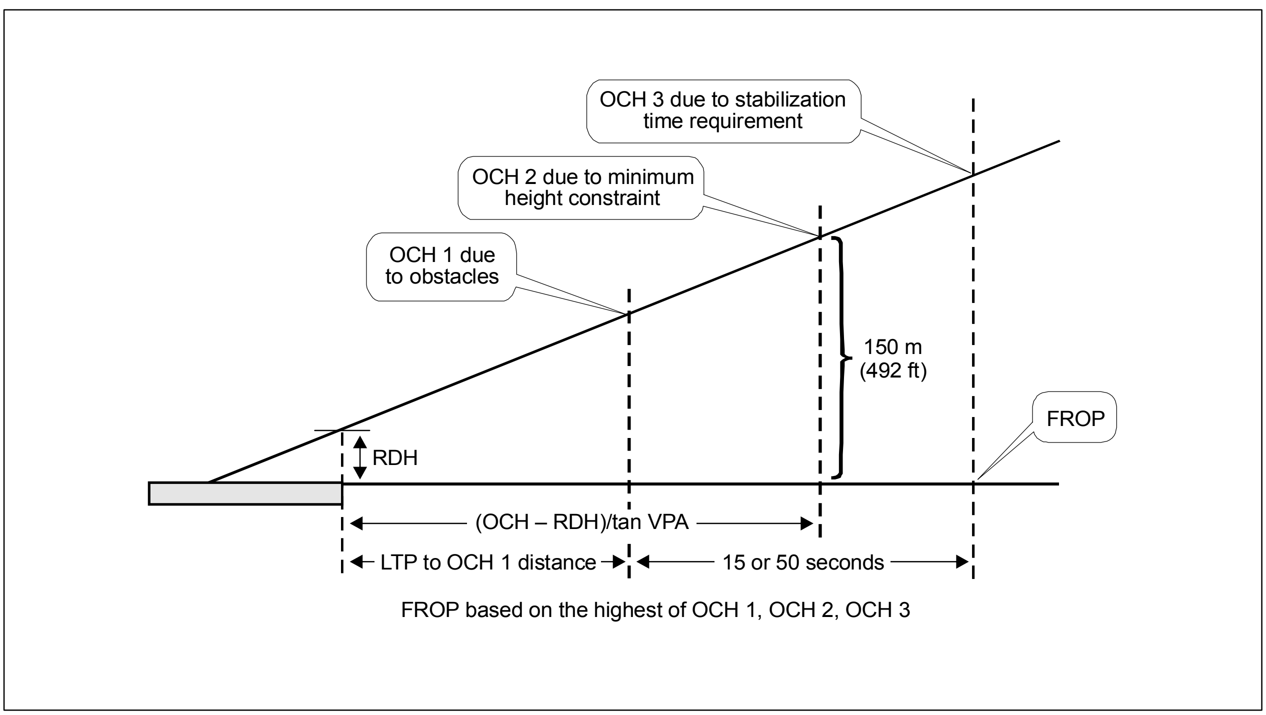

Figure 4-16. Constraints on OCH and FROP

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.

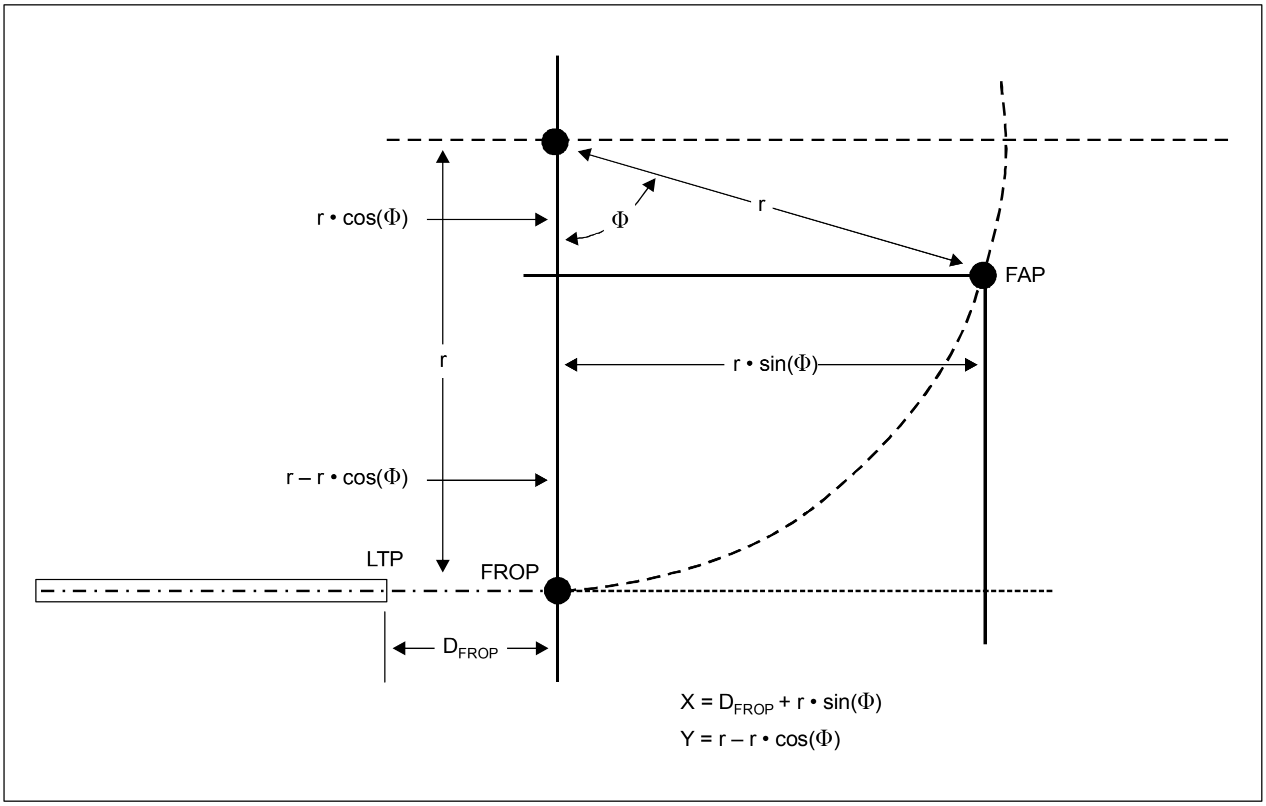

Figure 4-17. FAP within an RF leg

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.)

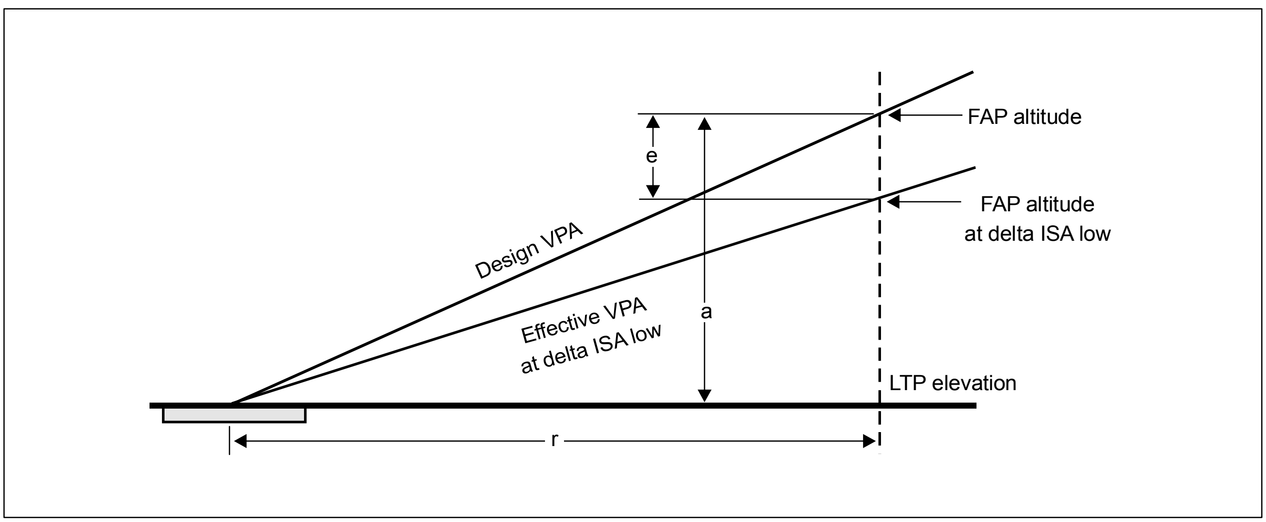

Figure 4-18. Effective VPA cold temperature

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).

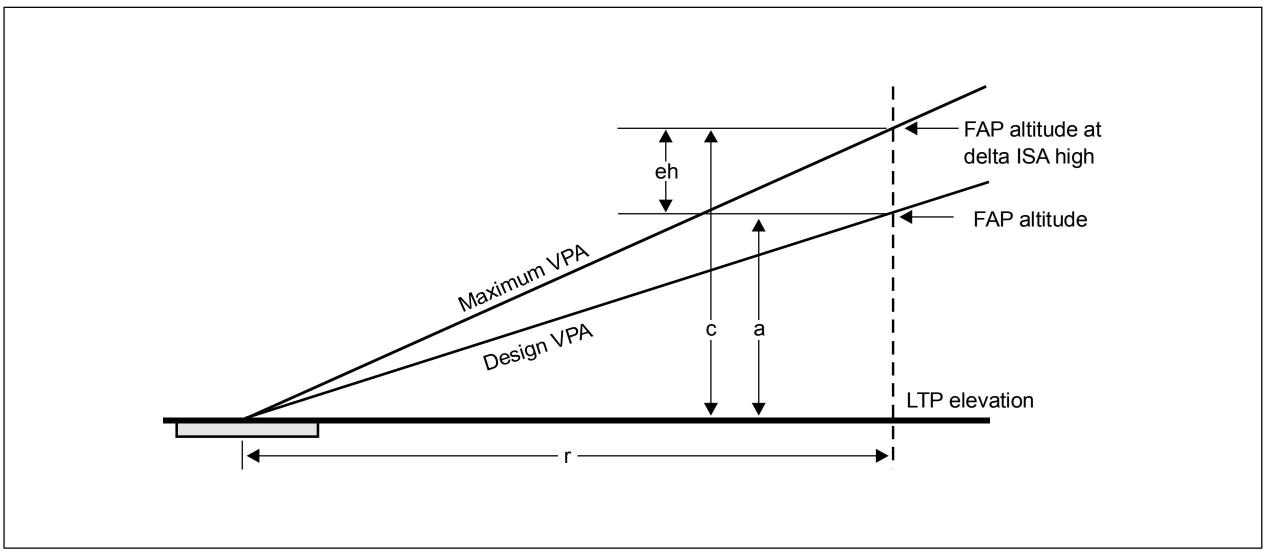

Figure 4-19. Effective VPA hot temperature

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**	

SI UNITS
Version 2.2
3/17/09

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
Version 2.2
3/17/09

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.

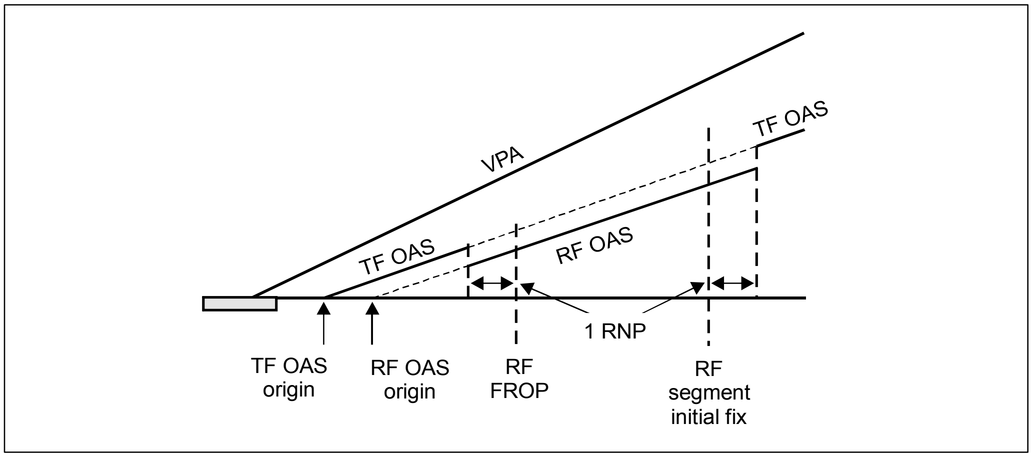

Figure 4-21. OAS adjustment for TF and RF legs

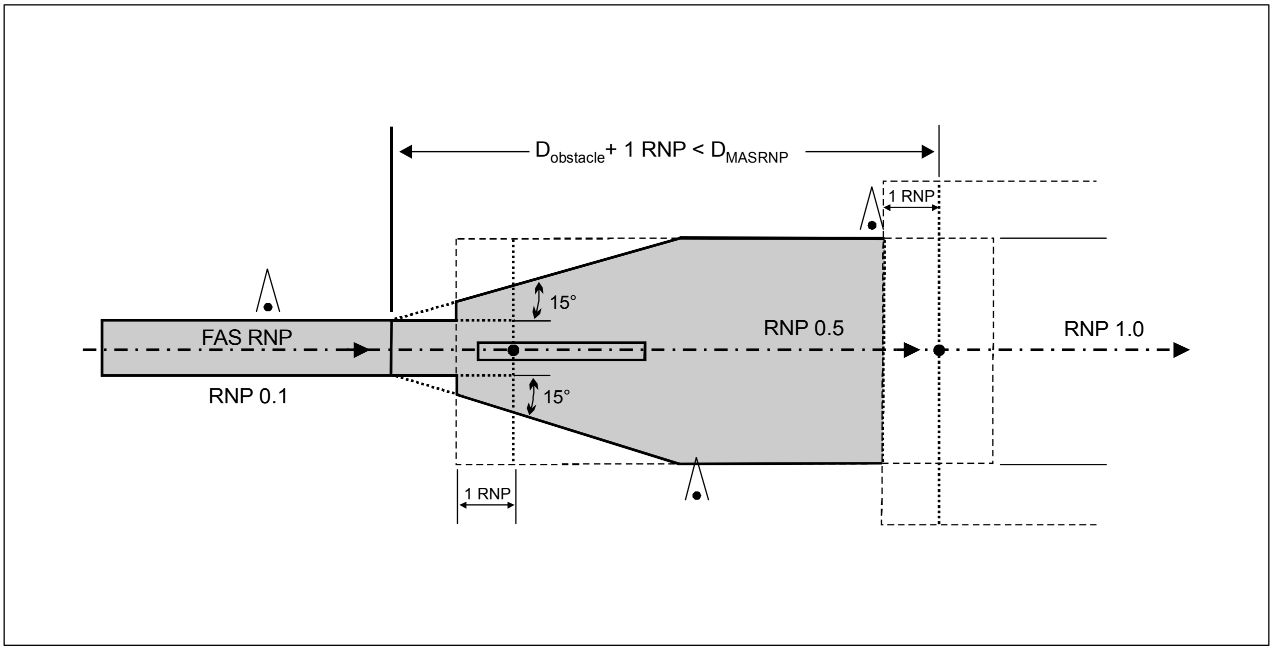

Figure 4-22. Maximum extension of RNP < 1.0 in the missed approach

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.

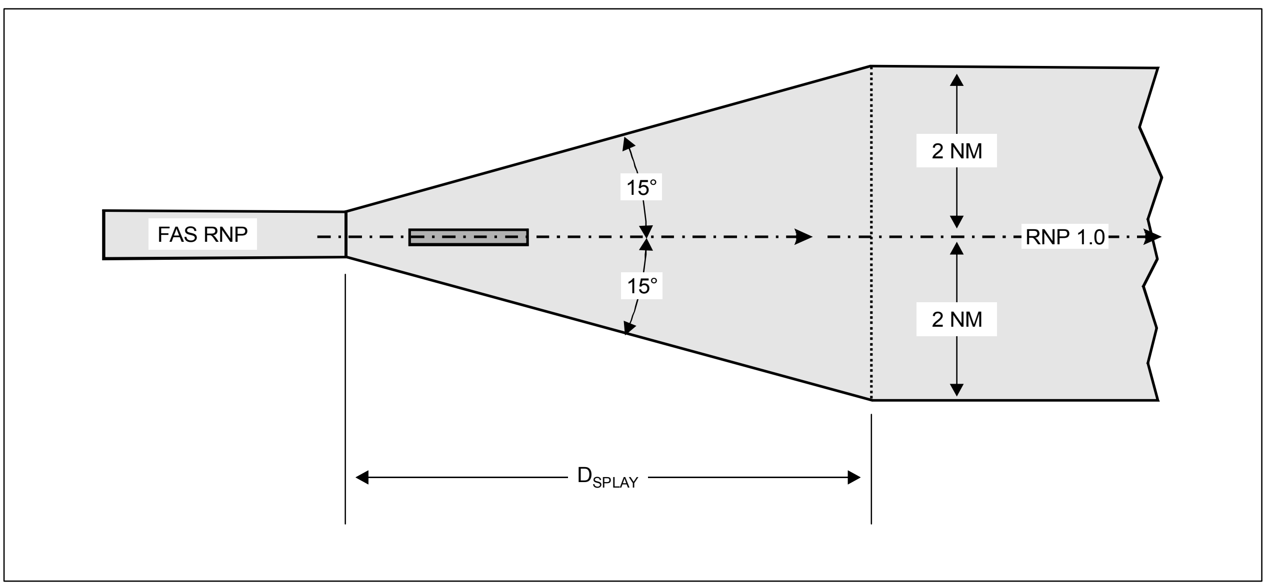

Figure 4-23. Missed approach splay

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”.

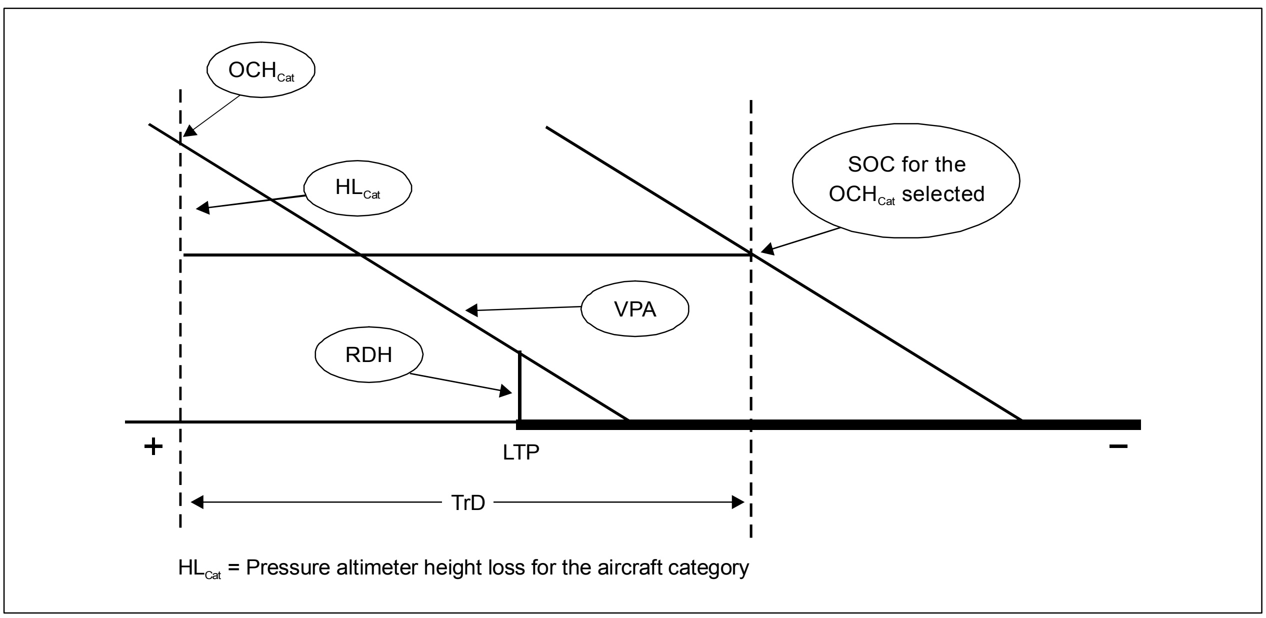

Figure 4-24. Determination of SOC

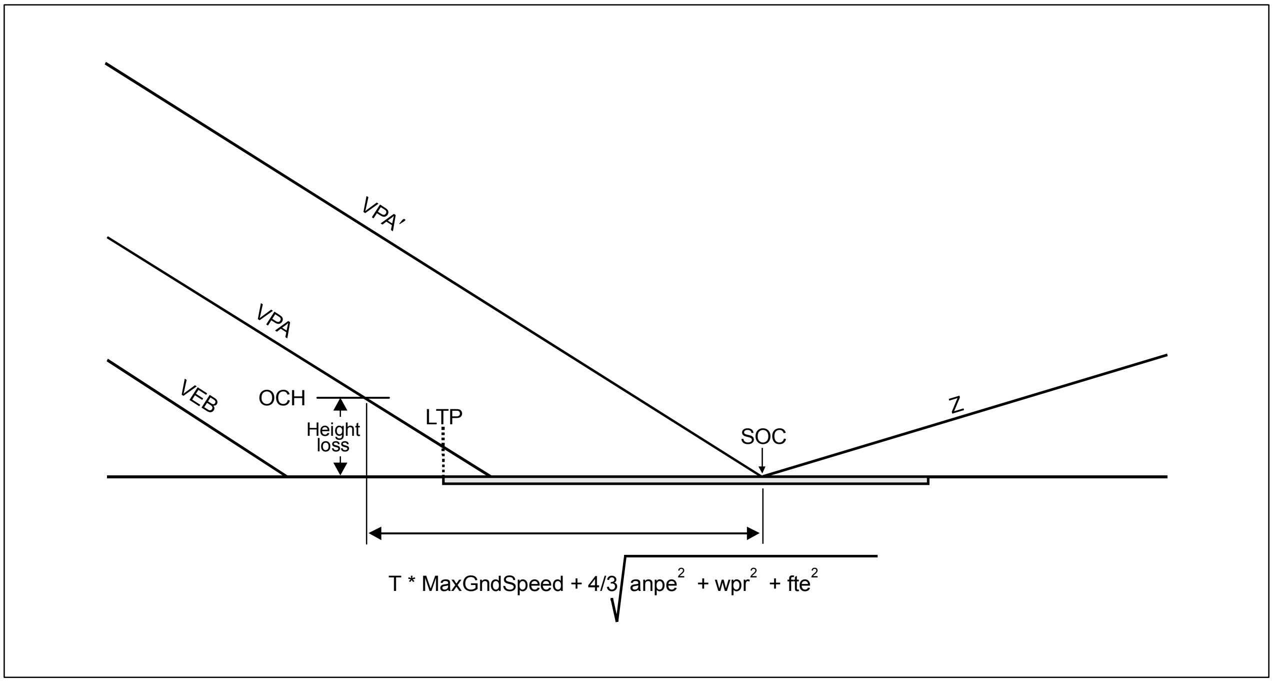

Figure 4-25. Missed approach surface (Z)

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

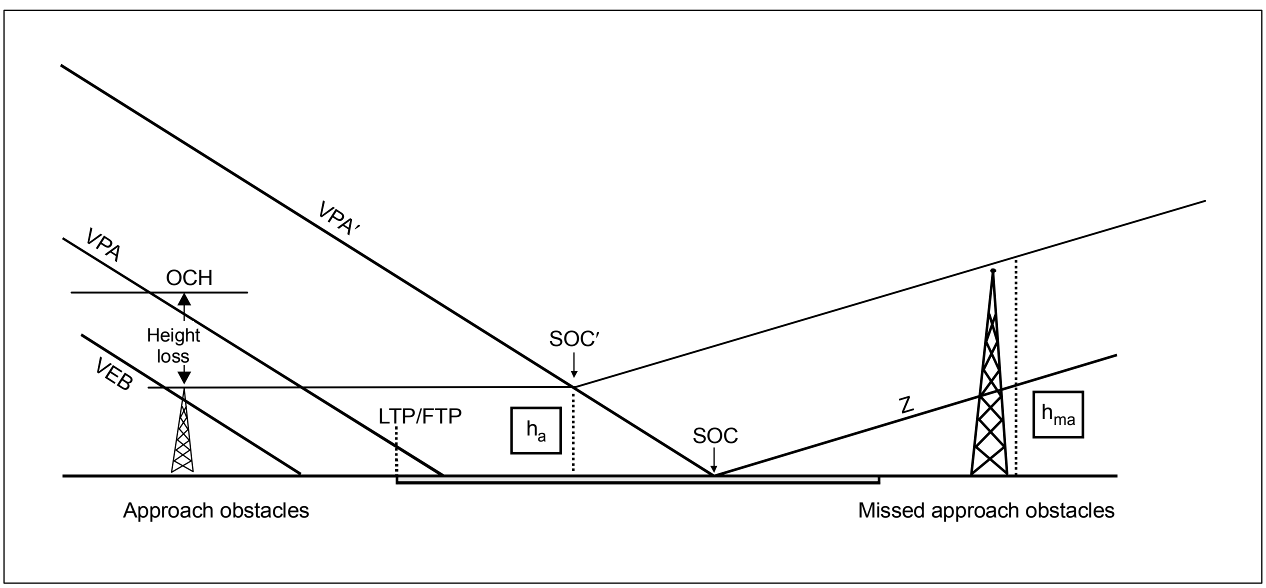

Figure 4-26. Missed approach obstacle after SOC

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).

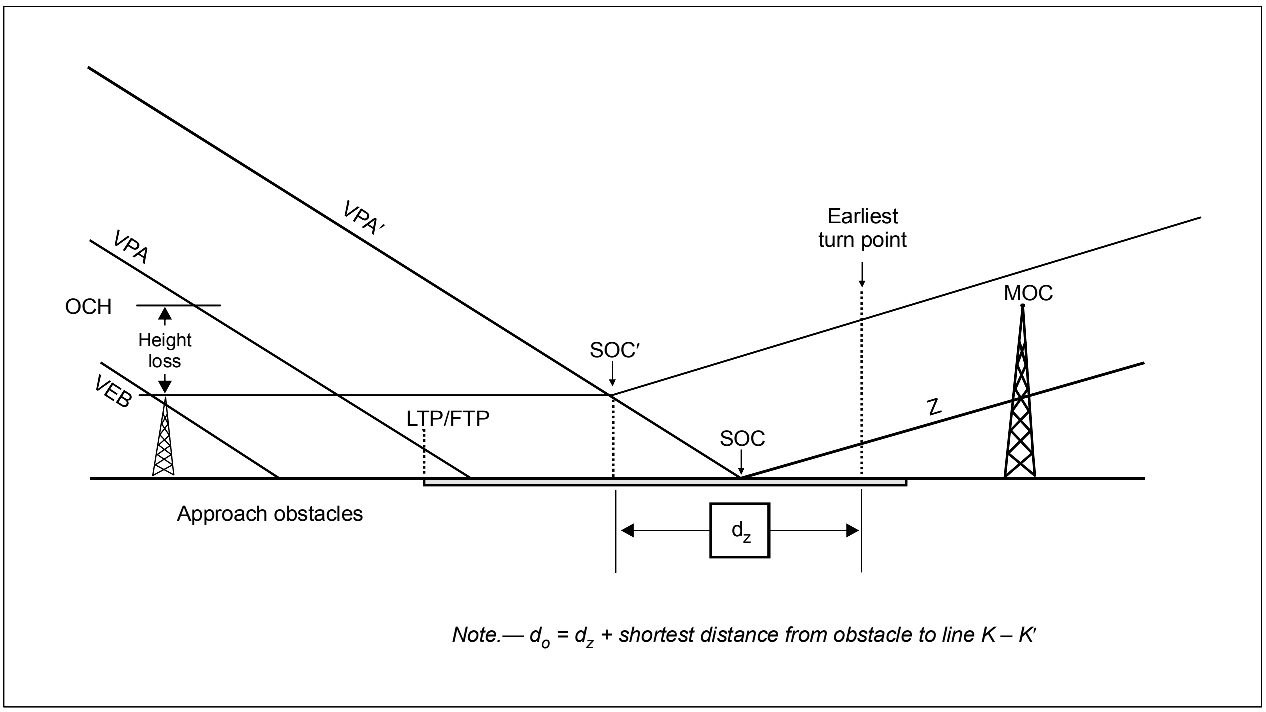

Figure 4-27. Turning missed approach

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 + 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.

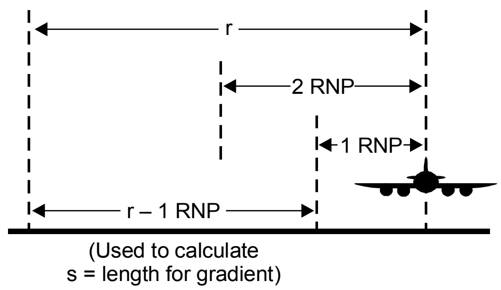

Figure 4-28. Radius for calculating track length for gradient

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

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

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

The atis: 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):

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

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

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

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

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:

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

Three standard deviation formulas for RSS computations:

The anpe: $\text{anpe} = 1.225 \cdot \text{rnp} \cdot \frac{1852}{0.3048} \cdot \tan \text{VPA}$

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

The fte: fte = 75

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

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

The atis: atis = 20

Bias error computations:

The isad: $\text{isad} = \dfrac{(\text{elev} - \text{LTP}_{\text{elev}}) \cdot \Delta\text{ISA}}{288 + \Delta\text{ISA} - 0.5 \cdot 0.00198 \cdot \text{elev}}$

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

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

The anpe:

$$\begin{aligned} \text{anpe} &= 1.225 \cdot \text{rnp} \cdot \frac{1852}{0.3048} \cdot \tan \text{VPA} \\ &= 1.225 \cdot 0.14 \cdot \frac{1852}{0.3048} \cdot \tan 3^\circ \\ &= 54.6117 \end{aligned}$$

The wpr:

$$\begin{aligned} \text{wpr} &= 60 \cdot \tan \text{VPA} \\ &= 60 \cdot \tan 3^\circ \\ &= 3.1445 \end{aligned}$$

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

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

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

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

$$\mathrm{MOC}_{250} = \mathrm{bg} - \mathrm{isad}_{250} + \frac{4}{3}\sqrt{\mathrm{anpe}^2 + \mathrm{wpr}^2 + \mathrm{fte}^2 + \mathrm{ase}_{250}{}^2 + \mathrm{vae}_{250}{}^2 + \mathrm{atis}^2}$$

$$= 40.7902 + 18.7572 + \frac{4}{3}\sqrt{54.6117^2 + 3.1445^2 + 75^2 + 59.2400^2 + 0.8349^2 + 20^2}$$

$$= 208.782$$

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

$$= 40.7902 + 250.432 + \frac{4}{3}\sqrt{54.6117^2 + 3.1445^2 + 75^2 + 77.4680^2 + 11.020^2 + 20^2}$$

$$= 455.282$$

CALCULATING THE OBSTACLE ASSESSMENT SURFACE (OAS) GRADIENT

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

$$\text{OAS gradient} = \frac{(\mathrm{fap} - \mathrm{ltpelev} - \mathrm{MOC}_{\mathrm{FAP}}) - (250 - \mathrm{MOC}_{250})}{\dfrac{\mathrm{FAP} - \mathrm{LTP}_{\mathrm{elev}} - 250}{\tan \mathrm{VPA}}}$$

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

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

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.

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

$$= \left(\frac{250 - 55}{\tan(3)}\right) - \frac{(250 - 208.782)}{0.04817}$$

$$= 2865.179$$

— END —