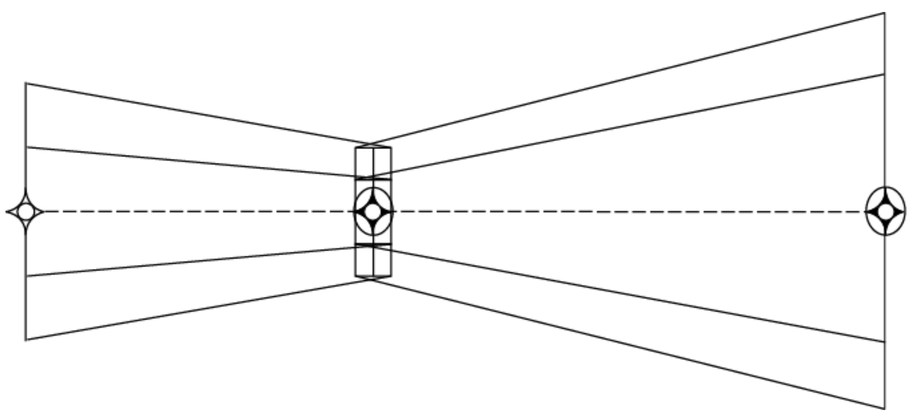
Government of Canada / Gouvernement du Canada

TP 308/GPH 209

CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7



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5 January 2017

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RECORD OF AMENDMENTS

AMENDMENT NO.	EFFECTIVE DATE	DATE ENTERED	ENTERED BY
Change 1	01 July 1996	1 July 1996	Incorporated
Change 2	30 November 2001	30 November 2001	Incorporated
Change 3	15 May 2006	15 May 2006	Incorporated
Change 4	01 January 2008	01 January 2008	Incorporated
Change 5	01 January 2009	01 January 2009	Incorporated
Change 5.2	11 February 2010	11 February 2010	Incorporated
Change 5.3	15 December 2011	15 December 2011	Incorporated
Change 6.0	17 October 2013	17 October 2013	Incorporated
Change 7	5 January 2017	5 January 2017	Incorporated

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FORWARD

This publication prescribes standardized methods for use in designing instrument flight procedures. It is to be used by personnel charged with the responsibility for the preparation, approval and promulgation of instrument procedures. Compliance with criteria contained herein is not a substitute for sound judgment and common sense. These criteria do not relieve procedure designers and supervisory personnel from exercising initiative or taking appropriate action in recognizing both the capabilities and limitations of aircraft and navigational aid performance. These criteria are predicated on normal aircraft operations for considering obstacle clearance requirements.

Obstacle clearance is the primary safety consideration in the development of instrument procedures. Obstruction clearances quoted in this publication are the lowest or smallest values that can be accepted consistent with flight safety.

In the event of a conflict or disaccord between English and French versions of this criteria, the English version is considered the authority.

Recommendations concerning changes or additions should be provided to one of the following:

Department of National Defense (DND)
Division Instrument Check Pilot (DICP)
1 Canadian Air Division Headquarters
PO Box 17000
Station Forces
Winnipeg, MB R3J 3Y5

Transport Canada
Chief of Standards (AARTA)
Aerodromes and Air Navigation
Place de Ville, Tower "C",
330 Sparks St.
Ottawa, ON K1A 0N5

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CHANGE 7 REVISION—CHANGE PAGE

EXPLANATION OF CHANGES

Change 7 to the *Criteria for the Development of Instrument Procedures* (TP308/GPH209) introduces new instrument procedure design criteria for Performance Based Navigation (PBN).

Following the lead of the US Federal Aviation Administration (FAA), all of FAA 8260.58 Performance Based Navigation (PBN) and partial FAA 8260.42B United States Standard for Helicopter Area Navigation (RNAV) are now integrated into TP308/GPH209 Volume 2 – Performance Based Navigation (PBN).

CARs 803.02(b) states that no person shall publish or submit for publishing in the Canada Air Pilot an instrument procedure unless the procedure has been developed by a person who has successfully completed training in the interpretation and application of the standards and criteria specified in the manual entitled Criteria for the Development of Instrument Procedures, which training has been accepted by the Minister.

The volume and chapter numbers are identified on the inside top right corner of the page. The chapter and page numbers (example 1-1) are on the bottom centre of the page. The revision number (Change 7.0) is on the bottom left corner and the date of issue is bottom right. The vertical change lines located outside of the left border indicate modifications or corrections made from TP308/GPH 209 Change 6.0. The change lines were not added to the new Volume 2, Annex F and Vol 1/3 Alphabetical Index.

For administrative purposes, most table and figure numbers have continued to be revised to be compatible with the FAA's Terminal Instrument Procedures Criteria (TERPs). Most tables and diagrams for each chapter remain at or near the text where they are first mentioned.

Training requirements for criteria in adherence to CARs 803.02 is contained in the AC announcing the implementation of a change to the Criteria for the Development of Instrument Procedures (TP308/GPH209).

TP308/GPH209 will be amended as required. Updates and notices will be posted via AC, at:

https://www.tc.gc.ca/eng/civilaviation/opssvs/managementservices-referencecentre-acs-800-menu-512.htm

ADVISORY CIRCULARS

Publication of Change 7 supersedes the following TP 308/GPH 209 ACs:

- AC 803-001, Issue 6, dated 2013-10-11 – TP308/GPH209 – Change 6.0 – Criteria for the Development of Instrument Procedures.
- AC 803-005, Issue 1, dated 2016-01-28, File Transfer Protocol (FTP) site for TP308/GPH209 (Criteria for the Development of Instrument Procedures).

The following TP 308/GPH 209 AC remains in effect:

- AC 803-003, Issue 2, dated 2009-04-09 – TP308/GPH209 – Diverse Departure Climb Gradient.
- AC 803-004, Issue 2, dated 2014-06-30 Restricted Instrument Procedures.

EFFECTIVE DATE

5 January 2017.

Significant areas of new direction, guidance, and policy included in this change are as follows:

<u>Volume 1, General Criteria</u>

(1) **Chapter 1 – Administration**

(a) Para 104. Existing Procedures – Revised;

(b) Para 109. Heliport Geometric Centre (HGC)/Aerodrome Geometric Centre (AGC) – Added;

(c) Para 120. Procedure Development Requirements – Revised;

(d) Para 120. Supplementary Note – Added;

(e) Para 131. Establish And Revise Instrument Procedures – Revised;

(f) Para 132. Periodic Review – Added;

(g) Para 141. Non-Standard Procedures – Revised;

(h) Para 150a. Military Aerodromes – Revised; and

(i) Para 150b. Civil Aerodromes – Revised.

(2) **Chapter 2 – General Criteria**

(a) Figure 2-1a. Note – Revoked;

(b) Para 203. Sloping Obstacle Clearance Surfaces (OCS) – Revised;

(c) Para 203. (Two) Supplementary Note – Added;

(d) Figure 2-1-3. Climb Segment – Revised;

(e) Para 210. Unites of Measurement – Revised;

(f) Para 216. Controlling Obstacle(s) – Added;

(g) Para 216. Supplementary Note – Added;

(h) Para 217. Obstacle Height Assessments – Revised;

(i) Para 218-219. Reserved – Revised;

(j) Para 221. Supplementary Note – Added;

(k) Para 232a. Alignment – Revised;

(l) Formula 2-1. Distance Flown Along Arc, Distance to lead Radial/Bearing. Para 232a. – Revised;

(m) Para 232c. Obstacle Clearance – Revised;

(n) Para 232d. Descent Gradient – Distances Revised;

(o) Figure 2-3. Initial approach intersection angle > than 90 – Revised;

(p) Para 233. Obstacle Clearance – Revised;

(q) Figure 2-4-1. Most Common DR Segment – Revised;

(r) Figure 2-4-2. Example DR Segment – Revised;

(s) Figure 2-4-3. Example DR Segment – Revised;

(t) Figure 2-4-4. Example DR Initial Segment– Revised;

(u) Figure 2-4-5. DR Initial Segment With Boundary Outside – Revised;

(v) Para 234. Initial Approach Segment Based On A Procedure Turn (PT) – Revised;

(w) Table 2-1B: PT Completion Altitude Difference. Para 234d – Revised;

(x) Para 235. Initial Approach Based On High Altitude Teardrop Penetration – Revised;

(y) Figure 2-6a: Obstacle Clearance Areas. Paras 234.c and 235.c. – Revised;

(z) Figure 2-9-1. Example of Initial Course Reversal – Revised;

(aa) Figure 2-9-2. Example of Initial Course Reversal – Revised;

(bb) Figure 2-9-3. Note – Added;

(cc) Para 242. Obstacle Clearance – Revised;

(dd) Para 242. Supplementary Note – Added;

(ee) Para 243. Intermediate Approach Segment Based On An Arc – Revised;

(ff) Para 252. Descent Angle/Gradient – Revised;

(gg) Figure 2-14-9. Final Length Given FAF Altitude – Revised;

(hh) Figure 2-14-11. FAF Net Given Segment Length – Renamed;

(ii) Figure 2-14-11. FAF Net Given Segment Length – Values Revised;

(jj) Para 276. Turning Missed Approach Obstacle Clearance – Revised;

(kk) Para 277. Combination Straight And Turning Missed Approach Area – Revised;

(ll) Para 279. Missed Approach Climb Gradient – Added;

(mm) Figure 2-29. Intermediate Or Initial Approach Fix Errors – Revised;

(nn) Figure 2-29. Note – Added;

(oo) Para 288. Supplementary Note – Added;

(pp) Para 289. Obstacles Close To a FAF or SDF – Revised;

(qq) Para 289. Supplementary Note – Added;

(rr) Figure 2-36a: Obstacle Close-In To A Fix Para 289 – Revised;

(ss) Figure 2-36b. Example Of Obstacle Close In To Fix – Revised; and

(tt) Figure 2-36c. 7:1 Slope Worksheet (Example) – Revised.

(3) **Chapter 3 – Take-Off and Landing Minima**

(a) Para 323c. Remote Altimeter Setting Source (RASS) – Revised;

(b) Figure 3-37c. Elevation Differential Area (EDA) – Revised;

(c) Table 3-1. Standard Straight-in And Circling Minima – Revised;

(d) Table 3-2. Non-Precision Minima Visibility Matrix. – Revised; and

(e) Table 3-5. Minimum HAT for PA and APV – Renamed.

(4) **Chapter 4 – On-Airport VOR (No FAF)**

(a) Para 413c. Obstacle Clearance – Revised; and

(b) Para 423. Final Approach Segment – Revised.

(5) **Chapter 5 – TACAN, VOR/DME AND VOR WITH FAF**

(a) Para 500. General – Revised;

(b) Para 513. Final Approach Segment – Revised;

(c) Para 523. Final Approach Segment – Revised;

(d) Figure 5-51a. Minimum Obstacle Clearance – Revised; and

(e) Figure 5-54a. Minimum Obstacle Clearance – Revised.

(6) **Chapter 6 – NDB PROCEDURE ON-AIRPORT FACILITY, NO FAF**

(a) Figure 6-55. Alignment Options for Final Approach Course – Revised;

(b) Figure 6-55. Supplementary Note – Added; and

(c) Figure 6-57a. Secondary ROC – Revised.

(7) **Chapter 7 – NDB WITH FAF**

(a) Para 713. Final Approach Segment – Revised;

(b) Table 7-15. Minimum Length of Final Approach Segment – NDB (NM) – Formatting; and

(c) Figure 7-66a: Minimum Obstacle Clearance – Revised.

(8) **Chapter 8 – EMERGENCY VHF/UHF DF PROCEDURES**

(a) Para 811b. Obstacle Clearance – Revised;

(b) Para 812. Intermediate Approach Segment – Revised; and

(c) Para 813. Final Approach Segment – Revised.

(9) **Chapter 9 – LOCALIZER**

(a) Para 901. Use of Localizer Only – Revised; and

(b) Para 903. Area – Revised.

(10) **Chapter 12 – DEPARTURE PROCEDURE**

(a) Para 1200. General – Revised;

(b) Para 1202. Diverse Departures – Revised;

(c) Para 1205c. Climb gradients – Revised;

(d) Para 1208. Required Minima – Revised;

(e) Para 1208. Supplementary Note – Added;

(f) Para 1209. Visual Climb Over Airport (VCOA) – Revised;

(g) Para 1210. Supplementary Note – Added;

(h) Para 1211. Establishment of Altitude For Visual Climb Area – Revised;

(i) Para 1212. Straight Departure Area – Revised;

(j) Para 1213. Published Annotations – Added;

(k) Table 12-1. Departure Turn Radii – Formatting;

(l) Table 12-2 Visual Climb Area Radii – Formatting;

(m) Figure 12-116A. Zone 1 Diverse Departure – Revised;

(n) Figure 12-116E. Supplementary Note – Added;

(o) Figure 12-116F. Supplementary Note – Added;

(p) Figure 12-117. Variations of DR Straight Departure Areas – Revised;

(q) Figure12-118. Variations of a straight departure area to a NAVAID – Revised; and

(r) Figure12-118. Supplementary Note – Added.

(11) **Chapter 17 – EN ROUTE CRITERIA**

(a) Para 1715a. (4) Connecting lines – Revised;

(b) Para 1721. Obstacle Clearance, Secondary Areas – Revised;

(c) Figure 17-9. Airplane to drawing– Added;

(d) Figure 17-17. Cross Section, Secondary Area Obstacle Clearances – Revised;

(e) Figure 17-18. Plan View, Secondary Area Obstacle Clearances – Revised;

(f) Figure 17-19. Secondary Obstacle Clearance – Revised; and

(g) Figure 17-27. LF Segment Obstacle Clearance Area beyond 25 NM From Enroute Facility – Formatting.

(12) **Chapter 18 – HOLDING CRITERIA**

(a) Figure 18-3. DME Slant Range Distance – Revised; and

(b) Figure 18-9. Holding Template – Revised.

(13) **Alphabetical Index – Added**

<u>Volume 2, Performance Based Navigation (PBN) Construction</u>

(1) **Chapter 1 – PURPOSE** – Added;

(2) **Chapter 2 – BASIC CRITERIA INFORMATION** – Added;

(3) **Chapter 3 – GENERAL INFORMATION** – Added;

(4) **Chapter 4 – RNAV AND RNP DEPARTURE PROCEDUES** – Added;

(5) **Chapter 5 – TERMINAL ARRIVAL AREA (TAA) DESIGN** – Added;

(6) **Chapter 6 – STANDARD FOR REQUIRED NAVIGATION PERFORMANCE (RNP) APPROACH PROCEDURES WITH AUTHORIZATION REQUIRED (AR)** – Added;

(7) **Chapter 7 –AREA NAVIGATION (RNAV)** – Added;

(8) **Chapter 8 – STANDARD FOR HELICOPTER AREA NAVIGATION (RNAV)** – Added;

(9) **Appendix A. TERPS Standard Formulas for Geodetic Calculations** – Added; and

(10) **Appendix B. Initial Climb Area (ICA) Concept** – Added.

Volume 3, Precision Approach (PA) & Baro VNAV Approach Procedure Construction

(1) **Chapter 2 – General Criteria**

(a) Para 2.6.1c. Supplementary Note – Added;

(b) Para 2.9 Determining PFAF/FAF Coordinates – Revised;

(c) Para 2.9.1 Distance Measuring Equipment (DME) – Revised;

(d) Para 2.9.1 Supplementary Note – Added;

(e) Para 2.11.1. Area – Revised;

(f) Figure 2-6 Category II Critical Areas – Reference Removed; and

(g) Formula 2-2b. GQS Half-Width at RWT – Renamed & Revised.

(2) **Chapter 3 – Precision Final and Missed Approach Segments**

(a) Para 3.4.2 Height – Revised;

(b) Para 3.8.1 GPI Distance – Renamed;

(c) Para 3.9.1 Section 1 – Renamed;

(d) Para 3.9.1b. Section 1b. – Revised;

(e) Para 3.9.1d. (2) Turning Missed Approach – Revised;

(f) Para 3.9.1. Supplementary Note – Added;

(g) Para 3.9.2 RESERVED – Revised;

(h) Figure 3.6 X OCS – Renamed;

(i) Figure 3-11A. Straight Missed Approach – Reference Change; and

(j) Figure 3-11B. Turning Missed Approach – Reference Change.

(3) **Appendix 1 – Vertically-Guided Approach Obstacle Assessment and CAT II/III ILS Requirements**

(a) Para 1.0 General – Reference Change;

(b) Para 2.2.1 Glide Slope Antennas – Revised;

(c) Table 1. Acceptable Obstructions – Revised;

(d) Para 6.7 Approach Minimums – Revised;

(e) Para 6.8.2 Penetrations of the primary (W,X) surfaces are not authorized – Reference Change; and

(f) Para 6.9.1 Section 1 – Revised.

(4) **Alphabetical Index – Added**

Volume 4, Departure Procedure Construction

(1) NO CHANGE.

Volume 5, Helicopter Instrument Procedure Construction

(1) **Chapter 1. Helicopter Procedures**

(a) Para 101. Terminology And Abbreviations – Revised;

(b) Para 110. Descent Gradient – Revised;

(c) Para 111(a) Alignment – Revised;

(d) Para 112. Initial Approach Based On Procedure Turn – Revised;

(e) Para 114. Intermediate Approach Segment Based On An Arc – Revised;

(f) Para 126. Altitudes – Revised; and

(g) Para 127. Visibility – Revised.

(2) **Chapter 2. Helicopter Global Positioning System (GPS) Non-Precision Approach Criteria** – Revoked.

Annexes

(1) **Annex A – Glossary**

(a) Controlling obstacle – Revised.

(2) **Annex B – Minimum Vectoring Altitude**

(a) NO CHANGE.

(3) **Annex C – Procedures**

(a) NO CHANGE.

(4) **Annex D –Obstacle Limitation Surface (OLS) versus Obstacle Clearance Surfaces (OCS)**

(a) NO CHANGE.

(5) **Annex E – Terrain and Obstacle Data (TOD)**

(a) NO CHANGE.

(6) **Annex F – Precipitous Terrain Calculations** – Added.

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CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

VOLUME 1

GENERAL CRITERIA

TRANSPORT CANADA
NATIONAL DEFENCE

5 January 2017

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CHAPTER 1. ADMINISTRATION

100. Purpose

This manual contains the criteria that shall be used to formulate, review, approve and publish instrument procedures within Canada.

101. ICAO Annexes

No person shall introduce new or modify existing aeronautical information included in the Integrated Aeronautical Information Package of Canada, except:

a. in accordance with the standards set out in Annexes 4 and 15 to the Convention; and

b. in accordance with the processes and procedures established by the provider of aeronautical information services to meet the standards of Annexes 4 and 15 to the Convention.

Where ICAO Annexes 4 & 15 refers to PANS-OPS Doc 8168, reference shall be made to the applicable section(s) of the Criteria for the Development of Instrument Procedures (TP308/GPH209).

102. Reserved

103. Cancellation

This document supersedes all previous editions of TC TP308/DND GPH209, Criteria for the Development of Instrument Procedures.

104. Existing Procedures

Existing procedures, when subject to periodic review, shall be assessed for changes to criteria to determine if action to revise the procedure is required. New procedures shall be developed in accordance with these standards and criteria.

105. Type of Procedure

For use in Table 1-1 third column “type of procedure”

a. Precision Approach (PA)

An approach based on a navigation system that provides positive course and vertical path guidance conforming to ILS, MLS or PAR system performance standards contained in ICAO Annex 10.

b. Non-Precision Approach (NPA)

An approach which provides final course or lateral guidance. No vertical guidance is provided on an NPA. Types include but are not limited to NDB, VOR, LOC and certain RNAV approaches (etc. LNAV, LP)

c. Approach Procedure with Vertical Guidance (APV)

Approach type with stabilized descent using vertical guidance. APVs are divided into two types, those that use vertical guidance provided by:

(1) **Lateral Navigation / Vertical Navigation (LNAV/VNAV)** a path derived by the Baro-altimeter and the flight management systems, and

(2) **Localizer Performance with Vertical Guidance (LPV)** where the vertical guidance is provided by the Wide Area Augmentation System (WAAS).

106. Operating Minima

For use with Table 1-1 first column “NAVAID / Approach System Capability”

Approach operations are classified based on the lowest designed operating minima as:

a. Non precision: At or above 250 ft; and

b. Precision: below 250 ft.

107. Types of Instrument Procedures

Criteria are provided for the following types of authorized instrument procedures

a. Departure procedures

b. Enroute procedures

c. Holding procedures

d. Arrival procedures

e. Instrument approach procedures

108. Height Above Touchdown (HAT)/ Height Above Threshold (HATh)

Throughout this document all references to “HAT” should be interpreted to read “Height Above Touchdown/ Height Above Threshold “HAT/HATh” (as applicable)

109. Heliport Geometric Centre (HGC)/Aerodrome Geometric Centre (AGC)

For the purpose of this publication, all references to Heliport Reference Point (HRP) or Aerodrome Reference Point (ARP) within this document (or referenced by this document), is to be interpreted to mean Heliport Geometric Centre (HGC) or Aerodrome Geometric Centre (AGC) respectively, except as otherwise noted.

110—119. Reserved

120. Procedure Development Requirements

Prior to the publishing of any instrument procedure, the following associated minimum standards shall be met:

- **a. Aerodrome**. Table 1-1 represents the type of instrument procedure, associated minima and application (public or restricted use) authorized for any combination of NAVAID/approach system capability versus the landing surface and applicable aerodrome design standards or aerodrome authorization. Table 1-1 does not apply to PINSA procedures or non-instrument Heliports.
- **b. Navigation Facility**. All electronic and visual navigation facilities used shall meet the applicable standard and the requirements of flight inspection and calibration.
- **c. Obstruction** Marking and Lighting. Buildings, structures and objects, including objects of natural growth shall be marked and lighted in accordance with CAR 621.19, Standards *Obstruction Markings* or DND CETO C-98-01 0-003/MG-004.
- **d. Altimeter Setting Source**. All instrument approach procedures shall be predicated on the availability of an approved altimeter-setting source in accordance with CAR 804.01. See Para 323.c.
- **e. Communications**. In controlled airspace air-to-ground communications with an ATS facility shall be available at the initial approach fix minimum altitude and at the missed approach clearance limit altitude. At lower altitudes communications shall be required where essential to the safe and efficient use of airspace. Air-to-ground communication normally consists of UHF or VHF radio, but other communications may be approved at locations that have a special need and capability.
- **f. Flight Check**. All instrument approach procedures, departure procedures, airways and air routes shall be flight checked prior to approval and at least once within a 5 year period for existing procedures. Flight checks shall be conducted by a person who has successfully completed training in the interpretation and application of the criteria found in this publication. ***Guidance material for Flight checks can be found in ICAO DOC 9906.***

121. Retention and Cancellation

Before an instrument procedure is cancelled, coordination with civil and military users shall be effected. Care shall be taken not to cancel procedures required by the military or required by air carrier operators at provisional or alternate airports. Military procedures shall be retained or cancelled as required by the appropriate military authority.

122—129. Reserved

130. Responsibility

a. Military Aerodromes. The DND shall establish and approve terminal instrument procedures for aerodromes under their jurisdiction and be responsible for the publication of these procedures.

b. Civil Procedures at Military Aerodrom*es*. At those military aerodromes where a need for civil approach procedures is identified, the appropriate civil authority shall coordinate with the DND and the procedure sponsor, before any approval/ publication/ revision/ cancellation of such procedures.

c. Civil Aerodromes. The appropriate civil authority shall establish terminal instrument procedures for civil aerodromes in accordance with this publication and be responsible for the publication of these procedures.

d. Military Procedures at Civil Aerodromes. At those civil aerodromes where the DND has a special requirement for approach or departure procedures the DND shall formulate, coordinate with the appropriate civil authorities, approve and publish such procedures. The civil authority shall be informed prior to cancellation of any of these DND procedures.

131. Establish And Revise Instrument Procedures

DND or the appropriate civil authority shall establish or revise terminal instrument procedures when:

a. new facilities are installed;

b. changes to existing facilities necessitate a change to an approved procedure;

c. additional procedures are necessary;

d. new obstacles dictate revision of existing procedures.

e. an operational assessment dictates;

f. there is a change to standards or criteria that may affect flight safety; or

g. there is a change to airspace structure.

132. Periodic Review

All procedures shall be subjected to a periodic review. The maximum interval for this review is five years.

133—139. Reserved

Certified Aerodromes			TP308	
NAVAID/ Approach System Capability	**Landing Surface**	**Type of Procedure**	**Minima Authorized**	**Application**
Precision	Precision	PA CAT I, II, III, NPA or APV	Applicable Minima	Public or Restricted
Precision	Non-Precision	PA, NPA or APV	250 feet HAA/HAT	Public or Restricted
Precision	Non-Instrument	PA, NPA or APV	500 feet HAA/HAT	Public or Restricted
Non-Precision	Precision	NPA or APV	250 feet HAA/HAT	Public or Restricted
Non-Precision	Non-Precision	NPA or APV	250 feet HAA/HAT	Public or Restricted
Non-Precision	Non-Instrument	NPA or APV	500 feet HAA/HAT	Public or Restricted
Non-Certified Aerodromes			**TP308**	
NAVAID/ Approach System Capability	**Aerodrome Authorization Landing Surface**	**Type of Procedure**	**Minima Authorized**	**Application**
Precision	Non-Precision	PA, NPA or APV	250 feet HAA/HAT	Restricted
Precision	Non-Instrument	PA, NPA or APV	500 feet HAA/HAT	Restricted
Non-Precision	Non-Precision	NPA or APV	250 feet HAA/HAT	Restricted
Non-Precision	Non-Instrument	NPA or APV	500 feet HAA/HAT	Restricted
NAVAID/ Approach System Capability	**Aerodrome Operator Attestation (1)**	**Type of Procedure**	**Minima Authorized**	**Application**
Precision	Non-Precision	PA, NPA or APV	250 feet HAA/HAT	Public or Restricted
Precision	Non-Instrument	PA, NPA or APV	500 feet HAA/HAT	Public or Restricted
Non-Precision	Non-Precision	NPA or APV	250 feet HAA/HAT	Public or Restricted
Non-Precision	Non-Instrument	NPA or APV	500 feet HAA/HAT	Public or Restricted
NAVAID/ Approach System Capability	**No Aerodrome Status**	**Type of Procedure**	**Minima Authorized**	**Application**
Precision, Non-Precision	Landing surface designed to no standards	PA, NPA or APV	500 feet HAA/HAT	Restricted

Note: (1) Operational note providing wingspan advisory information shall be published on the instrument procedure approach plate.

Table 1-1: Instrument Procedure & Minima Authorized Versus Aerodrome Status, Para 120.a.

140. Formulation

Procedures shall be prepared in accordance with this publication as determined by the types of navigation facility and procedure to be used. To permit use by aircraft with limited navigational equipment the complete procedure should be, whenever possible, formulated on the basis of a single navigation facility. However, the use of an additional facility in the procedure may be considered if its use would provide an operational advantage.

141. Non-Standard Procedures

The standards contained in this publication are based on reasonable assessment of the factors that contribute to flight technical errors in aircraft navigation and maneuvering, and errors in airborne and ground facility accuracy. They are designed primarily to assure the safety of all users. The dimensions of obstacle assessment areas are influenced by the need to provide for a smooth transition to and from the en route system. Every effort shall be made to formulate procedures in accordance with these standards and criteria; however, peculiarities of terrain, navigation information, obstacles, etc. may require special consideration. In such cases, Transport Canada or Department of National Defense (DND), as appropriate, may approve non-standard procedures provided the deviations are fully documented and an equivalent level of safety exists. A non-standard procedure is not a substandard procedure, but is one that has been approved after special study of the local problems has demonstrated that no degradation of safety is involved. These procedures must also include a cautionary note identifying the divergence from the standards or criteria.

142—149. Reserved

150. Coordination

It is necessary to coordinate terminal instrument procedures to protect the interests of all users of airspace.

a. Military Aerodromes. Military and/or civilian procedures at a military aerodrome shall be coordinated with the appropriate base authorities. When a military and/or civilian procedure conflicts with other military/civil activities it shall be coordinated with all appropriate authorities concerned. Coordination shall occur between the procedure sponsor, procedure designer, the appropriate military (DND) authorities and the appropriate civil AIS Authority.

b. Civil Aerodromes. Prior to establishing or revising terminal instrument procedures related to aircraft performance, e.g., descent profiles, the appropriate civil authority shall coordinate with the appropriate users as considered necessary. Coordination with DND is required when a military operating unit is based at a civil aerodrome or when the proximity of a military aerodrome may cause a procedural conflict. New or revised military procedures at civil aerodromes shall be coordinated by the appropriate Wing Instrument Check Pilot (WICP) and the civil AIS Authority. Complete coordination will be evidenced by the appropriate signatures being included in the Instrument Procedure Design File. Required signatures include the procedure designer, independent reviewer, flight check pilot, and applicable Air Traffic Services (ATS) representative.

c. Air Traffic Control. Prior to establishing or revising terminal instrument procedures for a military or civil aerodrome, the initiating office shall coordinate with the appropriate Air Traffic Control office.

d. Airspace Action. Where action to designate or restructure controlled airspace for a procedure is planned, such action shall be approved by Transport Canada AARTA and should be initiated sufficiently in advance so that effective dates of the procedure and the airspace action coincide. Effective dates should also coincide with approved AIRAC dates.

e. NOTAM. A NOTAM to change minimum altitudes may be issued in case of emergencies, i.e., facility outages, facility out of tolerance, new penetrations of critical surfaces, etc. However, a complete new procedure may not be issued by NOTAM, except where military requirements dictate.

151. Coordination Conflicts

Coordination conflicts amongst stakeholders that cannot be satisfactorily resolved by the AIS Authority shall be submitted to Transport Canada and/or the appropriate Military Aeronautical Authority for resolution.

152. – 159. Reserved

160. Identification of Procedures.

Instrument procedures shall be identified to be meaningful to the pilot, and to permit ready identification in ATC phraseology.

161. Straight-In Procedure Identification.

Instrument procedures that meet criteria for authorization of straight-in landing minima shall be identified by a prefix describing the navigational system providing the final approach guidance and the runway to which the final approach course is aligned:

a. General – The following items shall be included in procedure identification of straight-in procedures.

(1) The acronym for the navigational system used for guidance on the final approach segment
(2) The acronym "RWY" to denote a straight-in procedure
(3) The runway number of the straight-in runway

Example(s): VOR RWY 18R

b. Duplicate Procedures – When there is more than one separately published procedure using the same final approach guidance to the same runway, a duplicate procedure character shall be used to uniquely identify the approach procedures. This character shall begin with "Z" and proceed through the alphabet in reverse order.

Example(s): ILS Z RWY 28L RNAV (GNSS) Z RWY 12
ILS Y RWY 28L RNAV (RNP) Y RWY 12

c. Multiple Procedures – When procedures are combined on one chart, the word 'or' shall indicate that either type of equipment may be used to execute the final approach.

Example(s): ILS or NDB RWY 02

d. DME Requirement – if DME is required for a VOR or NDB procedure, then a slash "/" followed by "DME" shall be included in the identification.

Example(s): VOR/DME RWY 18 NDB/DME RWY 27L

e. Northern Domestic Airspace – When the procedure is within northern domestic airspace and the procedure tracks are specified in true degrees, the procedure identification may be suffixed with "(TRUE)".

Example(s): RNAV (GNSS) RWY 34 (TRUE)

f. Non-RNAV – Conventional procedures identification examples include:

(1) Category 2 or 3 Instrument Landing System (ILS CAT II or III)
....ILS CAT II or III RWY 05
(2) Category 1 Instrument Landing System (ILS)..................................ILS RWY 24R
(3) Microwave Landing System (MLS)...MLS RWY 12
(4) Localizer Only (LOC) ....LOC RWY 06
(5) Localizer Back Course (LOC(BC)) .... LOC (BC) RWY 18
(6) VHF Omni Directional Range (VOR)... VOR RWY 27
(7) VOR with Distance Measuring Equipment (DME) .... VOR/DME RWY 27R

(8) Tactical Air Navigational Aid (TACAN) .... TACAN RWY 09

(9) Non Directional Beacon (NDB)... NDB RWY 12

(10) NDB with DME...NDB/DME RWY 12

g. RNAV – Area Navigation (RNAV) procedures identification examples include:

(1) RNAV based on the Global Navigation Satellite System (GNSS)

....RNAV (GNSS) RWY 12

(2) RNAV based on Required Navigational Performance (RNP)

.... RNAV (RNP) RWY 29R

(3) Ground Based Augmentation System (GBAS) Landing System (GLS)

....GLS RWY 06

162. Circling Procedure Identification.

Instrument procedures which do not meet criteria for authorization of straight-in landing minima shall be identified by a prefix describing the navigational system providing the final approach guidance and an alphabetical suffix. The first procedure formulated shall bear the suffix “A” even though there may be no intention to formulate additional procedures. If additional procedures are formulated they shall be identified alphabetically in sequence. A revised procedure will bear its original identification.

Example(s): RNAV (GNSS) A VOR B
NDB/DME C (TRUE)

163. Differentiation.

Where high altitude procedures are required, the procedure identification shall be prefixed with the letters “HI”.

Example(s): HI TACAN RWY 15.

164. – 169. Reserved

170. Submission

Instrument procedures shall be submitted as detailed by NAV CANADA.

- **a.** DND procedures shall be submitted by the designer in accordance with GPH 209 and 1 Cdn Air Div Orders, Vol 2, 2-009, instruction for Developing and Revising Instrument Procedures. A proper and complete submission shall include copies of all maps and calculations used in the development of the procedure and a sufficient number of copies of the completed draft to provide all intermediate agencies with at least one copy.
- **b.** Civil procedures (public or restricted) shall be submitted in accordance with NAV CANADA process and procedures.
- **c.** When a procedure is submitted it shall show the name and signature of the Designer, Independent Reviewer, Flight Check Pilot, and the individual responsible for ATS coordination.

171. Issuance

- **a.** DND is responsible for the release of military approved instrument procedures.
- **b.** NAV CANADA is responsible for the release and distribution of all other instrument procedures.

172. Effective Date

Instrument procedures and revisions thereto shall be processed in sufficient time to permit publication and distribution in advance of the effective ICAO, Aeronautical Information Regulation and Control (AIRAC) date. Effective dates should normally coincide with scheduled airspace changes except when safety or operational effectiveness is jeopardized. In this case the originator shall specify an appropriate effective date.

173—179. Reserved

180. TP308/GPH209 Amendment Procedures

Amendments to TP308/GPH209 should normally be produced once per year. Bases/Agencies may submit amendment proposals to DICP/Transport Canada AARTA at anytime. DICP and Transport Canada AARTA staffs shall meet to review proposals for incorporation as appropriate. DND/TC Aviation will liaise with the DOD/FAA regarding U.S. TERPS.

181. Amendment Printing/Distribution

DICP and TC AARTA shall incorporate the adopted amendments into TP308/GPH209. Transport Canada AARTA shall prepare the amendment directive and coordinate the publishing requirements.

182—199. Reserved

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CHAPTER 2. GENERAL CRITERIA

200. Scope

This chapter contains only that information common to all types of terminal instrument procedures. Criteria that do not have general application are located in the individual chapters concerned with the specific types of facilities.

SECTION 1. COMMON INFORMATION

201. TP308/GPH209 Criteria

a. TP308/GPH209 specifies the minimum measure of obstacle clearance that is considered by Transport Canada, to supply a satisfactory level of vertical protection. The validity of the protection is dependent, in part, on assumed aircraft performance. In the case of TP308/GPH209, it is assumed that aircraft will perform within certification requirements.

b. The following is an excerpt from the foreword of this document: "These criteria are predicated on normal aircraft operations for considering obstacle clearance requirements." Normal aircraft operation means all aircraft systems are functioning normally, all required navigational aids (NAVAID's) are performing within flight inspection parameters, and the pilot is conducting operations utilizing instrument procedures based on TP308/GPH209 standards to provide the required obstacle clearance (ROC). While the application of TP308/GPH209 criteria indirectly addresses issues of flyability and efficient use of NAVAID's, the major safety contribution is the provision of obstacle clearance standards. This facet of TP308/GPH209 allows aeronautical navigation in instrument meteorological conditions (IMC) without fear of collision with unseen obstacles. ROC is provided through application of level and sloping Obstacle Clearance Surfaces (OCS).

202. Level OCS.

The level OCS concept is applicable to “level flight” segments. These segments are level flight operations intended for en route, initial, intermediate segments, and non-precision final approaches. A single ROC value is applied over the length of the segment. These values were determined through testing and observation of aircraft and pilot performance in various flight conditions. Typical ROC values are: for en route procedure segments, 1,000 feet (1,500 or 2,000 over mountainous terrain), as designated in TP1820 - Designated Airspace Handbook; and for initial segments, 1,000 feet, 500 feet in intermediate segments, and 350/300/250 feet in final segments.

a. This method of applying ROC results in a horizontal band of airspace that cannot be penetrated by obstacles. Since obstacles always extend upward from the ground, the bottom surface of the ROC band is mathematically placed on top of the highest obstacle within the segment. The depth (ROC value) of the band is added to the obstacle height to determine the minimum altitude authorized for the segment. The bottom surface of the ROC band is referred to as the level OCS. Therefore, level flight segments are evaluated by the level OCS application standard (see Figure 2-1-1).

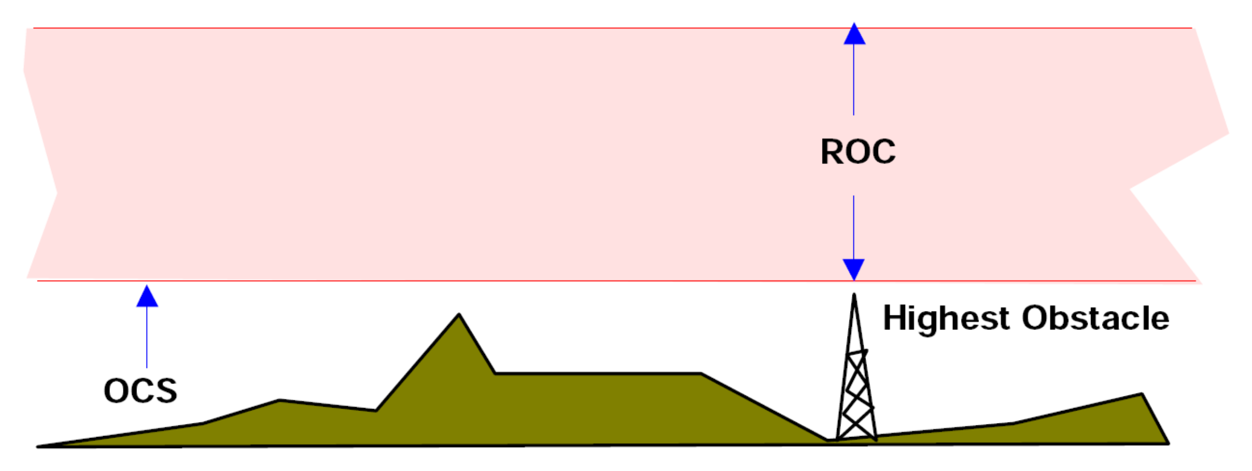


Figure 2-1-1: Minimum Segment Altitude. Para 202.a.

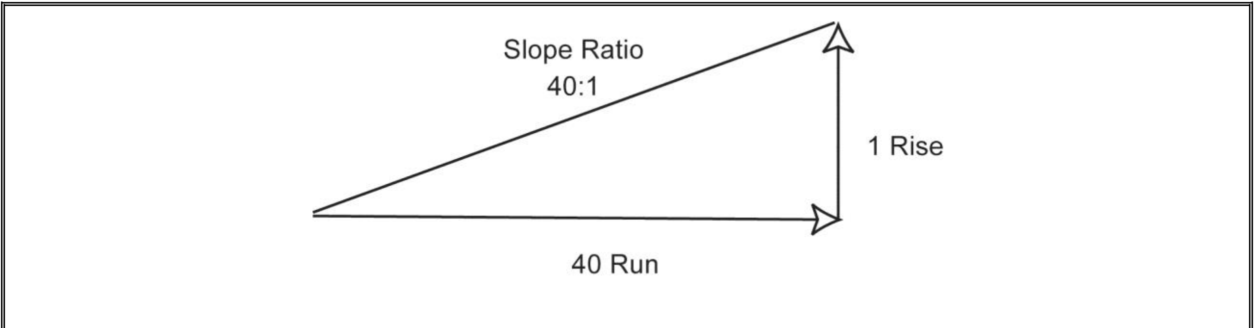


Figure 2-1a: Slope Ratio. Para 203.

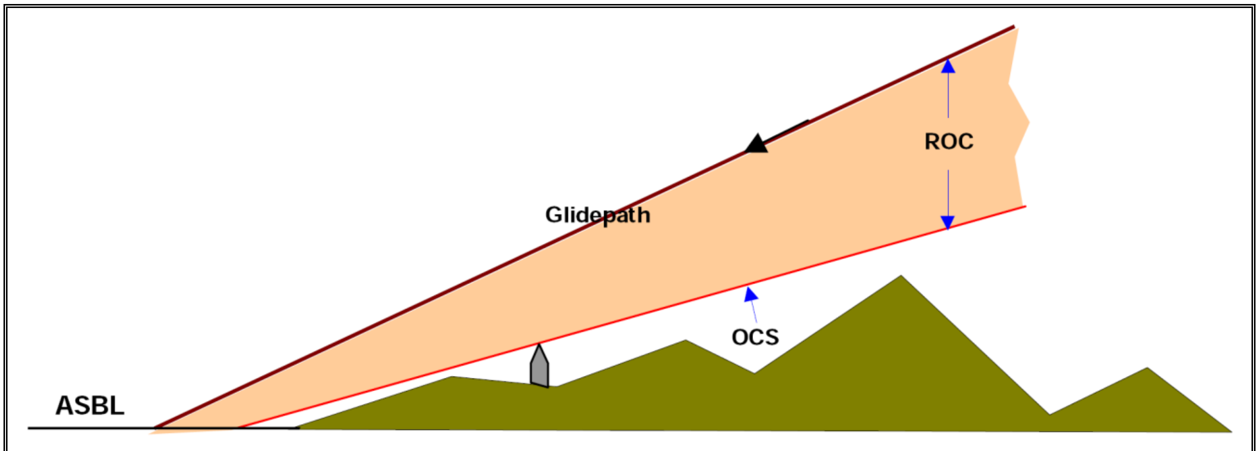


Figure 2-1-2: Precision Glide Path Descent. Para 203.a.

203. Sloping Obstacle Clearance Surfaces (OCS).

The method of applying ROC, in segments dedicated to descending on a glidepath or climbing in a departure or missed approach segment, requires a different obstacle clearance concept than the level OCS because the ROC value must vary throughout the segment. The value of ROC near the runway is relatively small, and the value at the opposite end of the segment is sufficient to satisfy one of the level surface standards as per Para 202. It follows then, that a sloping OCS is a more appropriate method of ROC application.

Supplementary Note: Slope ratios are normally expressed in terms of rise over run in engineering and professional technical jargon. However, TP308/GPH209 has traditionally expressed slope ratios in terms of run over rise; e.g., 34:1, 40:1 (see Figure 2-1a).

a. Descending on a Precision Glidepath. The obstacle evaluation method for descent on a glidepath is the application of a descending OCS below the glidepath. The vertical distance between the glidepath and the OCS is ROC; i.e., ROC = (glidepath height) - (OCS height). The ROC decreases with distance from the FAF as the OCS and glidepath converge on the approach surface baseline (ASBL) height (see Figure 2-1-2). The OCS slope and glidepath angle values are interdependent: OCS Slope = 102 ÷ glidepath angle; or glidepath angle = 102 ÷ OCS slope. This relationship is the standard that determines the ROC value since ROC = (glidepath height)-(OCS height).

(1) If the OCS is penetrated, the OCS slope may be adjusted upward, thereby increasing the glidepath angle. The glidepath angle would increase because it is dependent on the required slope.

(2) Descent on a glidepath generated by systems that do not meet the system precision requirements of ICAO Annex 10, such as barometric vertical navigation (BARO-VNAV), provide ROC through application of a descending sloping surface based on standards using differing formulas, but the concept is the same.

b. Climbing on departure or missed approach. The concept of providing obstacle clearance in the climb segment, in instrument procedures, is based on the aircraft maintaining a minimum climb gradient. The climb gradient must be sufficient to increase obstacle clearance along the flightpath so that the minimum ROC for the subsequent segment is achieved prior to leaving the climb segment (see Figure 2-1-3). For TP308/GPH209 purposes, the MINIMUM climb gradient that will provide adequate ROC in the climb segment is 200 ft/NM (400 ft/NM for COPTER procedures) unless a higher gradient is specified.

(1) The obstacle evaluation method for a climb segment is the application of a rising OCS below the minimum climbing flightpath. Whether the climb is for departure or missed approach is immaterial. The vertical distance between the climbing flightpath and the OCS is ROC. ROC for a climbing segment is defined as ROC = 0.24CG. This concept is often called the 24% rule. Altitude gained is dependent on climb gradient (CG) expressed in feet per NM. The minimum ROC supplied by the 200 ft/NM CG is 48 ft/NM (0.24 x 200 = 48). Since 48 of the 200 feet gained in 1 NM is ROC, the OCS height at that point must be 152 feet (200 – 48=152), or 76% of the CG (152 ÷ 200=0.76). The slope of a surface that rises 152 over 1 NM is 40 (6076.11548 ÷ 152 = 39.97 = 40).

(2) Where an obstruction penetrates the OCS, a climb gradient in excess of 200 feet/NM (400 feet/NM for COPTER procedures) is required to provide adequate ROC. Since the climb gradient will be greater than 200 ft/NM, ROC will be greater than 48 ft/NM (0.24 x CG>200=ROC>48). The ROC expressed in ft/NM can be calculated using the

formula: (0.24h) ÷ (0.76d) where "h" is the height of the obstacle above the altitude from which the climb is initiated, and "d" is the distance in NM from the initiation of climb to the obstacle. Normally, instead of calculating the ROC value, the required climb gradient is calculated directly using the formula: h ÷ (0.76d). Refer to Volume 2 for PBN climb gradient calculations.

Supplementary note: Military Option Climb Gradient for departure and missed approach will provide 48 ft of ROC for each NM of the flight path.

c. In the case of an instrument departure, the OCS is applied during the climb until at least the minimum en route value of ROC is attained. The OCS begins at the departure end of runway, at the elevation of the runway end. It is assumed aircraft will cross the departure end-of-runway at a height of at least 35 feet. However, for TP308/GPH209 purposes, aircraft are assumed to lift off at the runway end (unless the procedures state otherwise). The ROC value is zero at the runway end, and increases along the departure route until the appropriate ROC value is attained to allow en route flight to commence.

d. In the case of a missed approach procedure, the climbing flight path starts at the height of MDA or DA minus height loss. The OCS starts approximately at the MAP/DA point at an altitude of MDA/DA minus the final segment ROC and adjustments. Therefore, the final segment ROC is assured at the beginning of the OCS, and increases as the missed approach route progresses. The OCS is applied until at least the minimum initial or en route value of ROC is attained, as appropriate.

e. Extraordinary circumstances, such as a mechanical or electrical malfunction, may prevent an aircraft from achieving the 200 ft/NM minimum climb gradient assumed by TP308/GPH209. In these cases, adequate obstacle clearance may not be provided by published instrument procedures. Operational procedures contained outside TP308/GPH209 guidelines are required to cope with these abnormal scenarios.

204—209. Reserved

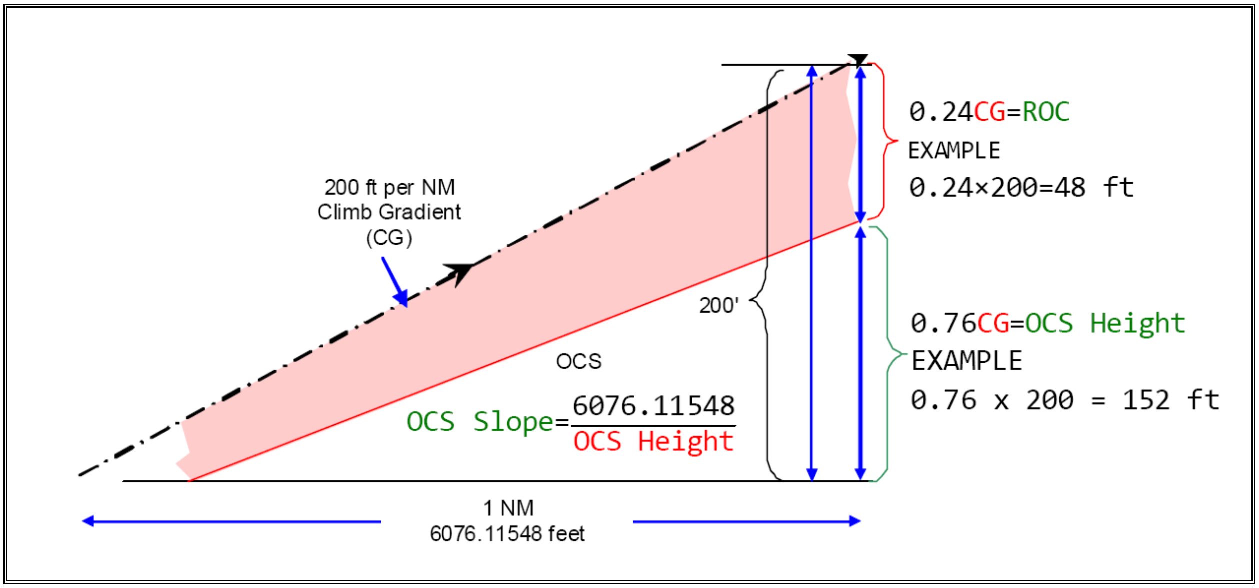


Figure 2-1-3: Climb Segment. Para 203.b.

210. Units Of Measurement

a. Bearings, Courses and Radials.

(1) Bearings and courses shall be expressed in degrees magnetic, except that true and/or grid shall be used within the Northern Domestic Airspace;

(2) Radials. VOR/TACAN radials shall normally be identified as the magnetic bearing FROM the facility and shall be prefixed with the letter "R" (e.g., R-130). When the facility is within the Northern Domestic Airspace and is oriented with grid (DND) or true north, radials shall be so indicated (e.g., R-130G, R-130T).

b. Altitudes. The unit of measure for altitude in this publication is feet

(1) Published altitudes in the areas of the Altimeter Setting Region shall be expressed in feet above MSL, e.g. 17,900 feet. Published altitudes above the transition level (18,000 ft.) shall be expressed as flight levels (FL); e.g. FL190. Normally, altitudes at the transition level will not be used.

(2) MSA, 100 Safe Altitude, TAA and Fix/WP up to the FAF, as well as the MA altitudes are rounded up to the next higher 100 foot increment;

(3) All other altitudes expressed in the approach shall be rounded off to the next higher 20-foot increment, except the ILS glide path check altitude which shall be rounded off to the nearest 10-foot increment.

(4) DA and DH values shall be rounded off to the next higher 1-foot increment.

c. Distances. Distances are to be expressed in nautical miles (6,076.11548 feet or 1852.0 meters per NM) and hundredths thereof, except:

(1) Where feet are required,

(2) Visibilities are expressed in statute miles (5280 feet per SM) and fractions thereof; and

(3) Runway Visual Range (RVR) is expressed in multiples of one hundred feet by increments of:

(a) 200 feet from 600 feet to 3,000 feet; and

(b) 500 feet from 3,000 feet to 6,000 feet.

Use the following formulas for feet and meter conversions:

$$\text{feet} = \frac{\text{meters}}{0.3048} \qquad \text{meters} = \text{feet} \times 0.3048$$

d. Speeds. Aircraft speeds shall be expressed in knots indicated airspeed (KIAS).

211. Positive Course Guidance (PCG)

Positive course guidance shall be provided for feeder routes, initial (except as provided for in Para 233.b), intermediate, and final approach segments. The segments of a procedure wherein positive course guidance is provided should be within the service volume of the facility(ies) used. Positive course guidance may be provided by one or more of the navigation systems for which criteria has been published herein.

212. Aircraft Categories

Aircraft performance directly affects the amount of airspace and the visibility, which is required for maneuvering during instrument procedures. The varying performance is acknowledged by the following system of aircraft speed categories.

Category A — speed less than 91 knots
Category B — speed 91 knots or more but less than 121 knots
Category C — speed 121 knots or more but less than 141 knots
Category D — speed 141 knots or more but less than 166 knots
Category E — speed 166 knots and greater

213. Aircraft Category Application

The approach category operating characteristics shall be used to determine turning radii, minimums, and obstacle clearance areas for circling, missed approach and certain departure procedures. When designing an instrument procedure, Category A, B, C and D normally will be considered for civil procedures and Category B, C, D and E will be considered for military procedures.

214. Procedure Construction

An instrument approach procedure (IAP) may have four separate segments. They are the initial, the intermediate, the final, and the missed approach segments. In addition, an area for circling the airport under visual conditions shall be considered. An approach segment begins and ends at the plotted position of the fix; however, under some circumstances certain segments may begin at specified points where no fixes are available. The fixes are named to coincide with the associated segment. For example, the intermediate segment begins at the intermediate fix (IF) and ends at the final approach fix (FAF). The order in which this chapter discusses the segments is the same order in which the pilot would fly them in a completed procedure; that is from an initial, through an intermediate, to a final approach. Only those segments that are required by local conditions need to be included in a procedure. In constructing the procedure, the final approach course (FAC) should be identified first because it is the least flexible and most critical of all the segments. When the final approach has been determined, the other segments should be blended with it to produce an orderly maneuvering pattern that is responsive to the local traffic flow. Consideration shall also be given to any accompanying controlled airspace to the extent it is feasible (see Figure 2-1-4).

215. Instrument Procedures And Class "F" Airspace

Instrument procedures may come in conflict with Class “F” airspace. Normally, the primary area obstacle clearance surface shall not penetrate the Class “F” airspace, however, instrument approach procedures may exist within Class “F” airspace when it is established for security reasons.

The vertical clearance from Class “F” airspace will vary depending upon the activity within the Class “F” airspace and the potential for conflict. The ROC for the instrument approach procedure segment overlying the Class “F” should be used as a guideline to establish obstacle clearance. In no case shall the ROC be less than 100 feet.

a. Where Class “F” restricted or advisory airspace has been established for military purposes or flight training activities, then the maximum ROC shall be applied.

b. Where Class “F” restricted airspace has been established for security reasons e.g. over a prison, the instrument procedure designer may elect to use a minimum of 100 feet of ROC.

c. Where Class “F” restricted airspace has been established for security reasons, e.g. visiting dignitaries, instrument procedures may exist within the Class “F”, and authorization to fly the procedure may be given by the Controlling Agency.

d. For missed approach and departure procedures Class F airspace shall not penetrate the OCS.

Note: Where Class “F” airspace influences an instrument procedure, the type of activity within the Class “F” shall be documented, as well as the amount of ROC that has been applied. Other known areas that could constitute a hazard, such as known blasting areas, should be treated as Class “F” airspace and documented.”

216. Controlling Obstacle(s)

The controlling obstacle in the segments of procedure shall be identified in the documentation submitted with the procedure. The minimum accuracy standards (Annex E) apply to all controlling obstacles. For sloping surface evaluations, the following standard shall be used to identify the controlling obstacles:

a. For PA and APV final segments, the controlling obstacle is that obstacle which, having penetrated the obstacle clearance surface requires the highest glide path angle (GPA) above 3 degrees and/or causes, the most adverse decision altitude (DA).

b. For missed approach segments, the controlling obstacle is that obstacle which, having penetrated the 40:1 OIS causes one of the following:

(1) Highest DA/MDA;

(2) Most adverse MAP relocation; or

(3) Highest climb gradient and climb gradient termination altitude (may be different obstacles).

c. For departure areas, the controlling obstacle is that obstacle (or obstacles) which require the highest climb gradient and climb gradient termination altitude (may be different obstacles).

Supplementary Note: Obstacles that do not penetrate the sloping surface are not subject to the minimum accuracy standards and should not be called controlling obstacle.

217. Obstacle Height Assessments

When assessing contour lines on a topographical map to determine obstacle height, the accepted method is to use the contour that is on or in the trapezoid being assessed. To this figure, add the next contour interval MINUS one contour unit (foot/metre, as appropriate). If the area is treed, then the average tree height (determined from local forestry authorities) is added to the terrain elevation. A survey or a well-documented flight check process may confirm controlling obstacle elevations that are questionable.

In determining the height of mobile objects, the following standard shall be used:

- **a.** 17.0 feet for mobile obstacles traversing multi-lane controlled access highways where over crossings are designed for a maximum of 17.0 feet vertical distance;
- **b.** 15 feet for any other public roadway;
- **c.** for a private roadway, 10 feet or the height of the highest mobile object, whichever is greater, that would normally traverse the road;
- **d.** 23 feet for a railroad; and
- **e.** for a waterway or any other traverse way not previously mentioned, an amount equal to the height of the highest mobile object that would normally traverse it.

218—219. Reserved

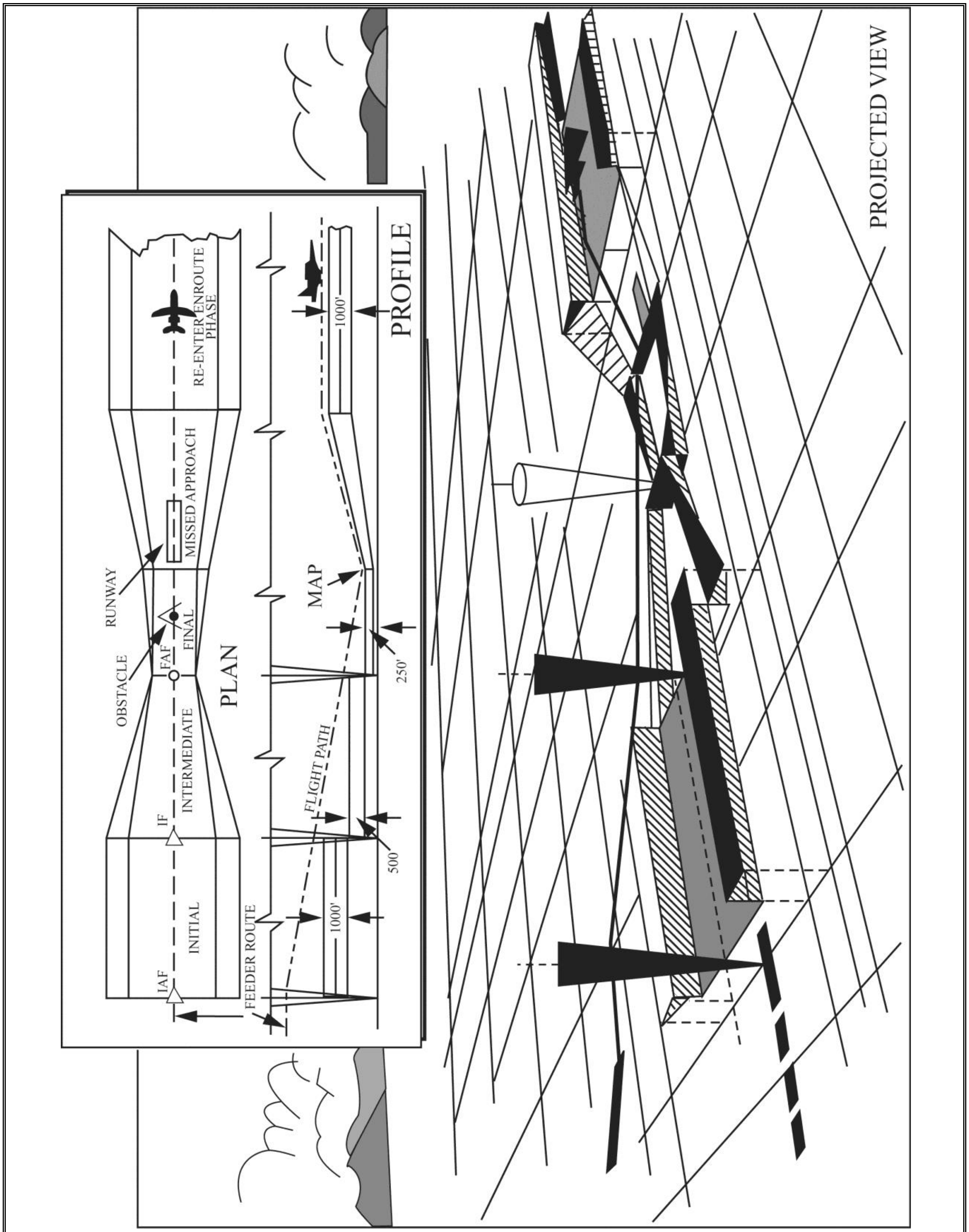


Figure 2-1-4: Segments Of An Approach Procedure. Para 214.

SECTION 2. EN ROUTE OPERATIONS

220. Feeder Routes

When the Initial Approach Fix (IAF) is part of the en route structure, there may be no need to designate additional routes for aircraft to proceed to the IAF. In some cases, however, it is necessary to designate feeder routes from the en route structure to the IAF. Only those feeder routes, which provide an operational advantage, shall be established and published. These should coincide with the local air traffic flow. The length of the feeder route shall not exceed the operational service volume of the facilities that provide navigational guidance, unless additional frequency protection is provided. En route airway obstacle clearance criteria normally apply to feeder routes, however feeder routes that are 25 NM or less may have 1,000 feet ROC applied. Feeder routes greater than 25 NM shall have en route airway obstacle clearance (Chapter 17) criteria applied. The minimum altitude established on feeder routes shall not be less than the altitude established at the IAF.

a. Construction of a feeder route connecting to a course reversal segment. The area considered for obstacle evaluation is oriented along the feeder route at a width appropriate to the type of route (VOR or NDB). The area terminates at the course reversal fix, and is defined by a line perpendicular to the feeder course through the course reversal fix.

b. The angle of intersection between the feeder route course and the next straight segment (feeder/initial) course shall not exceed 120°.

Descent Gradient. The OPTIMUM descent gradient of the feeder route is 250 feet per NM. Where a higher descent gradient is necessary, the MAXIMUM permissible gradient is 500 feet per NM. The OPTIMUM descent gradient for high altitude penetrations is 800 feet per NM. Where a higher descent gradient is necessary, the MAXIMUM permissible is 1000 feet per NM.

221. Safe Altitude/Minimum Sector Altitude (MSA)

A minimum safe altitude is the minimum altitude which provides at least 1,000 feet of obstacle clearance for emergency use, within a specified distance from the RNAV WP/primary navigation facility upon which a procedure is predicated or the aerodrome geographic centre (safe altitude 100 NM). These altitudes shall be rounded to the next higher 100-foot increment. Such altitudes will be identified as minimum sector altitudes or safe altitudes and shall be established as follows:

a. Minimum Sector Altitude (MSA). Establish an MSA for all procedures within a 25-mile radius of the WP/ facility, including the area 4 NM beyond the outer boundary. When the distance from the facility to the airport exceeds 25 NM, the radius shall be expanded to include the airport landing surfaces up to a maximum distance of 30 NM (see Figure 2-2-1). When the procedure does not use an omnidirectional facility, e.g. LOC [BC] with a fix for the FAF, use the primary omnidirectional facility in the area. If necessary to offer relief from obstacles, establish sector divisions, or a common safe altitude (no sectors) for the entire area around the facility. Sectors shall not be less than 90° in spread. Sector altitudes should be raised and combined with adjacent higher sectors when a height difference does not exceed 300 feet. A sector altitude shall also provide 1,000 feet of obstacle clearance in the adjacent sector or periphery area within 4 NM of the sector boundary line. For area navigation (RNAV) procedures, establish a common altitude within the specified radius of the runway waypoint (RWY WP), (normally the MAWP), for straight-in approaches; the airport waypoint (APT WP) for circling procedures; or for GPS approaches, from the WP used for the MSA centre (see Figure 2-2-2). APT WP is the same as the geographic centre of aerodrome.

b. Safe Altitude 100 NM. A safe altitude shall be established within a 100-NM radius of the geographic centre of the aerodrome. Where a requirement exists for these altitudes, these shall be established with a common altitude for the entire area. Where these altitudes are established in designated mountainous regions, they shall provide the appropriate obstacle clearance, either 1,500 or 2,000 feet. These altitudes shall be identified in published procedures as "Safe Altitude 100 NM".

Supplementary Notes:

1) With respect to the 100 NM safe altitudes, only the obstacles located within the designated mountainous regions receive the mountainous ROC, other obstacles receive the normal 1000 ft ROC

2) Use 2000 ft of ROC over eastern U.S. designated mountainous terrain areas.

222—229. reserved

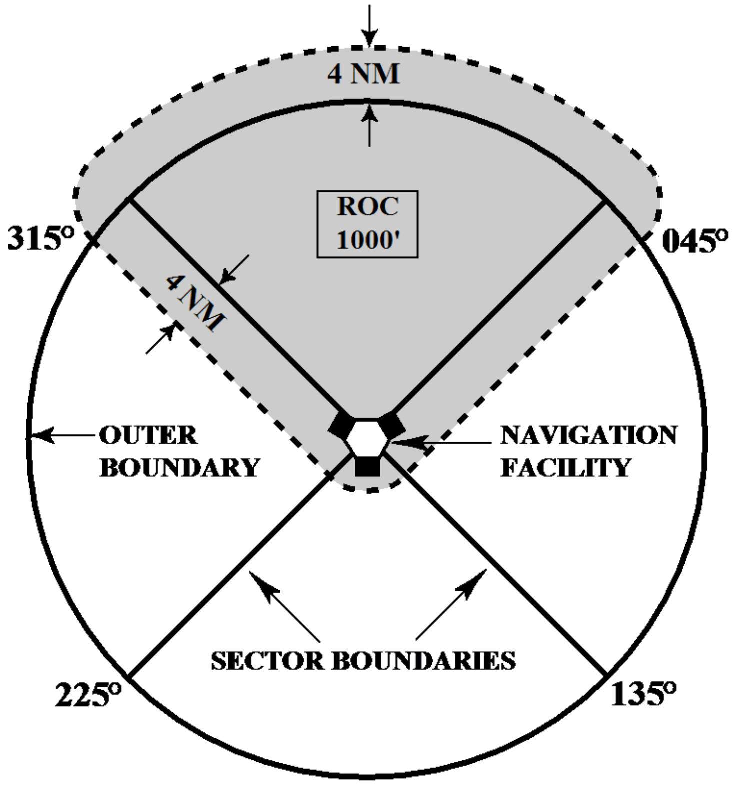


Figure 2-2-1: Non-RNAV MSA. Para 221.

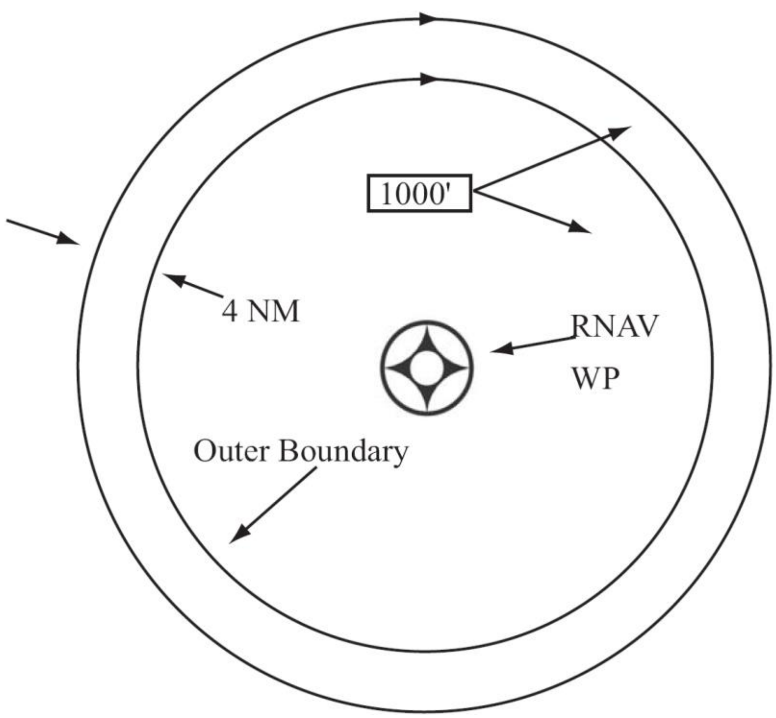


Figure 2-2-2: RNAV MSA. Para 221.

SECTION 3. INITIAL APPROACH

230. Initial Approach Segment

The instrument approach commences at the IAF. In the initial approach the aircraft has departed the en route phase of flight, and is maneuvering to enter the intermediate segment. When the IF is part of the en route structure, it may not be necessary to designate an initial approach segment. In this case the approach commences at the IF and intermediate segment criteria apply. An initial approach may be made along an arc, radial, course, heading, or radar vector, or a combination thereof. Procedure turns, holding pattern descents, and high altitude penetrations are initial segments. Positive course (track) guidance is required except when dead reckoning courses can be established over limited distances. Although more than one initial approach may be established for a procedure, the number should be limited to that which is justified by traffic flow or other operational requirements. Where holding is required prior to entering the initial approach segment, the holding fix and IAF should coincide. When this is not possible the IAF shall be located within the holding pattern on the inbound holding course.

231. Altitude Selection

Minimum altitudes in the initial approach segment shall be established in 100-foot increments; i.e., 1,549 feet may be shown as 1,500 feet as long as the ROC is not violated and 1,550 shall be shown as 1,600 feet. The altitude selected shall not be below the PT altitude where a PT is required. In addition, altitudes specified in the initial approach segment must not be lower than any altitude specified for any portion of the intermediate or final approach segments.

232. Initial Approach Segments Based On Straight Courses And Arcs With Positive Course Guidance (PCG)

a. Alignment.

(1) **Courses**. The angle of intersection between the initial approach course and the intermediate course shall not exceed 120°. When the angle is 90° or greater, a lead radial/bearing, which provides 2 NM of lead, shall be identified to assist in leading the turn onto the intermediate course (see Figure 2-3).

(2) **Arcs**. An arc may provide course guidance for all or a portion of an initial approach. The minimum arc radius shall be 7 NM, except for high altitude procedures, in which the minimum radius shall be at least 15 NM. When an arc of less than 15 NM radius is used in high altitude procedures, the descent gradient along the arc shall not exceed the criteria in Para 232.d and Table 2-1. An arc may join a course at or before the IF. When joining a course on or before the IF, the angle of intersection of the arc and the fix course shall not exceed 120°. When the angle is 90° or greater, a fix, lead radial or lead bearing which provides at least 2 NM of lead shall be identified to assist in leading the turn onto the intermediate course. DME arc courses should be predicated on collocated VOR/DME, NDB/DME or TACAN facilities. Where an operational advantage can be achieved non-collocated facilities may be used providing the two facilities are within 4 NM of each other and the angle subtended by the line joining the aircraft to the DME source and the bearing to the track guidance facility does not exceed 8°.

Formula 2-1. Distance Flown Along Arc, Distance to Lead Radial/Bearing. Para 232.a.	
Math Notation	$D_{ARC} = \frac{Radius * Angle}{57.3}$ $LRorLB = \frac{(2 * 57.3)}{Radius}$
Standard Text	DARC = (Radius * Angle) / 57.3 LR or LB = (2 * 57.3) / Radius
Given Values	
Radius =	Radius of arc flown (NM)
D_{ARC} =	Distance flown along arc (NM)
LR or LB =	Lead Radial (LR) or Lead Bearing (LB)
Angle =	number of degrees of arc flown

b. **Area**. The initial approach segment has no standard length. The length shall be sufficient to permit the altitude change required by the procedure and shall not exceed 50 NM unless an operational requirement exists. The total width of the initial approach segment shall be 6 NM on each side of the initial approach course. This width is divided into a primary area, which extends laterally 4 NM on each side of the course, and a secondary area, which extends laterally 2 NM on each side of the primary area (see Figure 2-10). When any portion of the initial approach is more than 50 NM from the navigation facility, the criteria for en route airways shall apply to that portion.

c. **Obstacle Clearance**. The obstacle clearance in the initial approach primary area shall be a minimum of 1,000 feet. In the secondary area 500 feet of obstacle clearance shall be provided at the inner edge, tapering uniformly to zero feet at the outer edge (see Figure 2-6a). Allowance for precipitous terrain should be made, as specified in Para 323.b. The altitudes selected by application of the obstacle clearance specified in this paragraph shall be rounded to the next higher 100-foot increment (see Para 231).

d. **Descent Gradient**. The OPTIMUM descent gradient in the initial approach is 250 feet per nautical mile. Where a higher descent gradient is necessary, the MAXIMUM permissible gradient is 500 feet per nautical mile. The OPTIMUM descent gradient for high altitude penetrations is 800 feet per nautical mile. Where a higher descent gradient is necessary, the MAXIMUM permissible gradient is 1,000 feet per nautical mile. The maximum descent gradient for a high altitude arc of less than 15-mile radius is found in Table 2-1.

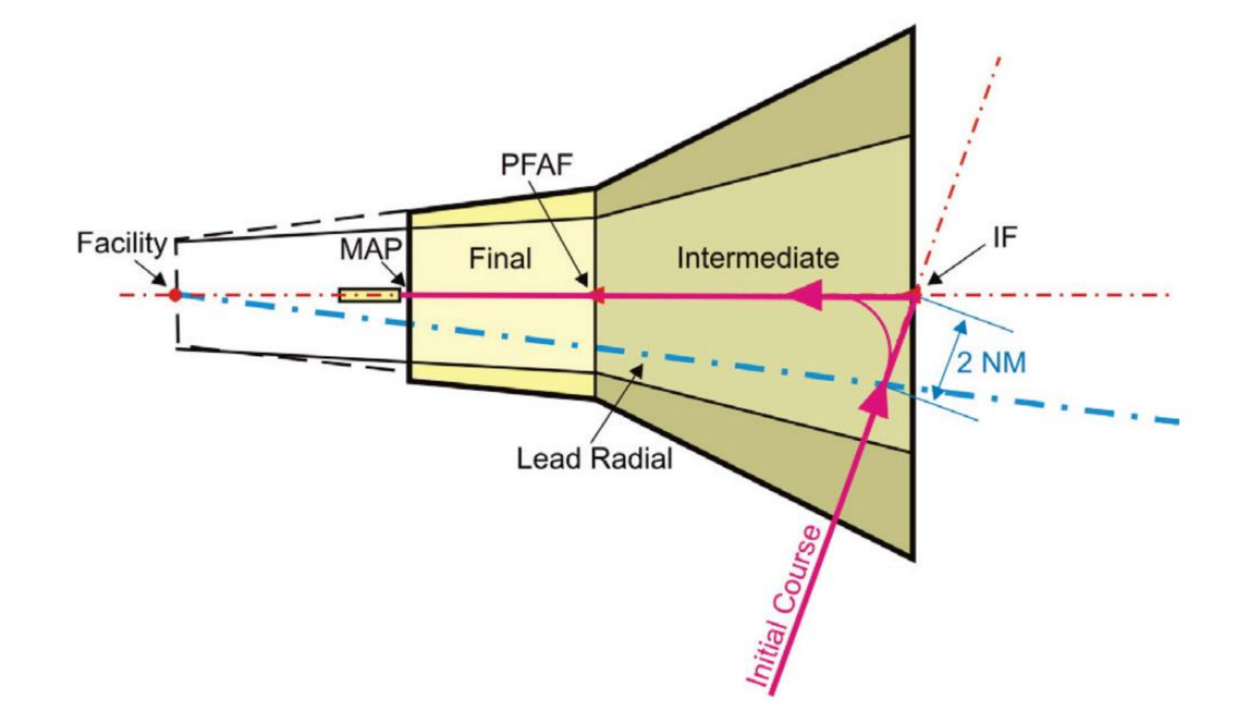


Figure 2-3: Initial approach interception angle greater than 90 degrees 232.a.(1)

MILES (NM)	Max Ft. Per NM
15	1,000
14	720
13	640
12	560
11	480
10	400
9	320
8	240
7	160

Table 2-1: Descent Gradient On High Altitude Arc Of Less Than 15 NM. Para 232a(2).

233. Initial Approach Segment Based On Dead Reckoning (DR)

a. Alignment. Each DR course shall intercept the extended intermediate course. For LOW altitude procedures the intercept point shall be at least 1 mile from the IF for each 2 NM of DR flown. For HIGH altitude procedures the intercept point shall be 1 mile prior to the IF for each 3 NM of DR flown. The intercept angle shall:

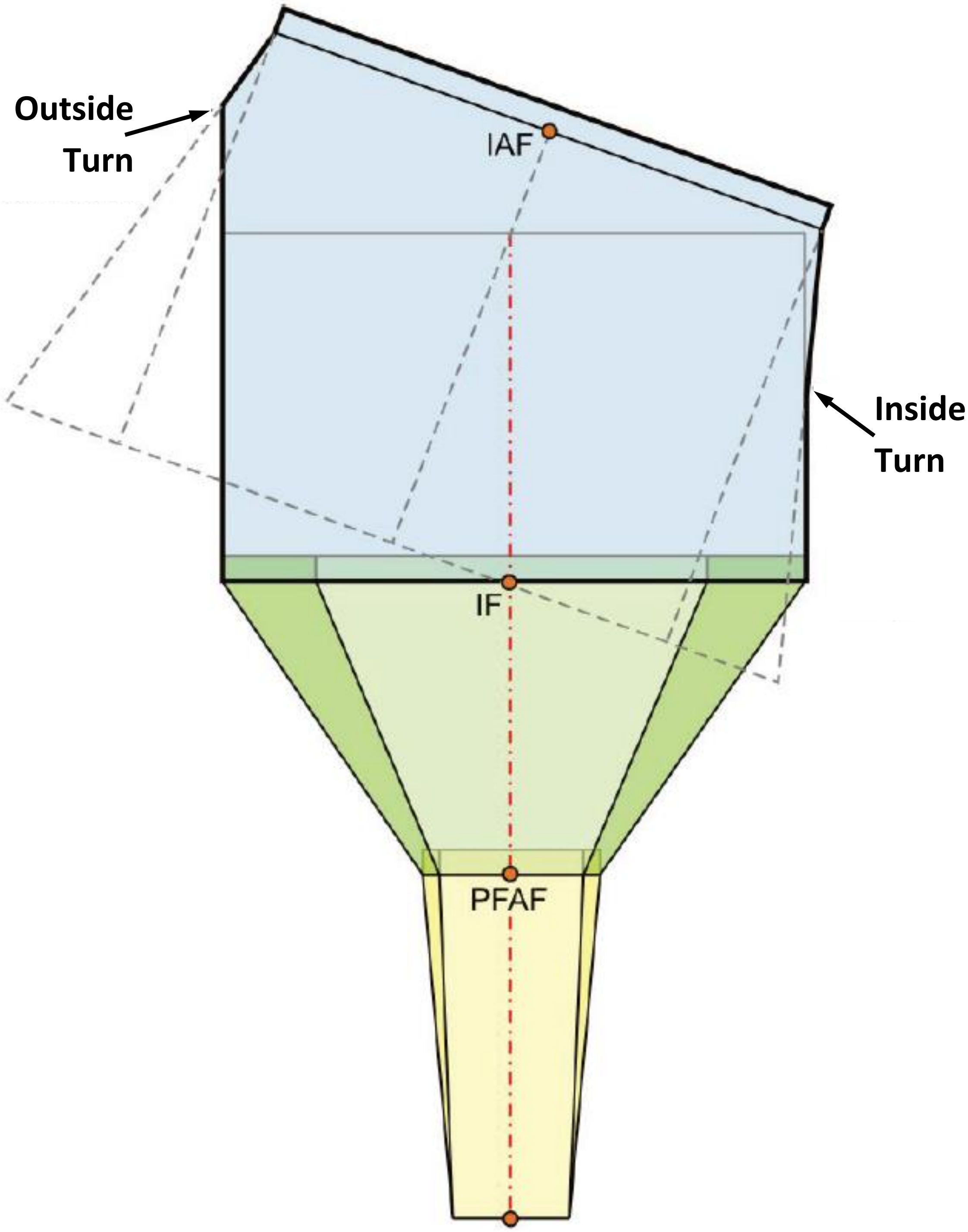
(1) not exceed 90°; and

(2) not be less than 45° except when DME is used or the DR distance is 3 NM or less.

b. Area. The MAXIMUM length of the DR portion of the initial segment is 10 NM (except Para 232.b applies for HIGH altitude procedures where DME is available throughout the DR segment). Where the DR course begins, the width is 6 NM on each side of the course, expanding outward by 15° until joining the points as depicted in Figures 2-4-1, 2-4-2, 2-4-3, 2-4-4, and 2-4-5.

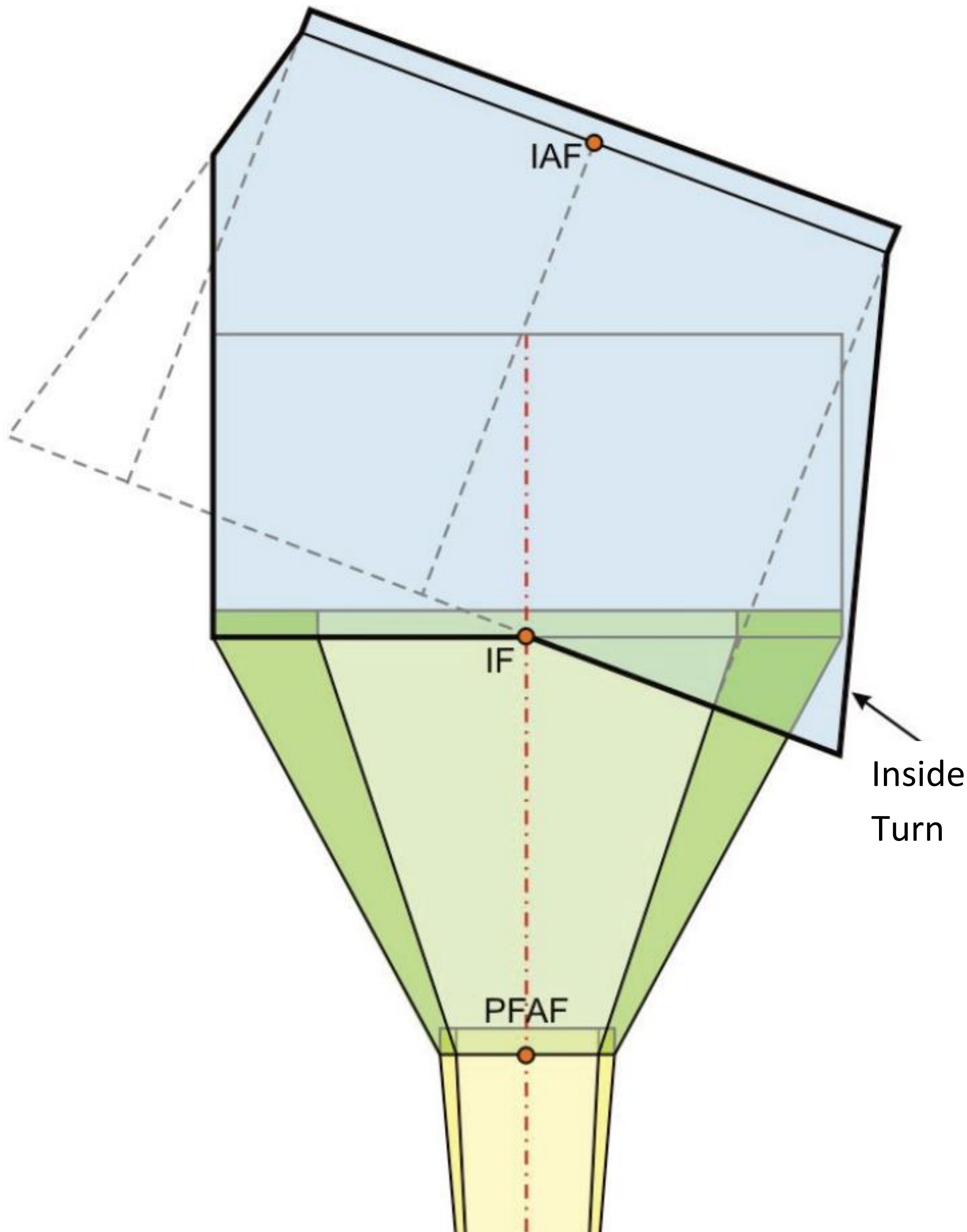
c. Obstacle Clearance. The obstacle clearance in the DR initial approach segment shall be a minimum 1,000 feet. There is no secondary area. Allowance for precipitous terrain shall be considered as specified in Para 323.b. The altitudes selected by application of the obstacle clearance specified in this paragraph shall be rounded in accordance with Para 231.

d. Descent Gradient. The OPTIMUM descent gradient in the initial approach is 250 feet per mile. Where a higher descent gradient is necessary, the maximum permissible gradient is 500 feet per nautical mile. The OPTIMUM descent gradient for high altitude penetrations is 800 feet per nautical mile. Where a higher descent gradient is necessary, the maximum permissible gradient is 1,000 feet per nautical mile.



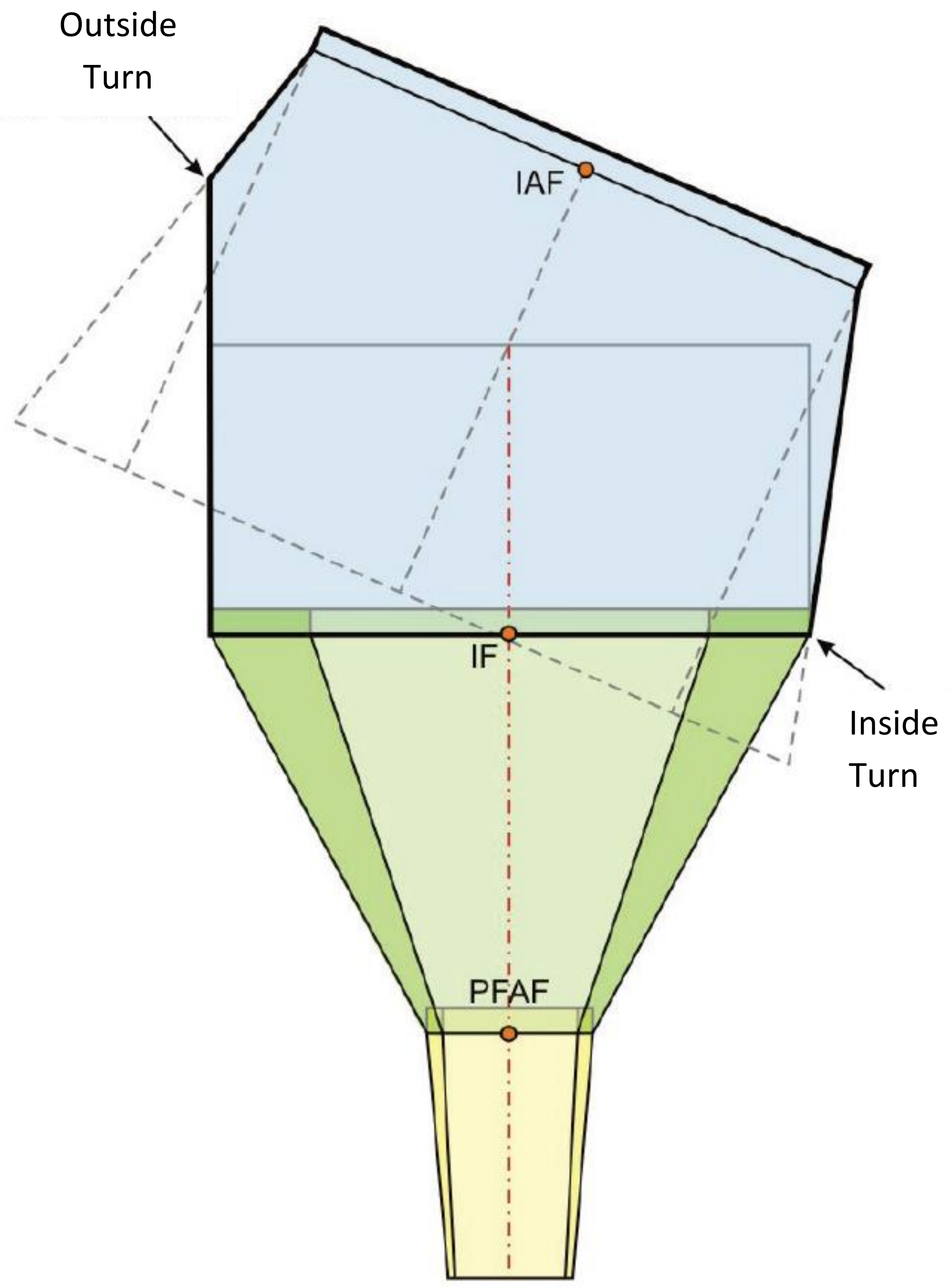
Outside and Inside Turns: Truncate segment at intersection of 15° expansion line and initial width centered on reciprocal of intermediate.

Figure 2-4-1: Example DR Segment. Para 233.b.



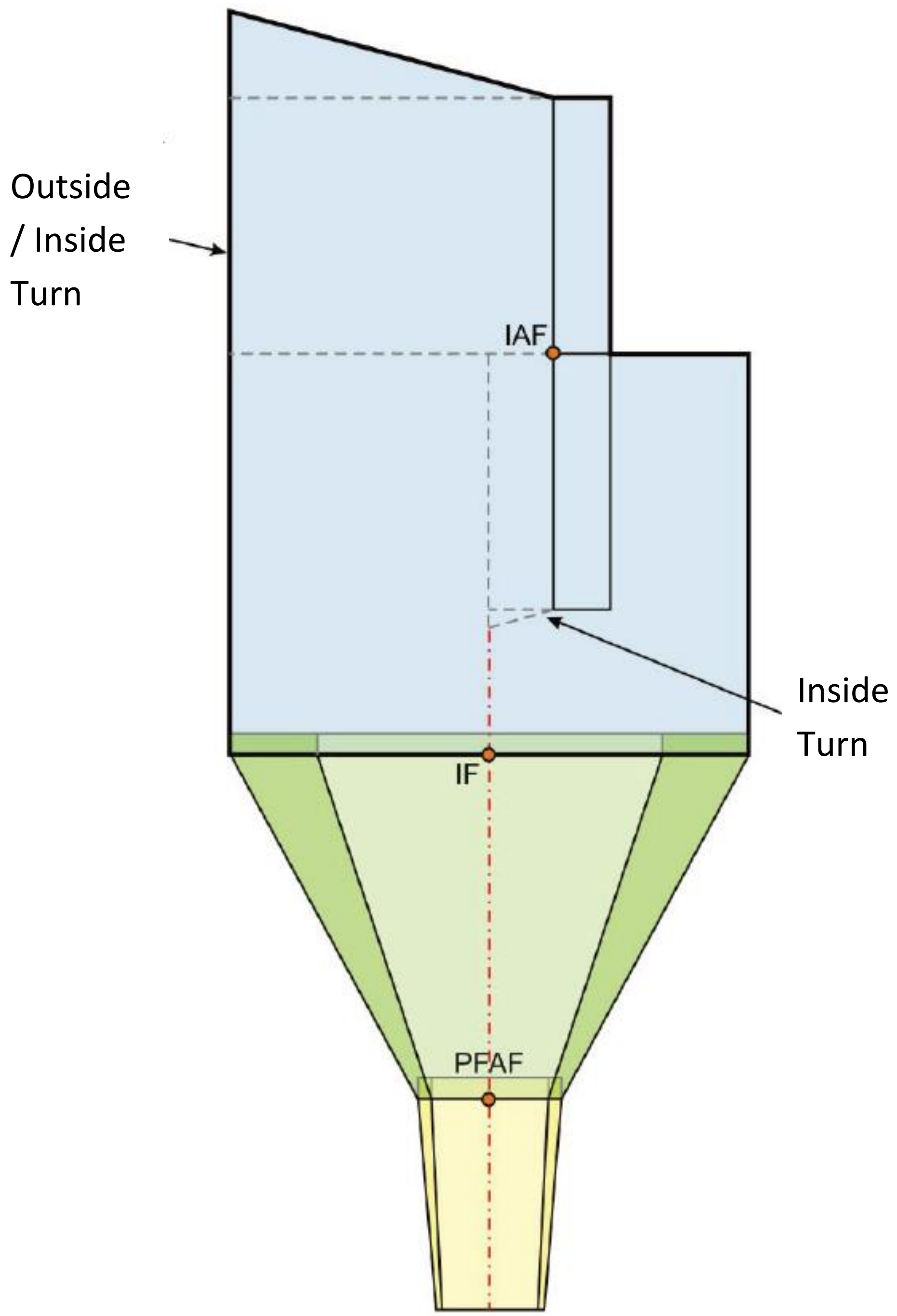
Inside Turn: Do not truncate when 15° expansion line does not intersect initial width centered on reciprocal of intermediate. When this part of the initial does not overlap the intermediate, DME is required.

Figure 2-4-2: Example DR Segment. Para 233.b.



Outside and Inside Turns: Truncate segment at intersection of 15° expansion line and initial width centered on reciprocal of intermediate.

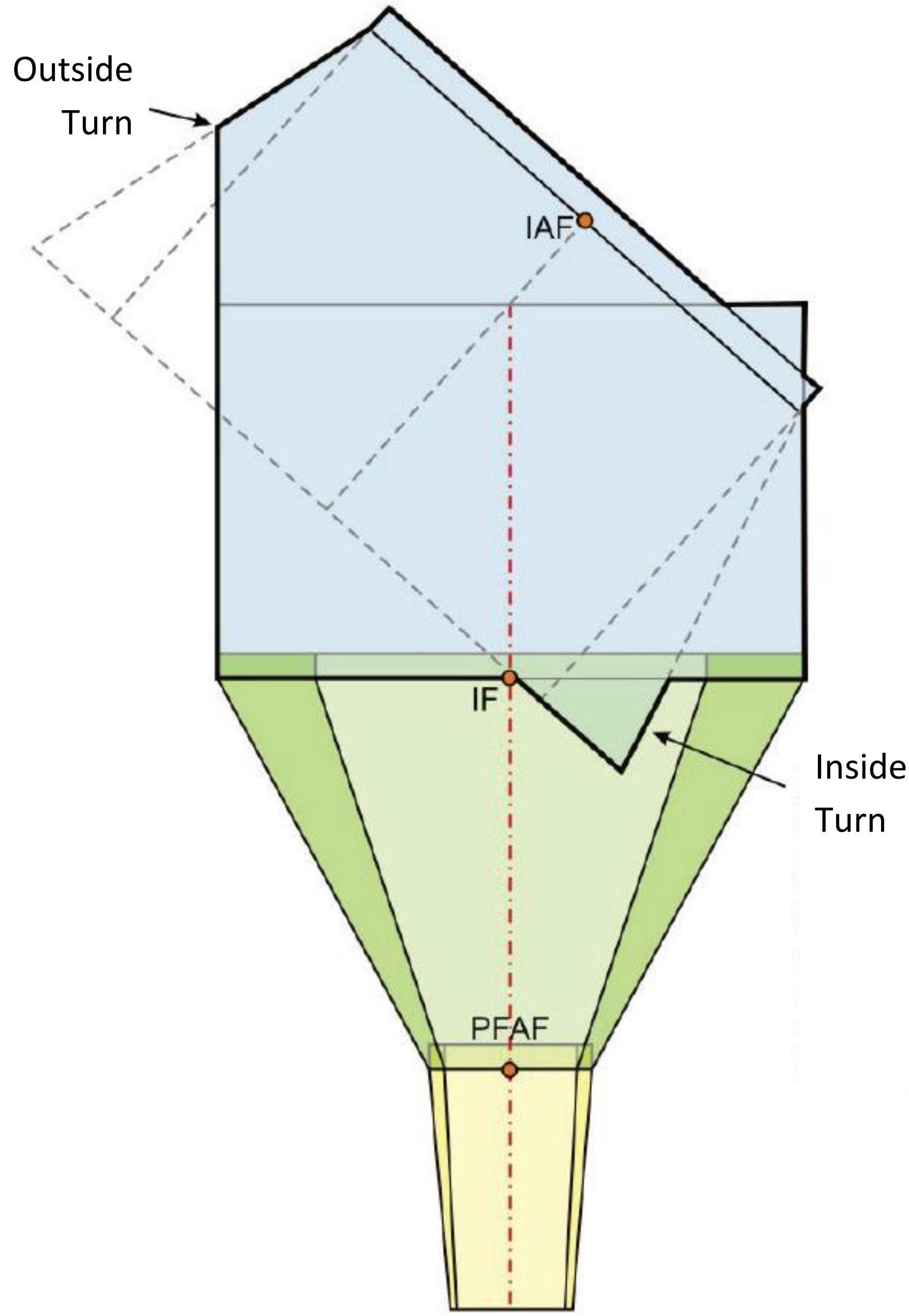
Figure 2-4-3: Example DR Segment. Para 233.



Outside / Inside Turn: Extend segment to intersection of 15° expansion line and initial width centered on reciprocal of intermediate.

Inside Turn: Do not truncate when 15° expansion line does not intersect initial width centered on reciprocal of intermediate. Continue to expand until reaching line perpendicular to DR course abeam IF.

Figure 2-4-4: Example DR Initial Segment. Para 233.b.



Outside Turn: Truncate segment at intersection of 15° expansion line and initial width centered on reciprocal of intermediate.

Inside Turn: Do not truncate when 15° expansion line does not intersect initial width centered on reciprocal of intermediate. Continue to expand until reaching line perpendicular to DR course abeam IF.

Figure 2-4-5: DR Initial Segment With Boundary Outside The Intermediate Segment. Para 233.b.

234. Initial Approach Segment Based On A Procedure Turn (PT)

A PT shall be specified when it is necessary to reverse direction to establish the aircraft on an intermediate or final approach course (FAC) except as specified in Para 234.e. A PT begins by overheading a facility or fix which meets the criteria for a holding fix (see Para 287.b) or for a FAF (see Para 287.c). The procedure shall specify the PT fix, the outbound and inbound course, the distance within which the PT shall be completed, and the direction of the PT. When a teardrop turn is used, the angle of divergence between the outbound course and the reciprocal of the inbound course shall be a MINIMUM of 15° or a MAXIMUM of 30° (see Para 235.a for high altitude teardrop penetrations). When the beginning of the intermediate or final approach segment associated with the PT is marked by no fix, the segment is deemed to begin on the inbound PT course at the maximum distance specified in the procedure. Where neither segment is marked by a fix, the final segment begins at the maximum distance specified in the procedure.

a. Alignment. When the inbound course of the procedure turn becomes the intermediate course it must meet the intermediate course alignment criteria. (See Para 242.a.) When the inbound course becomes the final approach course it must meet the final approach course alignment criteria. (See Para 250.) The wider side of the procedure turn area shall be oriented in the same direction as that prescribed for the procedure turn.

b. Area. The procedure turn areas are depicted in Figure 2-5. The normal procedure turn distance is 10 NM, (see Table 2-1A). Decrease this distance to 5 NM where only CAT "A" aircraft or helicopters are to be operating, and increase to 15 NM to accommodate operational requirements, or as specified in Para 234d. No extension of the PT is permitted without a FAF. When a procedure turn is authorized for use by Category "E" aircraft, a 15-mile PT distance shall be used. The PT segment is made up of the entry and maneuvering zones. The entry zone terminates at the inner boundary which extends perpendicular to the PT inbound course at the PT fix. The remainder of the procedure turn segment is the maneuvering zone. The entry and maneuvering zones are made up of primary and secondary areas. The PT primary area dimensions are based on the PT completion altitude, or the highest feeder route altitude, whichever is greater. To allow additional maneuvering area as the true airspeed increases at higher altitudes, the dimension of the PT primary area increases (see Table 2-1A). The PT secondary area is 2 NM on the outside of the primary area.

c. Obstacle Clearance. A minimum of 1,000 feet of clearance shall be provided in the primary area. In the secondary area, 500 feet of obstacle clearance shall be provided at the inner edge, tapering uniformly to zero feet at the outer edge (see Figure 2-6 and 2-6a). Allowance for precipitous terrain shall be considered as specified in Para 323.b. The primary and secondary areas determine obstacle clearance in both the entry and maneuvering zones. The use of entry and maneuvering zones provides further relief from obstacles. The entry zone is established to control the obstacle clearance until proceeding outbound from the procedure turn fix. The maneuvering zone is established to control obstacle clearance AFTER proceeding outbound from the procedure turn fix. (see Figure 2-5). The altitudes selected by application of the obstacle clearance specified in this paragraph shall be rounded to the next higher 100 feet increment (see Para 231).

d. Descent Gradient. The OPTIMUM descent gradient in the initial approach is 250 feet per nautical mile. Where a higher descent gradient is necessary, the MAXIMUM permissible gradient is 500 feet per nautical mile. Where a PT is established over a FAF, the PT completion altitude should be as close as possible to the FAF altitude. The difference between the PT completion altitude and the altitude over the FAF shall not be greater than those shown in Table 2-1B. If greater differences are required for a 5 or 10 nautical mile PT, the PT distance limits and maneuvering zone shall be increased at the rate of 1 nautical mile for each 200 feet of required altitude.

e. Elimination of PT. A PT is NOT required when an approach can be made direct from a specified IF to the FAF. The abbreviation "No PT" is used to denote that no procedure is necessary and will normally be shown adjacent to the IF. However, if the minimum altitude IF to FAF is not readily apparent, the No PT abbreviation will be shown at some point between the fix and the FAF. Design criteria outlined in Para 240-244 applies. Publishing an IF to permit a No PT approach does not preclude the publishing of a procedure turn as well, where operationally appropriate. A PT NEED NOT be established when an approach can be made from a properly aligned holding pattern. See Para 1820.a. In this case, the holding pattern in lieu of a PT, shall be established over a final or intermediate approach fix and the following conditions apply:

(1) If the holding pattern is established over the FAF (not applicable to RNAV procedures), an intermediate segment is not constructed. Ideally, establish the minimum holding altitude at the FAF altitude. In any case, the published holding altitude shall not be more than 300 feet above the FAF altitude.

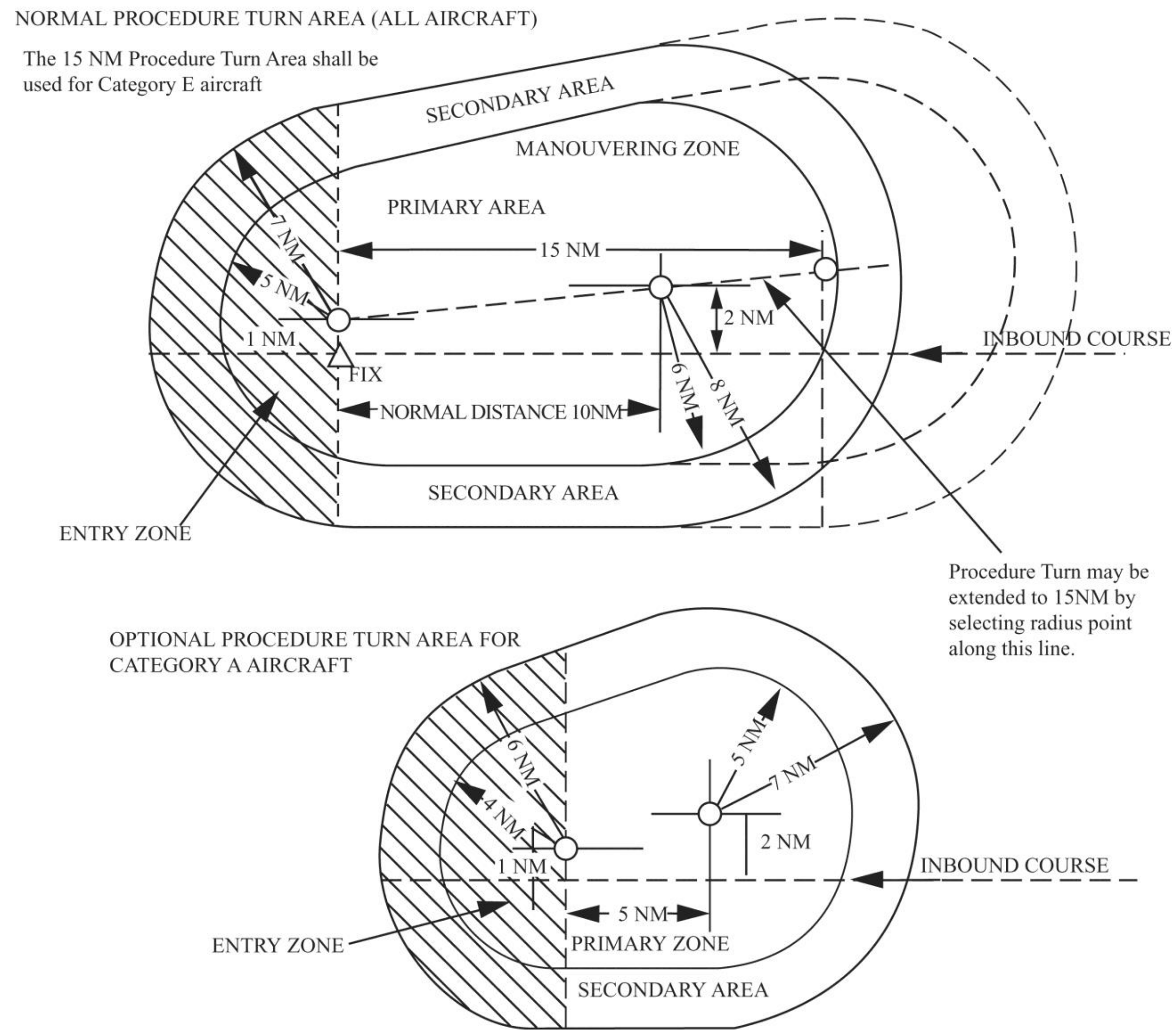
(2) If the holding pattern is established over the IF, the minimum holding altitude (MHA) shall permit descent to the FAF altitude within the descent gradient tolerances prescribed for the intermediate segment (see Para 242d).

≤ 6,000					
PT Length	Offset	R_1	R_2	R_3	R_4
5	2	4	6	5	7
>5-10	2	5	7	6	8
>10-15	β-4	5	7	β	β+2
$\beta = 0.1 \times (d - 10) + 6$					
Where d = PT Length (NM)					
> 6,000 ≤ 10,000					
PT Length	Offset	R_1	R_2	R_3	R_4
5	2	4	6	5	7
>5-10	2	6	8	7	9
>10-15	β-5	6	8	β	β+2
$\beta = 0.1 \times (d - 10) + 7$					
Where d = PT Length (NM)					
> 10,000					
PT Length	Offset	R_1	R_2	R_3	R_4
5	2	4	6	5	7
>5-10	2	7	9	8	10
>10-15	β-6	7	9	β	β+2
$\beta = 0.1 \times (d - 10) + 8$					
Where d = PT Length (NM)					

Table 2-1A: Procedure Turn Variables According To ASL Altitude, Para 234b.

Type of PT	Altitude Difference
15 NM PT from FAF	Within 3,000 ft of ALT over FAF
10 NM PT from FAF	Within 2,000 ft of ALT over FAF
5 NM PT from FAF	Within 1,000 ft of ALT over FAF
15 NM PT, no FAF	Not Authorized
10 NM PT, no FAF	With 1,500 ft of MDA on Final
5 NM PT, no FAF	With 1,000 ft of MDA on Final

Table 2-1B: PT Completion Altitude Difference. Para 234d.



Note: In the **normal** PT area example above:
R1 = 5 NM, R2 = 7 NM, R3 = 6 NM, and R4 = 8 NM.
In the **optional** PT area example above:
R1 = 4 NM, R2 = 6 NM, R3 = 5 NM, and R4 = 7 NM.

Figure 2-5: Procedure Turn Areas. Para 234.b.

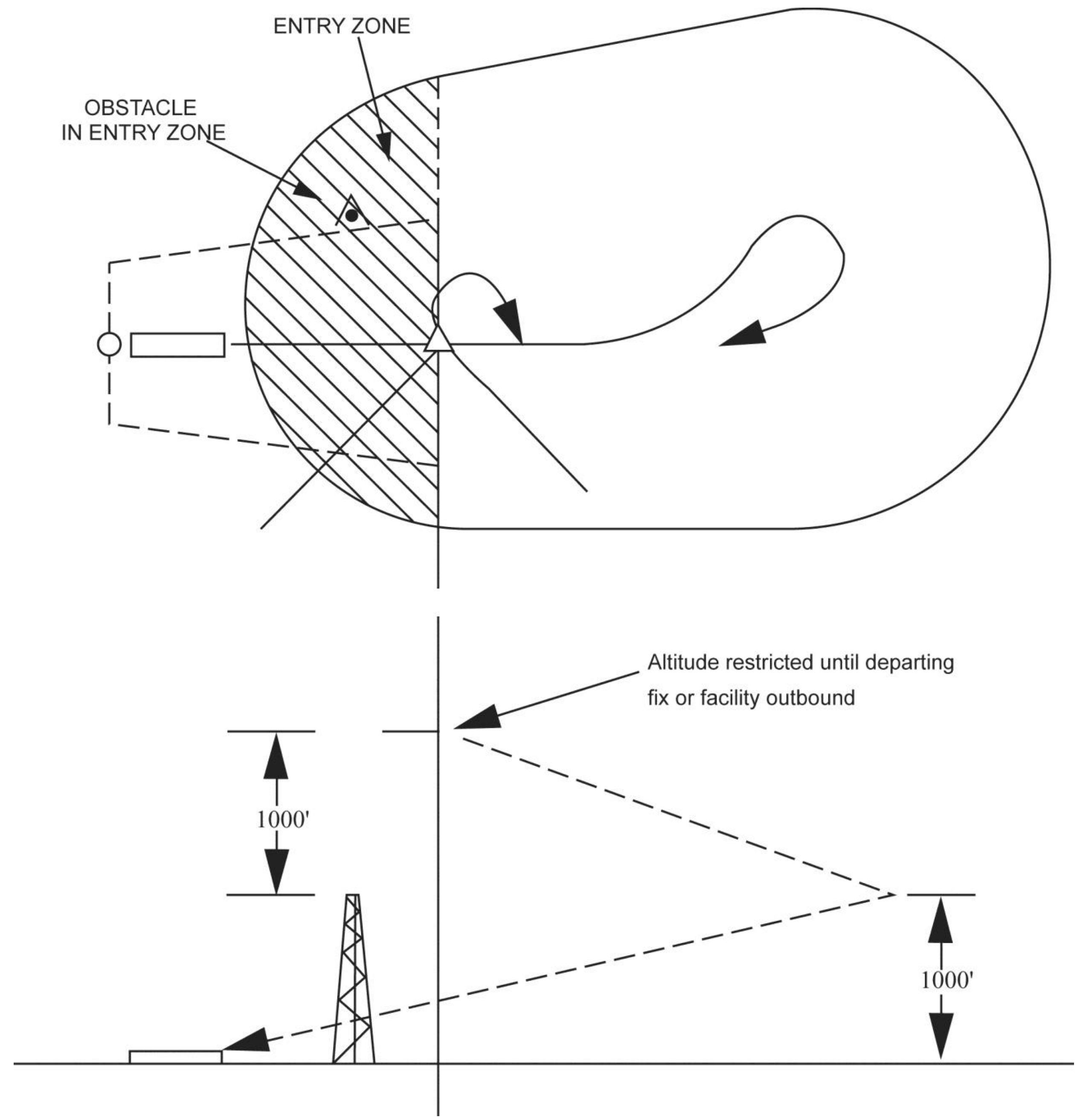


Figure 2-6: Procedure Turn Initial Approach Area. Para 234.c.

235. Initial Approach Based On High Altitude Teardrop Penetration

A teardrop penetration consists of departure from an IAF on an outbound course, followed by a turn toward and intercepting the inbound course at or prior to the IF or point. Its purpose is to permit an aircraft to reverse direction and lose considerable altitude within reasonably limited airspace. Where no IF is available to mark the beginning of the intermediate segment, it shall be assumed to commence at a point 10 NM prior to the FAF. When the facility is located on the airport, and no fix is available to mark the beginning of the final approach segment the criteria in Para 423 applies.

a. Alignment. The outbound penetration course shall be between 18 and 26° to the left or right of the reciprocal of the inbound course. The actual angular divergence between the courses will vary inversely with the distance from the facility at which the turn is made (see Table 2-2).

b. Area.

(1) **Size**. The size of the penetration turn area must be sufficient to accommodate both the turn and the altitude loss required by the procedure. The penetration turn distance shall not be less than 20 NM from the facility. The penetration turn distance depends on the altitude to be lost in the procedure and the point at which the descent is started (see Table 2-2). The aircraft should lose half the altitude or 5,000 ft., whichever is greater, outbound prior to starting the turn. The penetration turn area has a width of 6 NM on both sides of the flight track up to the IF or point, and shall encompass all the areas within the turn (see Figure 2-7).

(2) **Penetration Turn Table**. Table 2-2 should be used to compute the desired course divergence and penetration turn distances, which apply when a specific altitude loss outbound is required. It is assumed that the descent begins at the plotted position of the fix. When the procedure requires a delay before descent of more than 5 NM, the distance in excess of 5 NM should be added to the distance the turn commences. The course divergence and penetration turn distance should then be adjusted to correspond to the adjusted turn distance. Extrapolations may be made from the table.

(3) **Primary and Secondary Areas**. All of the penetration turn area, except the outer 2 NM of the 6 NM obstacle clearance area on the outer side of the penetration track, is primary area (see Figure 2-7). The outer 2 NM is secondary area. The outer 2 NM on both sides of the inbound penetration course should be treated as secondary area.

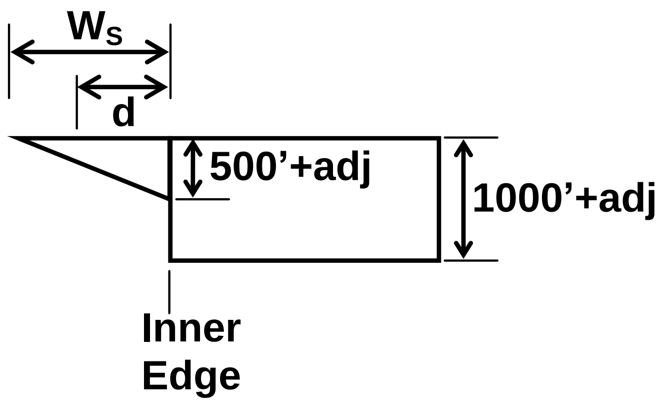
c. Obstacle Clearance. Obstacle clearance in the initial approach primary area shall be a MINIMUM of 1,000 feet. Obstacle clearance at the inner edge of the secondary area shall be 500 feet, tapering to zero feet at the outer edge (see Figure 2-6a). Where no IF is available, a 10 NM intermediate segment is assumed and normal obstacle clearance is applied to the controlling obstacle. The controlling obstacle, as well as the minimum altitude selected for the intermediate segment, may depend on the availability of an IF (see Figure 2-8). Allowance for precipitous terrain should be considered in the penetration turn area as specified in Para 323.b. The altitudes selected by application of the obstacle clearance specified in this paragraph shall be rounded to the next higher 100 feet increment. (See Para 231.)

d. Descent Gradient. The OPTIMUM descent gradient is 800 feet per nautical mile. The MAXIMUM gradient is 1,000 feet per nautical mile.

e. Penetration Turn Altitude. When an IF is NOT provided, the penetration turn completion altitude shall not be more than 4,000 feet above the FAF altitude.

ALT to be Lost Prior to Commencing Turn (ft)	Distance Turn Commences (NM)	Course Divergence (Degrees)	Specified Penetration Turn Distance (NM)
12,000	24	18	28
11,000	23	19	27
10,000	22	20	26
9,000	21	21	25
8,000	20	22	24
7,000	19	23	23
6,000	18	24	22
5,000	17	25	21
4,000	16	26	20

Table 2-2: Penetration Turn Distance/Divergence. Para 235a.



Primary ROC = 1000' + adjustments (adj)

Secondary ROC = $(500' + adj) \times \frac{(W_S - d)}{W_S}$

Where: d = distance from inner edge to obstacle (ft)

W_S = Width of secondary area (ft)

adj = adjustments (ft) as per para 323.

Figure 2-6a: Obstacle Clearance Areas. Paras 234.c and 235.c.

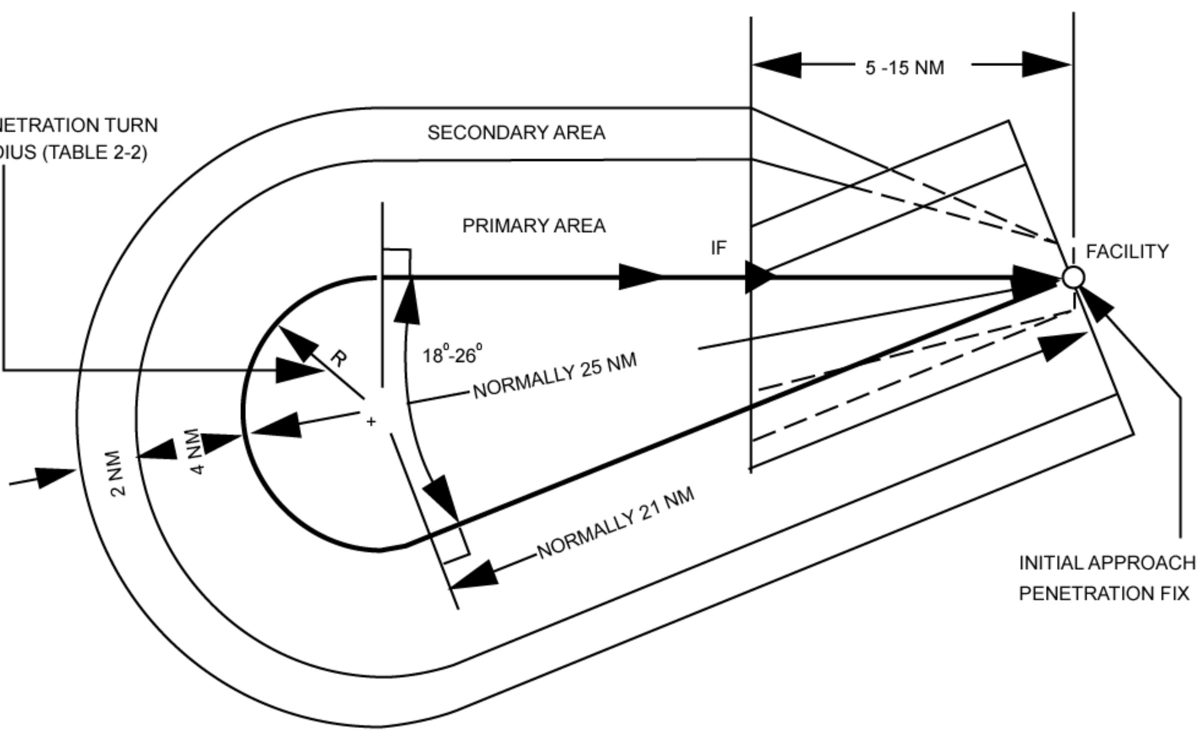


Figure 2-7: Typical Penetration Turn Initial Approach Area. Para 235.

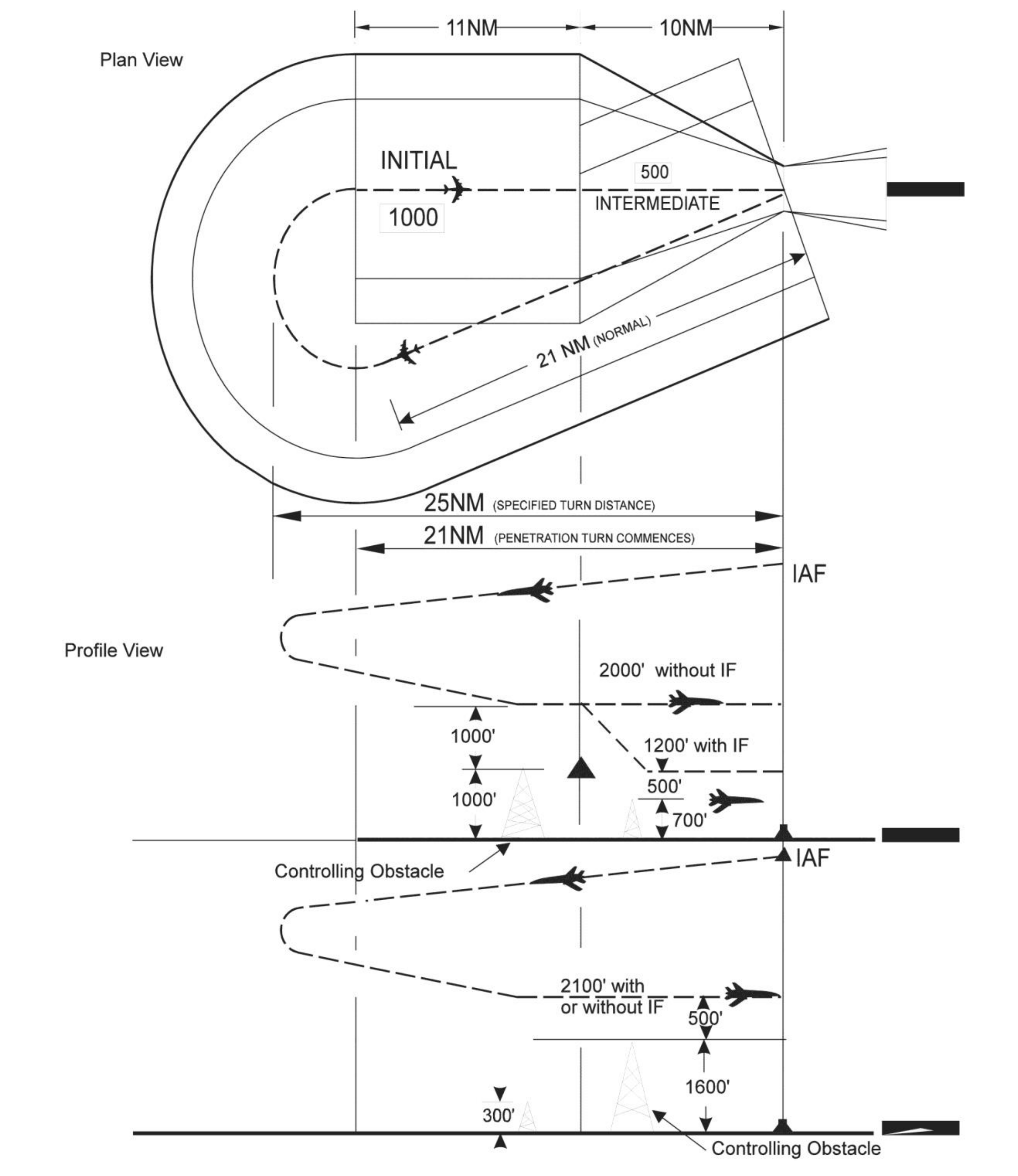


Figure 2-8: Penetration Turn Initial Approach Obstacle Clearance. Para 235.c.

236. Initial Approach Course Reversal Using Non-Collocated Facilities And A Turn Of 120° Or Greater To Intercept The Inbound Course (see Figures 2-9-1, 2-9-2, and 2-9-3)

a. Common Criteria.

(1) A turn point (TP) fix shall be established as shown in the figures. The fix error shall meet section 8 criteria, and shall not exceed plus-or-minus 2 NM.

(2) A flight path radius of 2.8 NM shall be used for procedures where the altitude at the TP fix is at or below 10,000 feet MSL, or 4 NM for procedures where the altitude at the TP fix is above 10,000 feet MSL.

(3) **Descent Gradient**. Para 232.d applies.

(4) **Obstacle Clearance**. Para 235.c applies.

(5) **Initial Distance**. When the course reversal turn intercepts the extended intermediate course, and when the course reversal turn intercepts a straight segment prior to intercepting the extended intermediate course, the minimum distance between the rollout point and the FAF is 10 NM.

(6) **ROC Reduction**. No reduction of secondary ROC is authorized in the course reversal area unless the TP fix is DME.

b. Figures 2-9-1 and 2-9-2. The rollout point shall be at or prior to the intermediate fix/point.

(1) Select the desired rollout point on the inbound course.

(2) Place the appropriate flight path arc tangent to the rollout point.

(3) From the outbound facility, place the outbound course tangent to the flight path arc. The point of tangency shall be the TP fix.

c. Figure 2-9-3.

(1) The point of intersection shall be at or prior to the IF/point (Para 242 applies). The angle shall be 90° or less.

(2) The distance between the rollout point and the point of intersection shall be no less than the distance shown in Table 2-2A.

(3) Para 235 and Table 2-2 should be used for high altitude procedures up to the point of intersection of the two inbound courses.

(4) Select the desired point of intersection. From the outbound facility draw a line through the point of intersection.

(5) At the outbound facility, measure the required number of degrees course divergence (may be either side of the line through the point of intersection) and draw the outbound course out the required distance. Connect the outbound course and the line through the point of intersection with the appropriate arc.

(6) Determine the desired rollout point on the line through the point of intersection.

(a) Place the appropriate flight path arc tangent to the rollout point.

(b) From the outbound facility draw the outbound course tangent to the flight path arc. The point of tangency is the TP fix.

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Angle "e" (Degrees)	NM
0 – 15	1
> 15 – 30	2
> 30 – 45	3
> 45 – 60	4
> 60 – 75	5
> 75 – 90	6

Table 2-2A: Minimum Distance From Roll Out Point To Point Of Intersection. Para 236c(2).

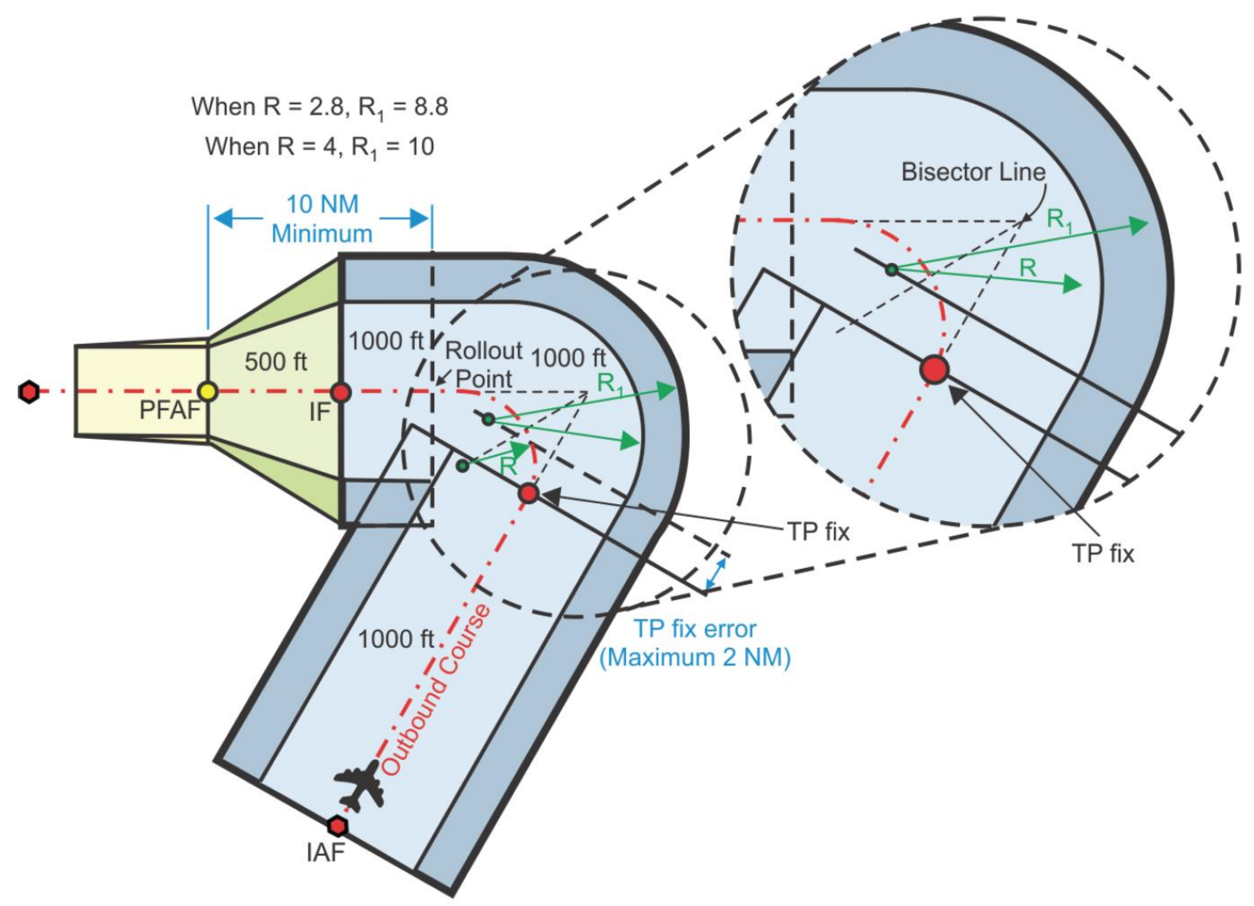


Figure 2-9-1: Example Of Initial Course Reversal. Para 236.

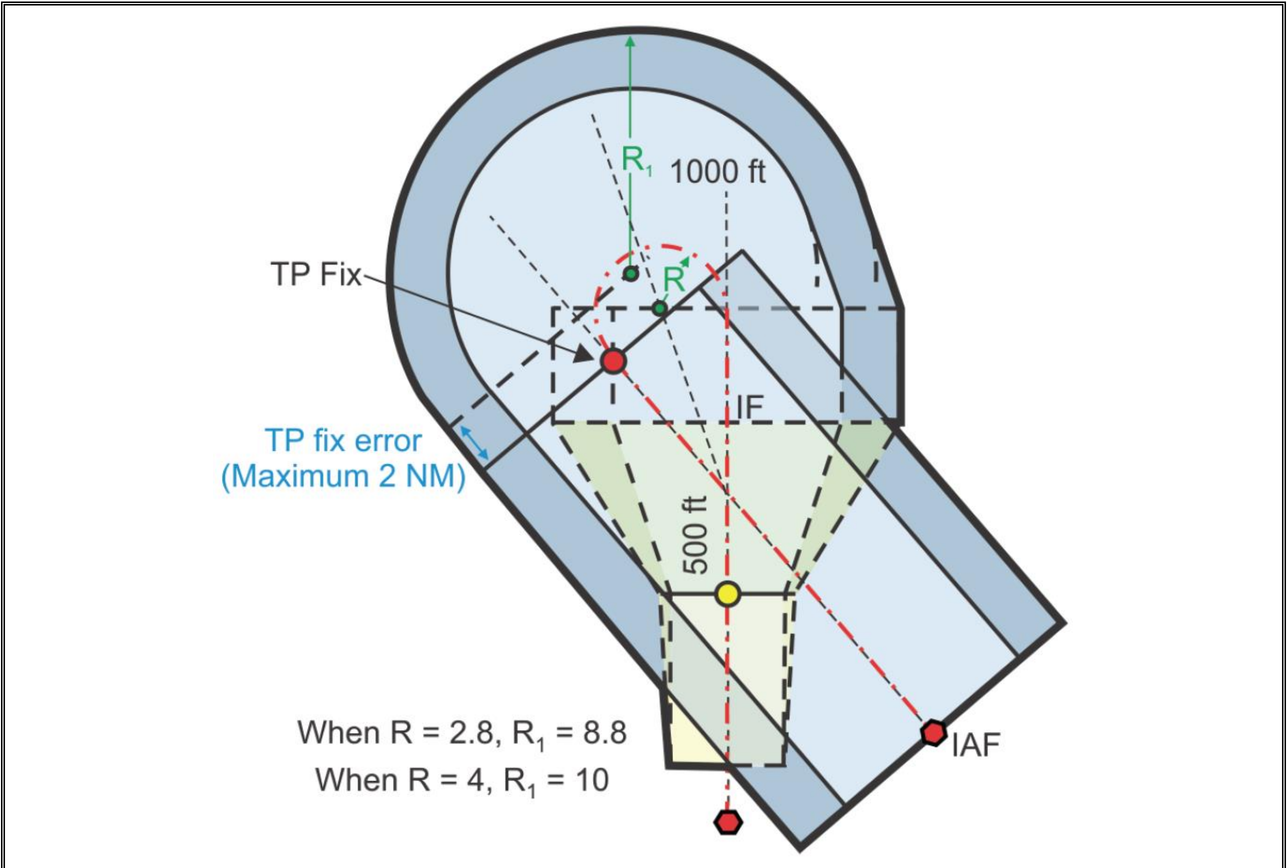
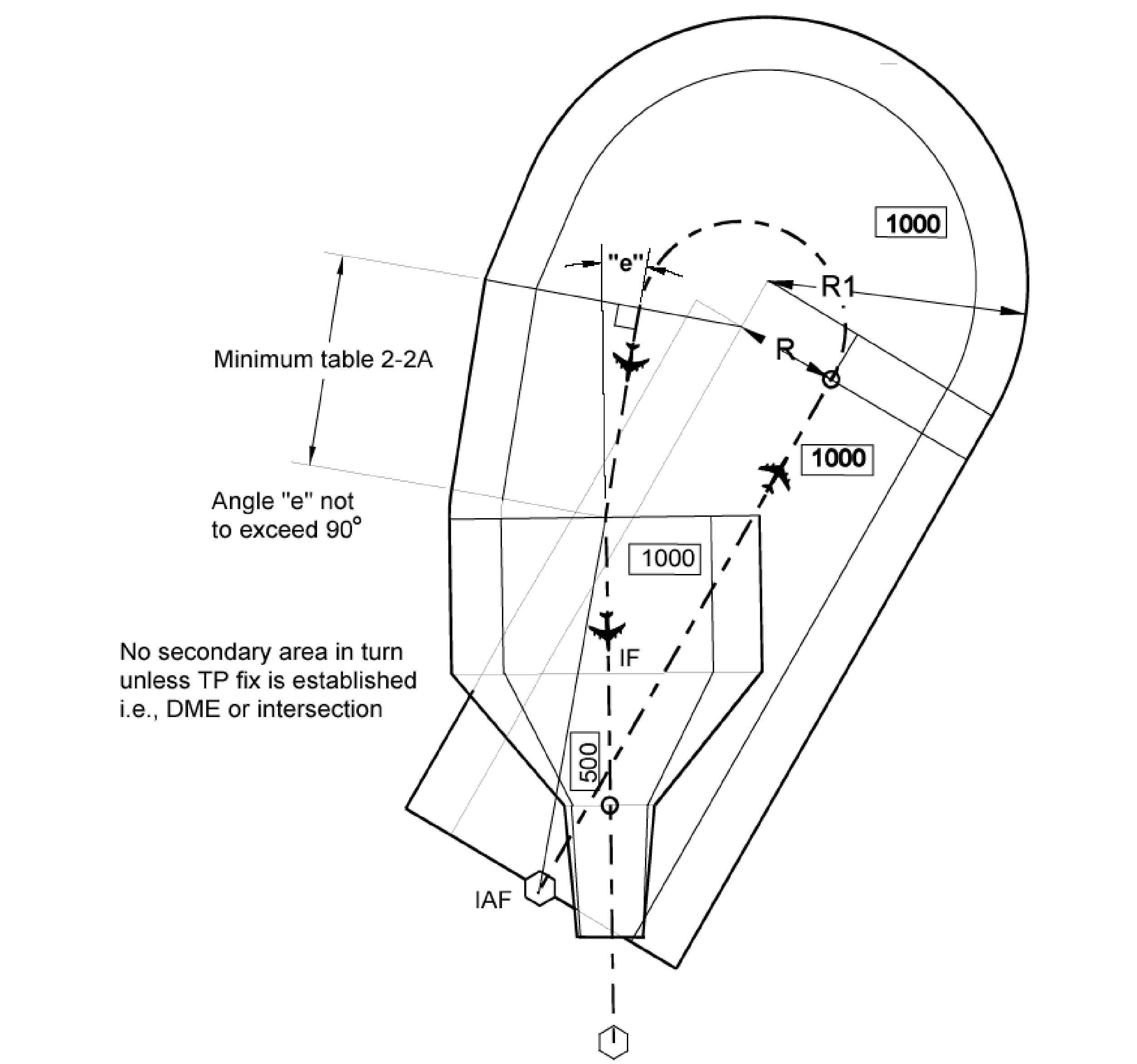


Figure 2-9-2 – Examples Of Initial Course Reversal. Para 236.



Figures 2-9-3 – Examples Of Initial Course Reversal. Para 236.

Note: When R = 2.8 , $R_1 = 8.8$

When R = 4 , $R_1 = 10$

SECTION 4. INTERMEDIATE APPROACHES

240. Intermediate Approach Segment

This is the segment which blends the initial approach segment into the final approach segment. It is the segment in which aircraft configuration, speed, and positioning adjustments are made for entry into the final approach segment. The intermediate segment begins at the IF point, and ends at the FAF. There are two types of intermediate segments: the "radial" or " course" intermediate segment and the "arc" intermediate segment. In either case, positive course guidance (PCG) shall be provided. See Figure 2-10 for typical approach segments.

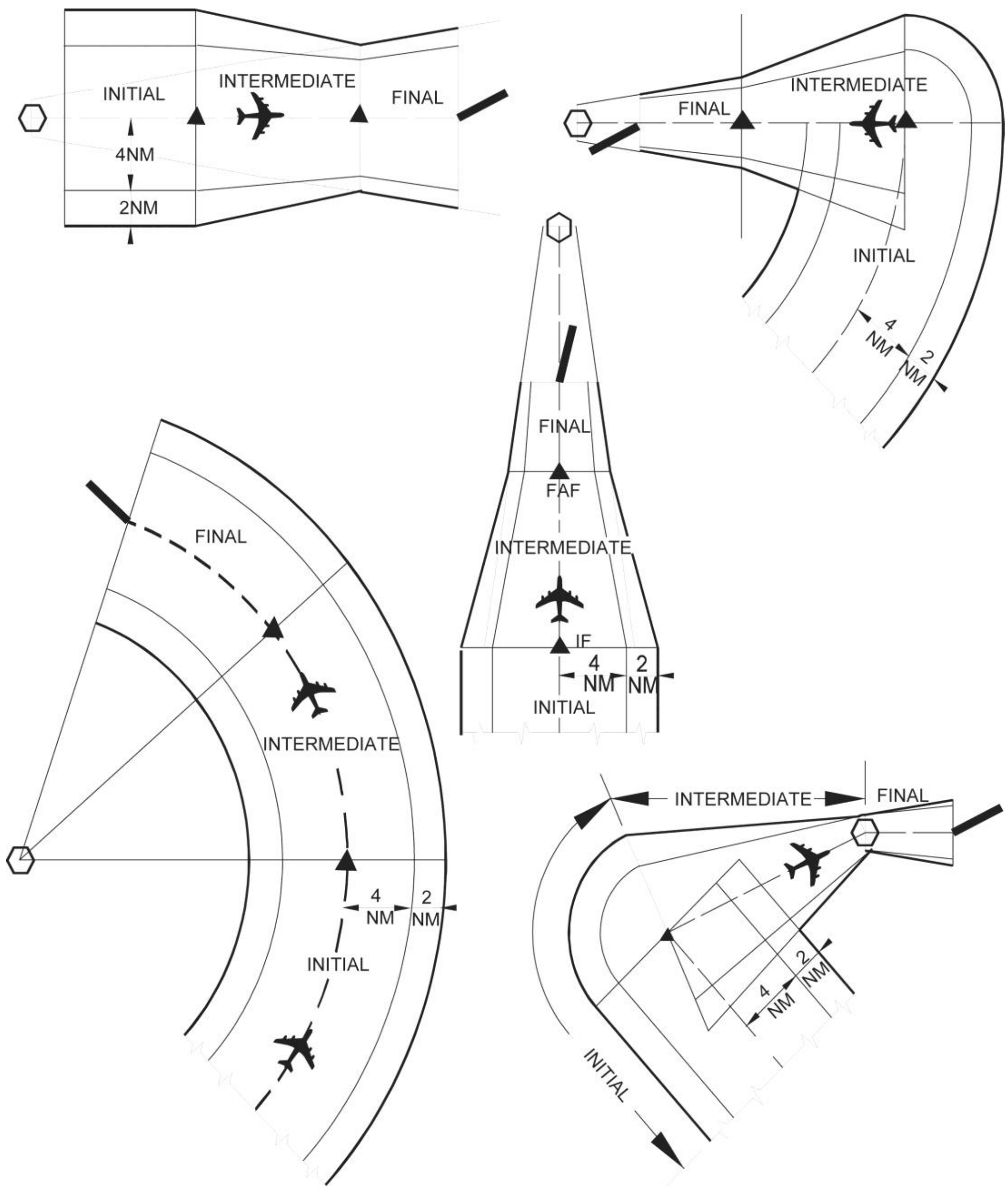


Figure 2-10: Typical Approach Segments. Paras 232.b and 240.

241. Altitude Selection

The MINIMUM altitude in the intermediate segment shall be established in 100-foot increments, without violating the ROC; i.e., 749 feet may be shown as 700 feet and 750 feet shall be shown as 800. In addition, the altitude selected for arrival over the FAF should be low enough to permit descent from the FAF to the airport for a straight-in landing whenever possible.

242. Intermediate Approach Segment Based On Straight Courses

a. Alignment. The course to be flown in the intermediate segment shall be the same as the final approach course, except when the final approach fix is the navigation facility and it is not practical for the course to be identical. In such cases, the intermediate course shall not differ from the final approach course by more than 30° (see Figure 2-10).

b. Area.

(1) **Length**. The length of the intermediate segment is measured along the course to be flown. Where the initial segment joins the intermediate segment at angles up to 90°, the MINIMUM length is 5 NM for CAT A/B, and 6 NM for CAT C/D/E (except as specified in Volume 1, chapter 10 and 16, and Volume 3, chapter 2). Table 2-3 lists the minimum segment length where the initial approach course joins the intermediate course at an angle greater than 90° (see Figure 2-3). The MAXIMUM segment length is 15 NM. The OPTIMUM length is 10 NM. A distance greater than 10 NM should not be used unless an operational requirement justifies a greater distance.

(2) **Width**. The width of the intermediate segment is the same as the width of the segment it joins. When the intermediate segment is aligned with the initial or final approach segments, the width of the intermediate segment is determined by joining the outer edges of the initial segment with the outer edges of the final segment. When the intermediate segment is not aligned with the initial or final approach segments, the resulting gap on the outside of the turn is part of the preceding segment is closed by the appropriate arc (see Figure 2-10). For obstacle clearance purposes the intermediate segment is divided into a primary and a secondary area.

c. Obstacle Clearance. A minimum of 500 feet of obstacle clearance shall be provided in the primary area of the intermediate approach segment. In the secondary area, 500 feet of obstacle clearance shall be provided at the inner edge, tapering to zero feet at the outer edge (see Figure 2-10a). Allowance for precipitous terrain and RASS shall be considered as specified in Para 323.b. & c. The altitudes selected by application of the obstacle clearance specified in this paragraph may be rounded to the nearest 100 feet, provided the ROC is not violated (see Para 241).

d. Descent Gradients. Because the intermediate segment is used to prepare the aircraft speed and configuration for entry into the final approach segment, the gradient should be as flat as possible. The OPTIMUM descent gradient is 150 feet per nautical mile. The MAXIMUM gradient is 318 feet per nautical mile, except for a localizer approach published in conjunction with an ILS procedure. In this case, a higher descent gradient equal to the commissioned GS angle (provided it does not exceed 3°) is permissible. Higher gradients resulting from arithmetic rounding are also permissible.

Supplementary Notes:

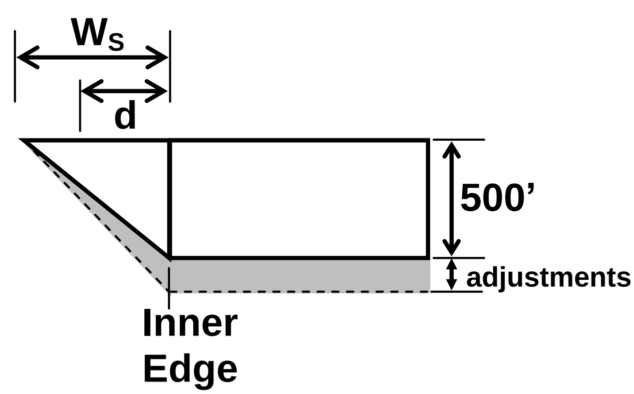
1) The intent of paragraph 242 d) is that the localizer descent gradient must not be higher than the published glideslope angle. For example, a localizer published in conjunction with an ILS that has a 2.75° glide slope, must not have an

intermediate segment descent gradient greater than 291 ft/nm. In this case, the maximum gradient of 318ft/nm specified in para 242d would not be applicable.

2) When the descent gradient exceeds 318 feet per nautical mile, the procedure specialist should assure an initial segment is provided prior to the intermediate segment to prepare the aircraft speed and configuration for entry into the final segment. The initial segment should be a minimum length of 5 NM and its descent gradient should not exceed 318 feet per nautical mile.

Angle (Degrees)	Minimum Length (NM)
91 – 96	6
> 96 – 102	7
> 102 – 108	8
> 108 – 114	9
> 114 – 120	10

Table 2-3: Minimum Intermediate Course Length (NM). Para 242.b(1).



Secondary ROC = $(500 + adj) \times \frac{(W_S - d)}{W_S}$

Where: d = distance from inner edge to obstacle (ft)

W_S = Width of secondary area (ft)

Adjustments = adjustments (ft) as per para 323.

Figure 2-10a: Obstacle Clearance Area. Paras 242.c and 243.c.

243. Intermediate Approach Segment Based On An Arc

Arcs with a radius of less than 7 NM or more than 30 NM from the navigation facility shall NOT be used. DME arc courses shall be predicated only on a DME collocated with a facility providing omnidirectional course information.

a. Alignment. The same arc shall be used for the intermediate and the final approach segments. No turns shall be required over the FAF.

b. Area.

(1) **Length**. The intermediate segment shall NOT be less than 5 NM or more than 15 NM in length, measured along the arc. The OPTIMUM length is 10 NM. A distance greater than 10 NM should not be used unless an operational requirement justifies the greater distance.

(2) **Width**. The total width of an arc intermediate segment is 6 NM on each side of the arc. For obstacle clearance purposes, this width is divided into a primary and a secondary area. The primary area extends 4 NM laterally on each side of the arc segment. The secondary areas extend 2 NM laterally on each side of the primary area (see Figure 2-10).

c. Obstacle Clearance. A minimum of 500 feet of obstacle clearance shall be provided in the primary area. In the secondary area, 500 feet of obstacle clearance shall be provided at the inner edge, tapering to zero feet at the outer edge (see Figure 2-10a). Allowance for precipitous terrain should be considered as specified in Para 323.b. The altitudes selected by application of the obstacle clearance specified in this paragraph may be rounded to the nearest 100 feet, provided the ROC is not violated. (See Para 241.)

d. Descent Gradients. Criteria specified in Para 242.d apply.

244. Intermediate Approach Segment Within A PT Segment

a. PT Over a FAF. When the FAF is a Facility (see Figure 2-11).

(1) The MAXIMUM intermediate length is 15 NM, the OPTIMUM is 10 NM, and the MINIMUM is 5 NM. Its width is the same as the final segment at the facility and expanding uniformly to 6 NM on each side of the course at 15 NM from the facility.

(2) The intermediate segment considered for obstacle clearance shall be the same length as the PT distance; e.g., if the procedure requires a PT to be completed within 5 NM, the intermediate segment shall be only 5 NM long, and the intermediate approach shall begin on the intermediate course 5 NM from the FAF.

(3) When establishing a step down fix within intermediate segment underlying a PT area:

(a) Table 2-1A shall be applied.

(b) Only one step down fix is authorized within the intermediate segment that underlies the PT maneuvering area.

(c) The distance between the PT fix/facility and a SDF underlying the PT area shall not exceed 4 NM.

(d) The MAXIMUM descent gradient from the IF point to the SDF is 200 feet/NM. The MAXIMUM descent gradient from the SDF to the FAF is 318 feet/NM.

b. PT Over a FAF When the FAF is Not a Facility (see Figure 2-12).

(1) The intermediate segment shall be 6 NM wide each side of the intermediate course at the PT distance.

(2) When establishing a step down fix within intermediate/initial segment underlying a PT area:

(a) Table 2-1A shall be applied.

(b) Only one step down fix is authorized within the intermediate segment that underlies the PT maneuvering area.

(c) The distance between the PT fix/facility and a SDF underlying the PT area shall not exceed 4 NM.

(d) The MAXIMUM descent gradient from the IF point to the SDF is 200 feet/NM. The MAXIMUM descent gradient from the SDF to the FAF is 318 feet/NM.

c. PT Over a Facility/Fix After the FAF (see Figure 2-13).

(1) The PT facility/fix to FAF distance shall not exceed 4 NM.

(2) The MAXIMUM PT distance is 15 NM.

(3) The length of the intermediate segment is from the start of the PT distance to the FAF and the MINIMUM length shall be 5 NM.

(4) Intermediate Segment Area.

(a) PT Over a Facility. The intermediate segment starts 15 NM from the facility at a width of 6 NM each side of the inbound course and connects to the width of the final segment at the FAF. The area considered for obstacle clearance is from the start of the PT distance to the FAF.

(b) PT Over a Fix (NOT a Facility). The intermediate segment starts at the PT distance at a width of 6 NM each side of the inbound course and connects to the width of the final segment at the FAF. The area considered for obstacle clearance is from the start of the PT distance to the FAF.

(5) The MAXIMUM descent gradient in the intermediate segment is 200 feet/NM. The PT distance may be increased in 1 NM increments up to 15 NM to meet descent limitations.

(6) When establishing a step down fix within intermediate/initial segment underlying a PT area:

(a) Only one step down fix is authorized within the intermediate segment that underlies the PT maneuvering area.

(b) The distance between the PT fix/facility and a stepdown fix (SDF) underlying the PT area shall not exceed 4 NM.

(c) The MAXIMUM descent gradient from the IF point to the SDF is 200 feet/NM. The MAXIMUM descent gradient from the SDF to the FAF is 318 feet/NM.

d. PT Over a Facility/Fix PRIOR to the FAF (see Figures 2-14-1 and 2-14-2).

(1) The MINIMUM PT distance is 5 NM.

(2) The length of the intermediate segment is from the start of the PT distance to the FAF and the MAXIMUM length is 15 NM.

(3) Intermediate Segment Area.

(a) PT Over a Facility. The intermediate segment starts 15 NM from the facility at a width of 6 NM each side of the inbound course and connects to the width of the final segment at the FAF. The area considered for obstacle clearance is from the start of the PT distance to the FAF.

(b) PT Over a Fix (NOT a Facility). The intermediate segment starts at the PT distance at a width of 6 NM each side of the inbound course and connects to the width of the final segment at the FAF. The area considered for obstacle clearance is from the start of the PT distance to the FAF.

(4) The MAXIMUM descent gradient is 200 feet/NM. If the PT facility/fix is a step-down fix, the descent gradient from the step-down fix to the FAF may be increased to a maximum of 318 feet/NM (see Figure 2-14-2). The PT distance may be increased in 1 NM increments up to 15 NM to meet descent limitations.

(5) When establishing a step down fix within an intermediate/initial segment underlying a PT area:

(a) When the PT fix is over a facility/fix prior to the FAF, the facility/fix is the SDF in the intermediate/initial area, and another SDF within this segment is not authorized.

(b) The MAXIMUM descent gradient from the IF point to the SDF is 200 feet/NM. The MAXIMUM descent gradient from the SDF to the FAF is 318 feet/NM.

e. PT Facility/Fix Used as an Intermediate Fix (see Figure 2-14-3).

(1) When the PT inbound course is the same as the intermediate course, either Para 244.d may be used, or a straight initial segment may be used from the start of the PT distance to the PT fix.

(2) When the PT inbound course is NOT the same as the intermediate course, an intermediate segment within the PT area is NOT authorized; ONLY a straight initial segment shall be used from the start of the PT distance to the PT fix.

(3) When a straight initial segment is used, the MAXIMUM descent gradient within the PT distance is 318 feet/NM, the PT distance may be increased in 1 NM increments up to 15 NM to meet descent limitations.

(4) When establishing a step down fix within an intermediate/initial segment underlying a PT area:

(a) Only one step down fix is authorized within the initial segment that underlies the PT maneuvering area.

(b) The distance from the PT fix/facility and a SDF underlying the PT area shall not exceed 4 NM.

(c) The MAXIMUM descent gradient from the PT completion point (turn distance) to the SDF, and from the SDF to the IAF is 318 feet/NM.

f. When a PT from a facility is required to intercept a localizer course, the PT facility is considered on the localizer course when it is located within the commissioned localizer course width.

245—249. Reserved

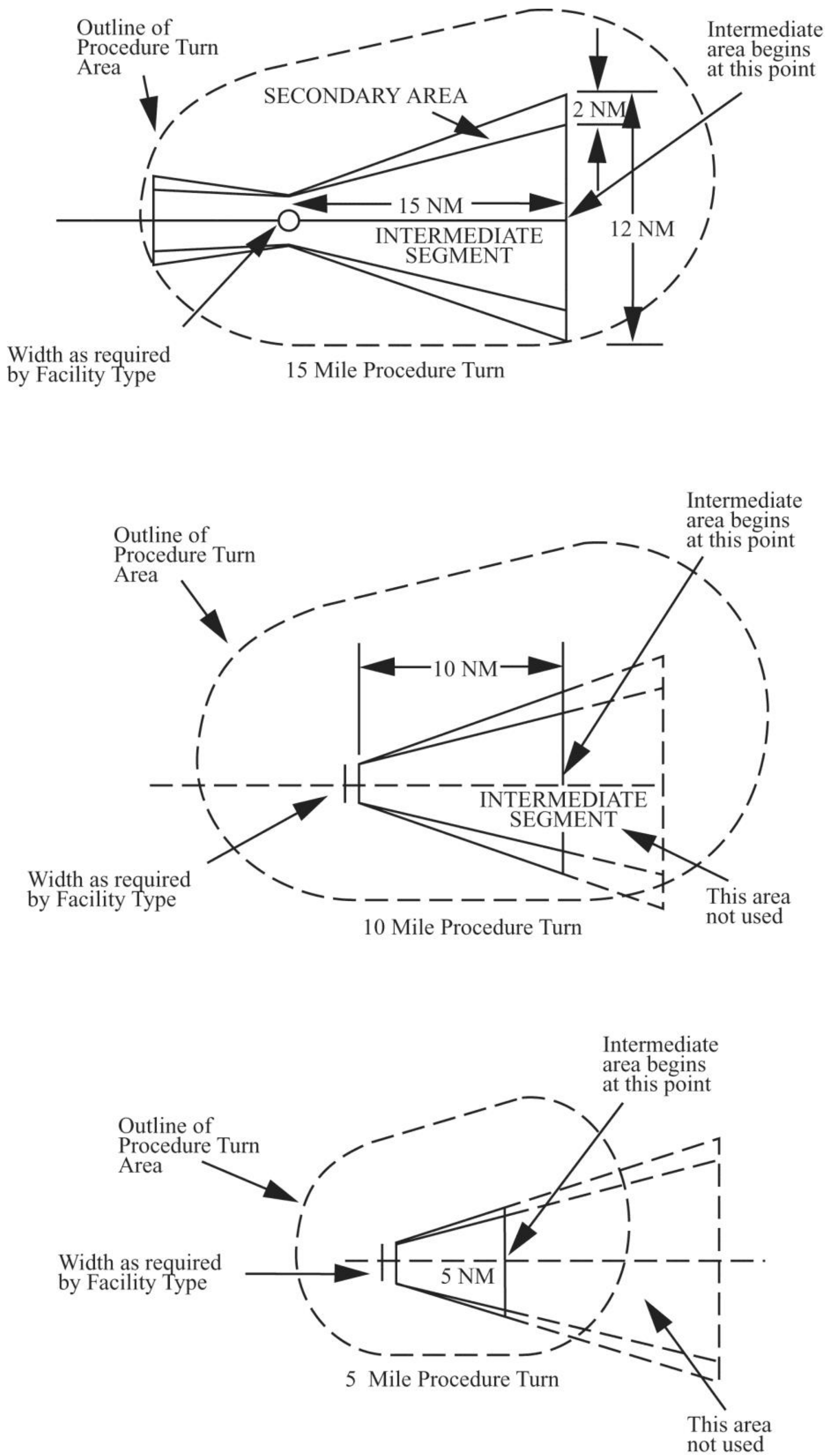


Figure 2-11: Intermediate Area Within A Procedure Turn Area. FAF Is The Facility. Para 244.a.

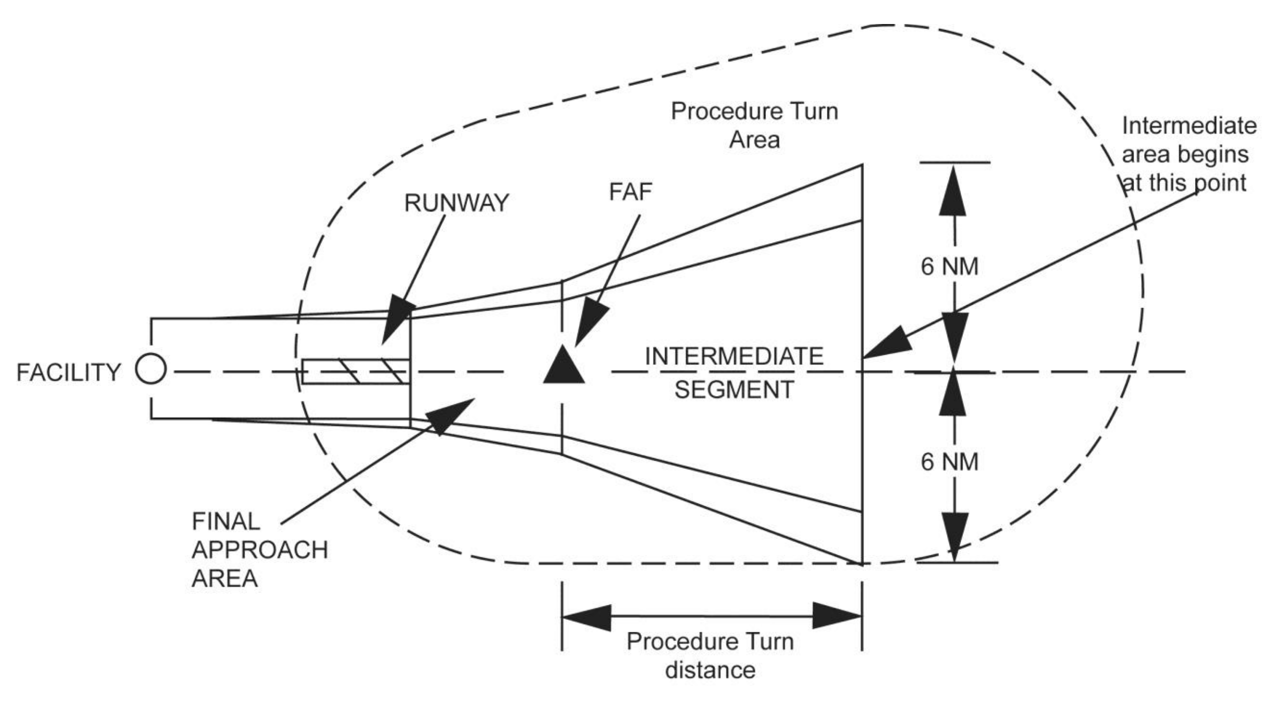


Figure 2-12: Intermediate Area Within The Procedure Turn Area. FAF Is Not The Facility. Para 244.b.

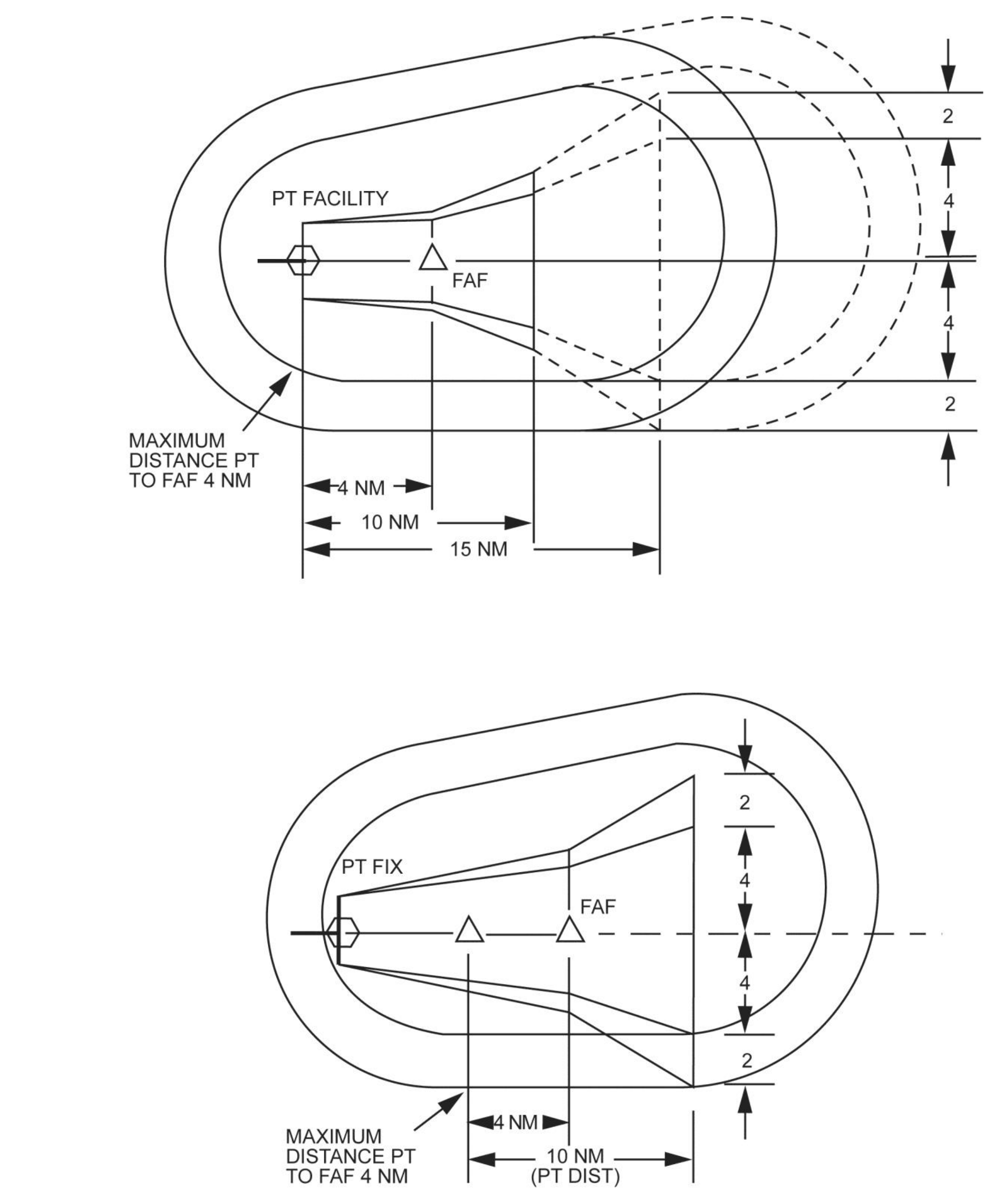


Figure 2-13: Intermediate Area Within The Procedure Turn. PT Over The Facility/Fix After The FAF. Para 244.c.

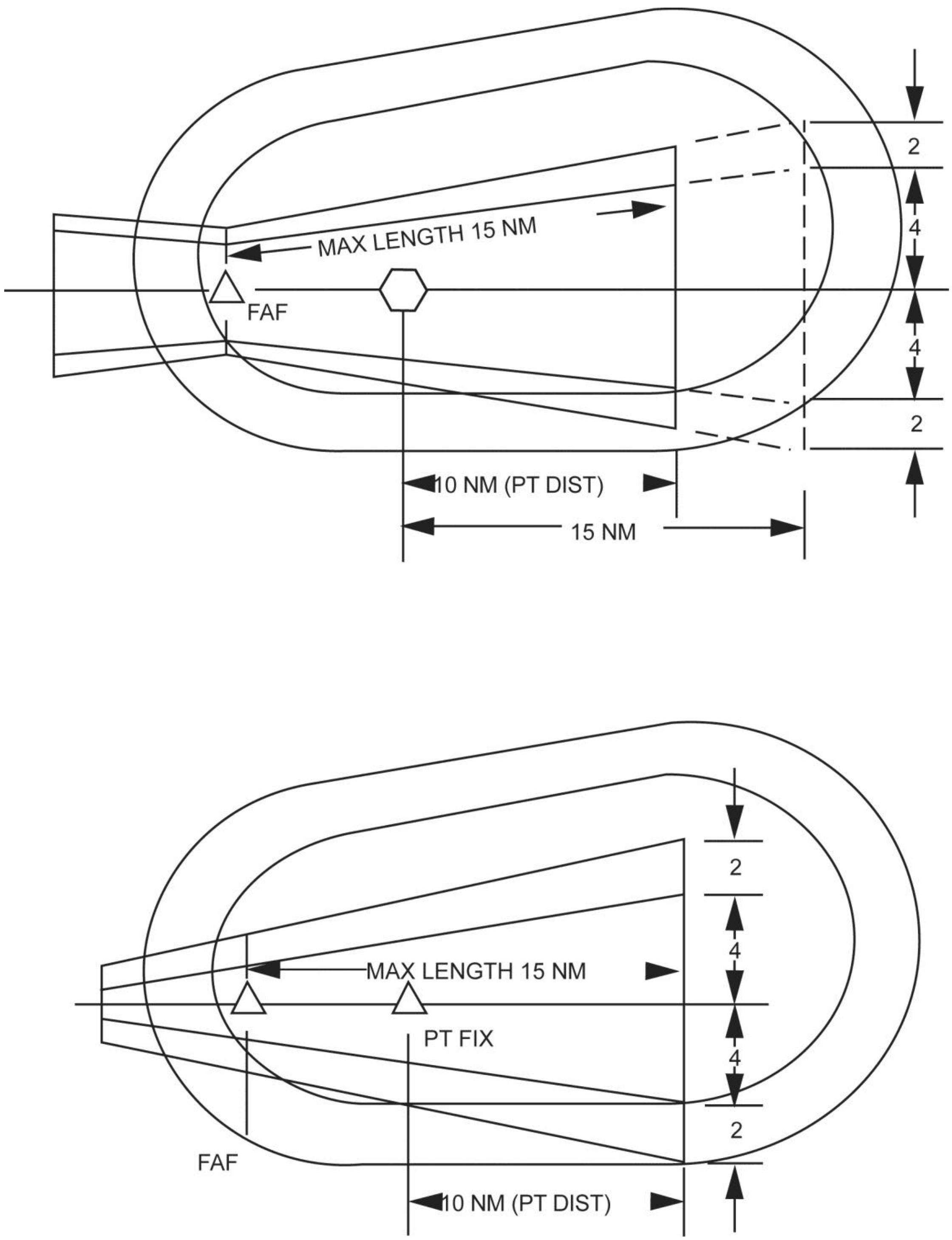


Figure 2-14-1: Intermediate Area Within The Procedure Turn Area. PT Over The Facility/Fix Prior To The FAF. Para 244.d.

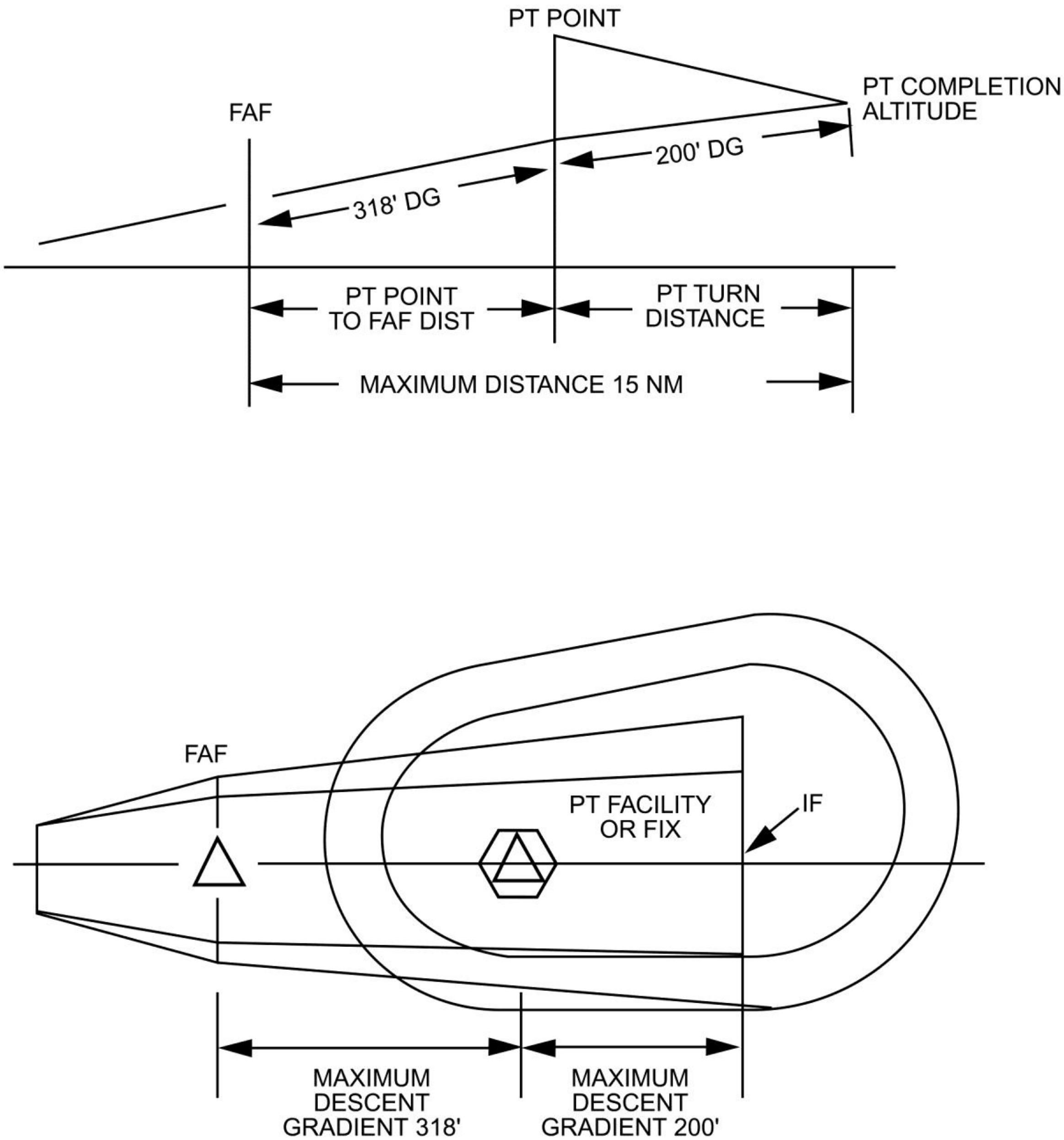


Figure 2-14-2: Intermediate Area Within The Procedure Turn Area. PT Facility/Fix Used As A Stepdown Fix. Para 244.d.(4).

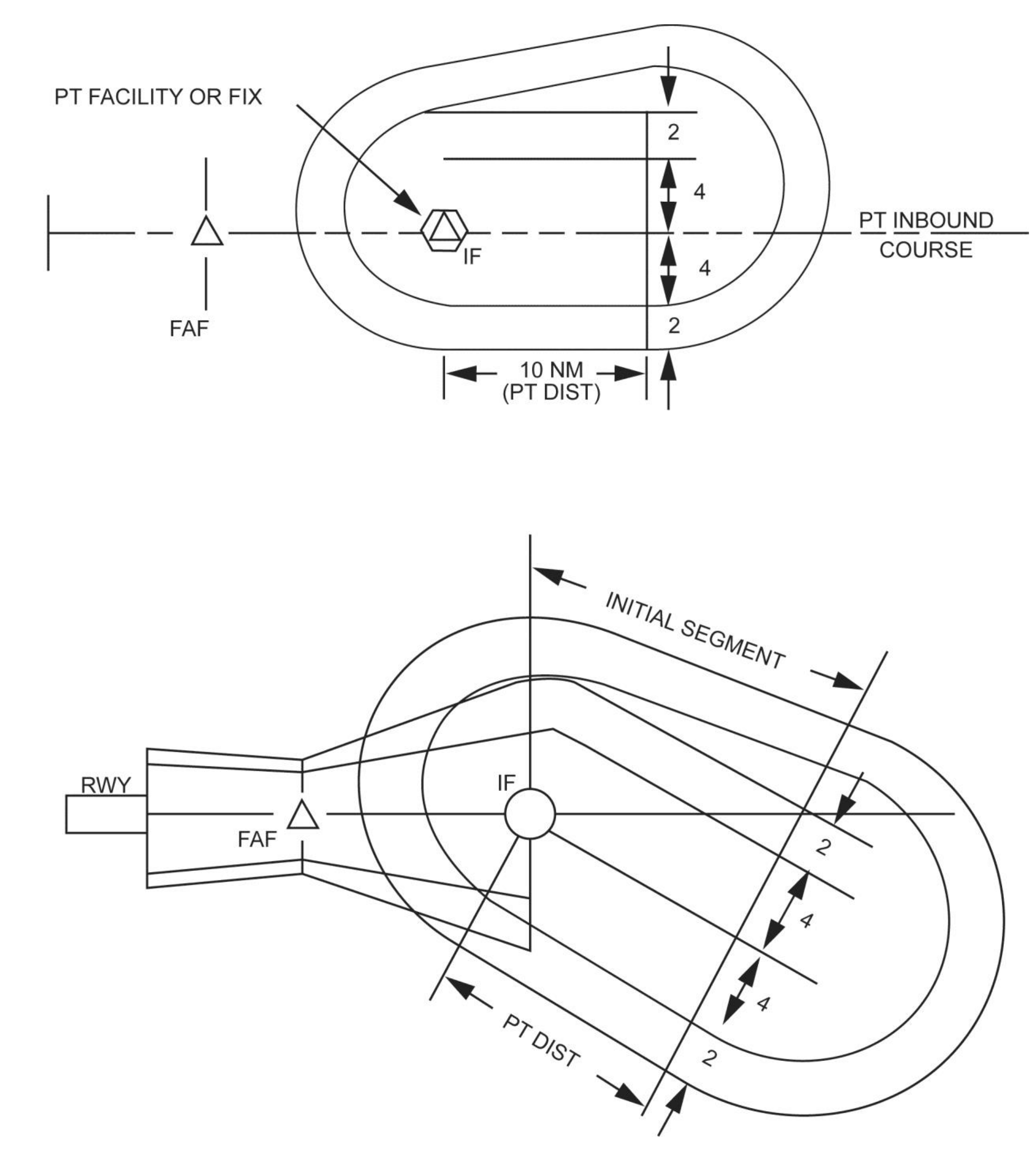


Figure 2-14-3: Use Of PT Fix For IF. Para 244.e.

Figure 2-14-4 to 2-14-6: Reserved

SECTION 5. FINAL APPROACH

250. Final Approach Segment

This is the segment in which alignment and descent for landing are accomplished. The final approach segment considered for obstacle clearance begins at the FAF or points and ends at the runway or missed approach point (MAP), whichever is encountered last. Final approach may be made to a runway for straight-in landing, or to an airport for a circling approach. Since the alignment and dimensions of the non-visual portions of the final approach segment vary with the location and type of navigation facility, applicable criteria are contained in chapters designated for specific navigation facilities.

251. Reserved

252. Descent Angle/Gradient.

The OPTIMUM non precision final segment descent gradient is 318 FT/NM, which approximates a 3.00° angle. The MAXIMUM descent gradient is 400 ft/NM, which approximates a descent angle of 3.77°. Calculate descent gradient from the plotted position of the FAF or SDF to the plotted position of the SDF or final endpoint (FEP) as appropriate (see Figure 2-14-7). The FEP is formed by the intersection of the FAC and a line perpendicular to the FAC that extends to the runway threshold (first useable landing surface for circling only procedures). When the maximum descent gradient is exceeded, straight-in minimums are NOT authorized; however, circling only minimums may be authorized if the maximum circling descent gradient is not exceeded (see Para 252.d). In these cases, publish the actual descent gradient to threshold crossing height (TCH) rather than to circling minimum descent altitude (CMDA).

a. Non-RNAV approaches. FAF and/or last SDF) location and altitude should be selected to provide a descent angle and TCH coincident (±0.20°, ±3’) with the lowest published visual glideslope indicator (VGSI) glideslope angle, when feasible; or, when VGSI is not installed, the FAF and/or last SDF location and altitude should be selected so as to achieve a near OPTIMUM final segment descent gradient. To determine the FAF or SDF altitude necessary to align the descent angle with the lowest VGSI, calculate the altitude gain of a plane with the slope of the lowest published VGSI glideslope angle emanating from the lowest published VGSI TCH to the FAF or SDF location. To determine the OPTIMUM FAF or SDF altitude, calculate the altitude gain of a 318 FT/NM gradient (3° angle) extending from the visual TCH to the FAF or SDF location. Round this altitude up or down to the 100’ increment for the FAF or 20’ increment for the SDF. Ensure that ROC requirements are not violated during the rounding process. If the gradient from TCH to SDF is greater than the gradient from TCH to FAF, continue the greater gradient to the FAF and adjust the FAF altitude accordingly. If application of hold-in-lieu of PT criteria in Para 234.e.1, or intermediate segment obstacles prohibit this altitude, consider relocating the FAF to achieve an altitude that will satisfy both the VGSI or OPTIMUM descent gradient (see Figure 2-14-8).

b. Reserved.

c. Determining Final Segment Descent Gradient and Angle.

(1) **Final Without SDF's**. Calculate the final descent gradient by dividing the height loss from FAF to TCH by the segment length in NM.

$$\boldsymbol{Descent\ Gradient} = \frac{\boldsymbol{Height\ Loss}}{\boldsymbol{Segment\ Length\ (NM)}}$$

The descent gradient divided by 6076.11548 is the arc tangent of the segment descent angle (Ө).

$$\boldsymbol{Tan(\theta)^{-1}} = \frac{\boldsymbol{Descent\ Gradient}}{\boldsymbol{6076.11548}}$$

For RNAV standard instrument approach procedures (SIAP), this angle is the glideslope computer setting.

(2) **Final With SDF**. The maximum descent angle is calculated using the difference between the FAF/stepdown altitudes and the stepdown/TCH altitudes as appropriate. Descent gradient and angle computations apply to each stepdown segment. Height loss in the last segment flown is from the SDF minimum altitude to the TCH (see Figure 2-14-10).

d. Circling Approaches. The maximum descent angle is calculated using the difference between the FAF/stepdown altitudes and stepdown/lowest CMDA as appropriate (see Figure 2-14-11).

253—259. Reserved

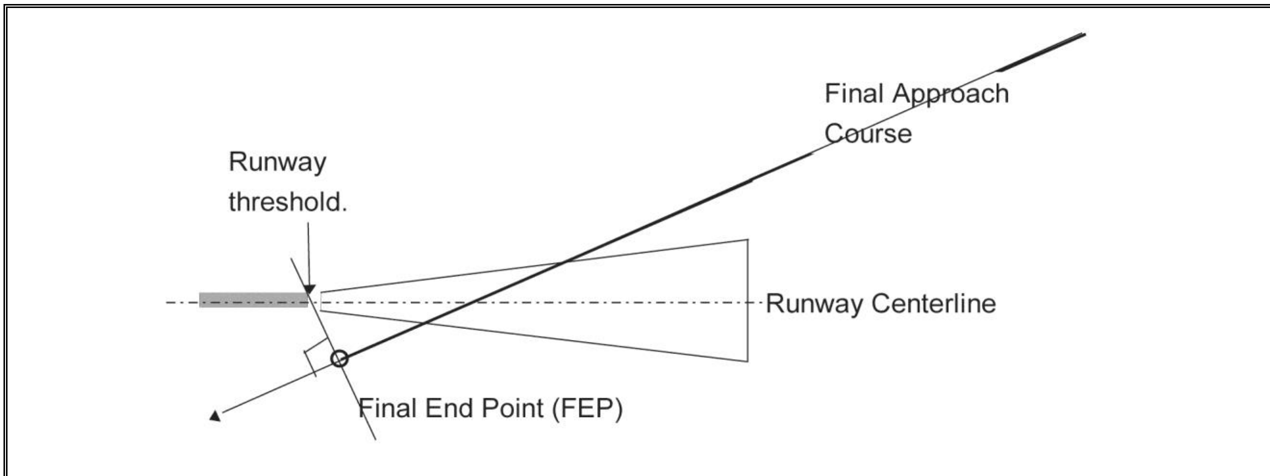
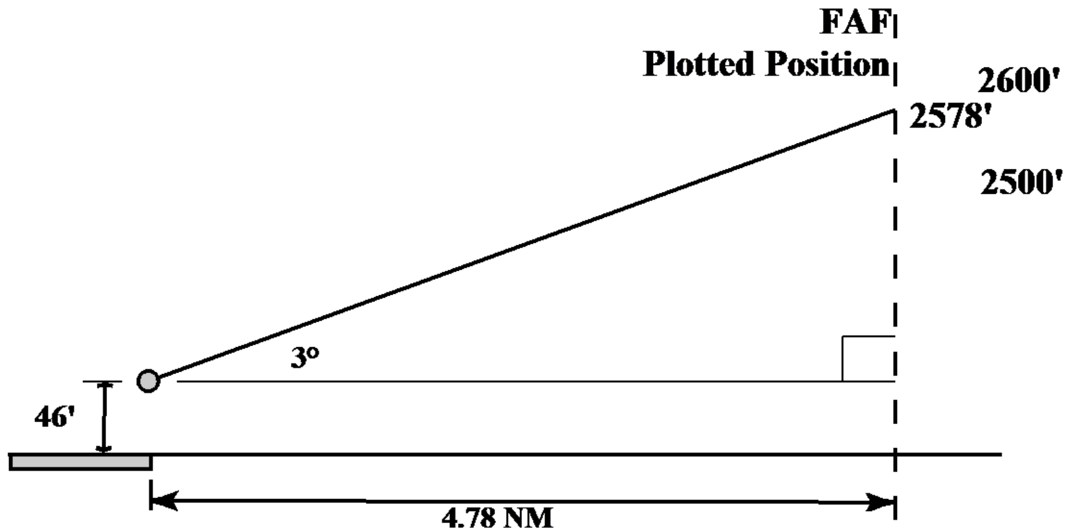


Figure 2-14-7: Final End Point. Para 252.



EXAMPLE	
Givens: THR elevation is 1,012' TCH is 46' Final Segment length is 4.78 NM	**Where** THRe = THR Elevation (ft) SL = Segment Length

Solution:

1. SL in **NM**

FAF Altitude = THRe + TCH + (318 x SL)

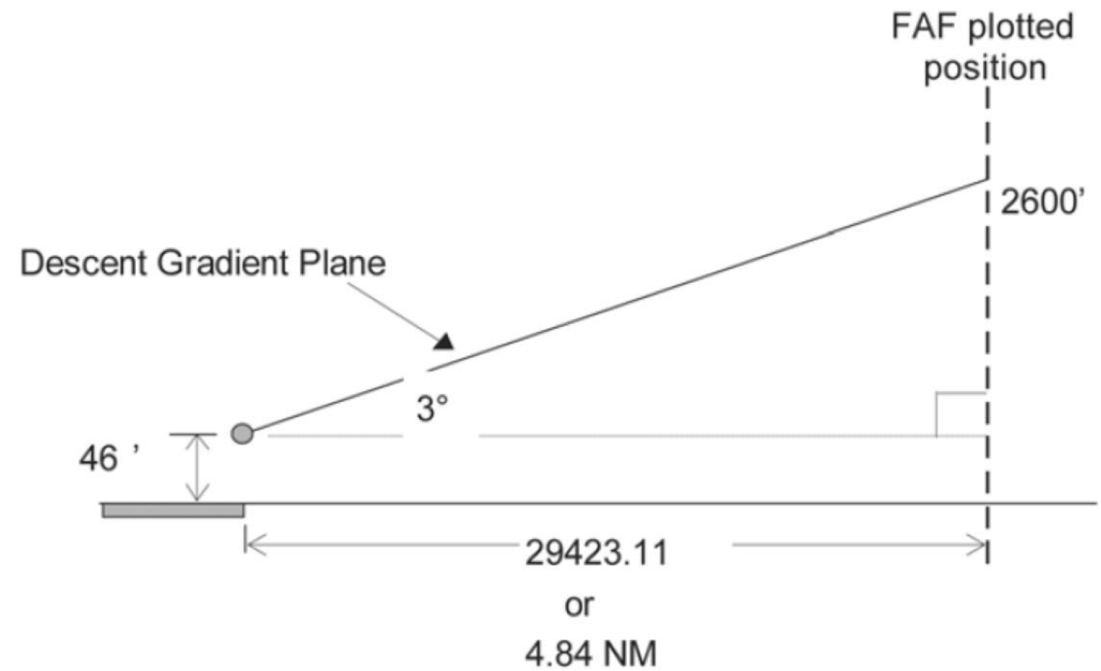
FAF Altitude = 1012 + 46 + (318 ft/NM x 4.78 NM) = **2578.04 ft**

2. SL in **feet**

FAF Altitude = THRe + TCH + (Tan (VGSI Angle) x SL X 6076.11548)

FAF Altitude = 1012 + 46 + (Tan (3) x 4.78 X 6076.11548) = **2580.12 ft**

Figure 2-14-8: FAF Activities Given Final Length. Para 252.a.



EXAMPLE

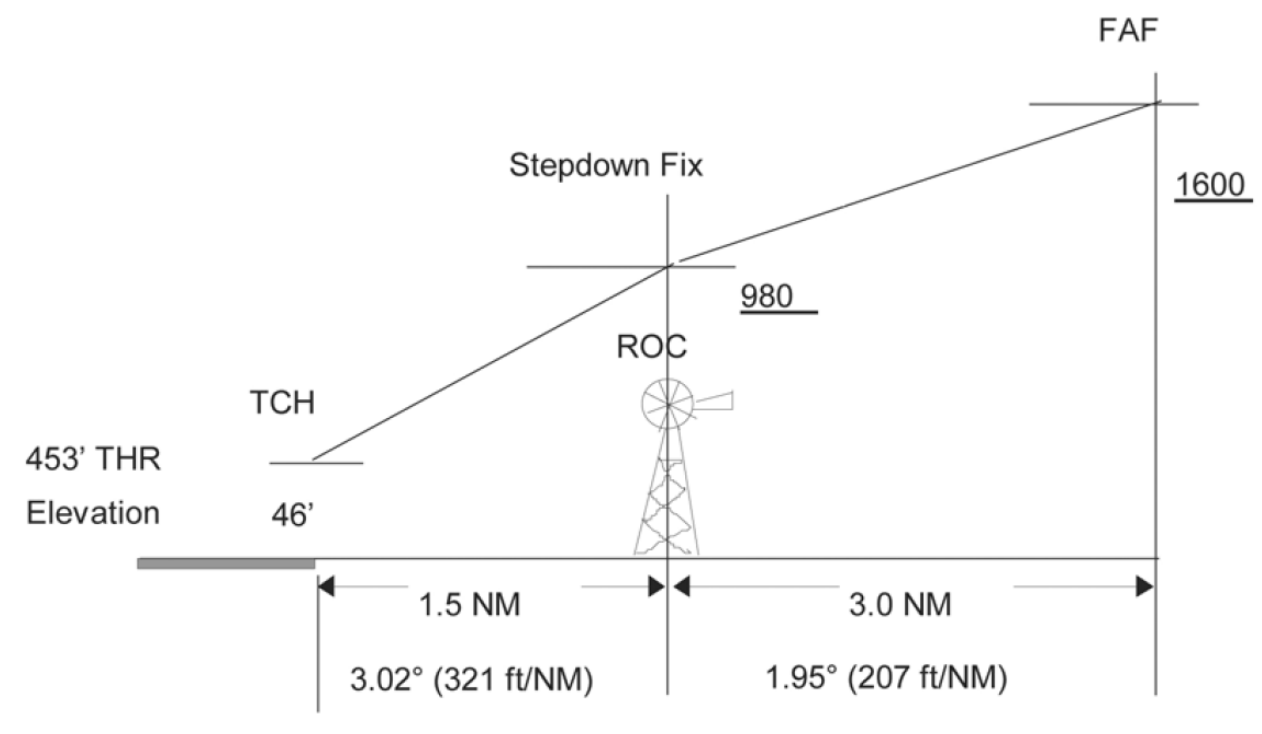
Givens:	**Where**
Descent Gradient Plane is 3° THR elevation is 1,012' TCH is 46' FAF Altitude is 2600'	SL = Segment Length (ft) THRe = THR Elevation (ft) TCH = Threshold Crossing Height (ft) SL = Segment Length DGP = Descent Gradiant Plane VGSI = Visual Ground Slope Indicator FAF_{ALT} = FAF Altitude

$$SL = \frac{(FAF_{ALT} - [THRe + TCH])}{tan(DGP\ or\ VGSI)}$$

$$SL = \frac{(2600 - [1012 + 46])}{tan(3°)}$$

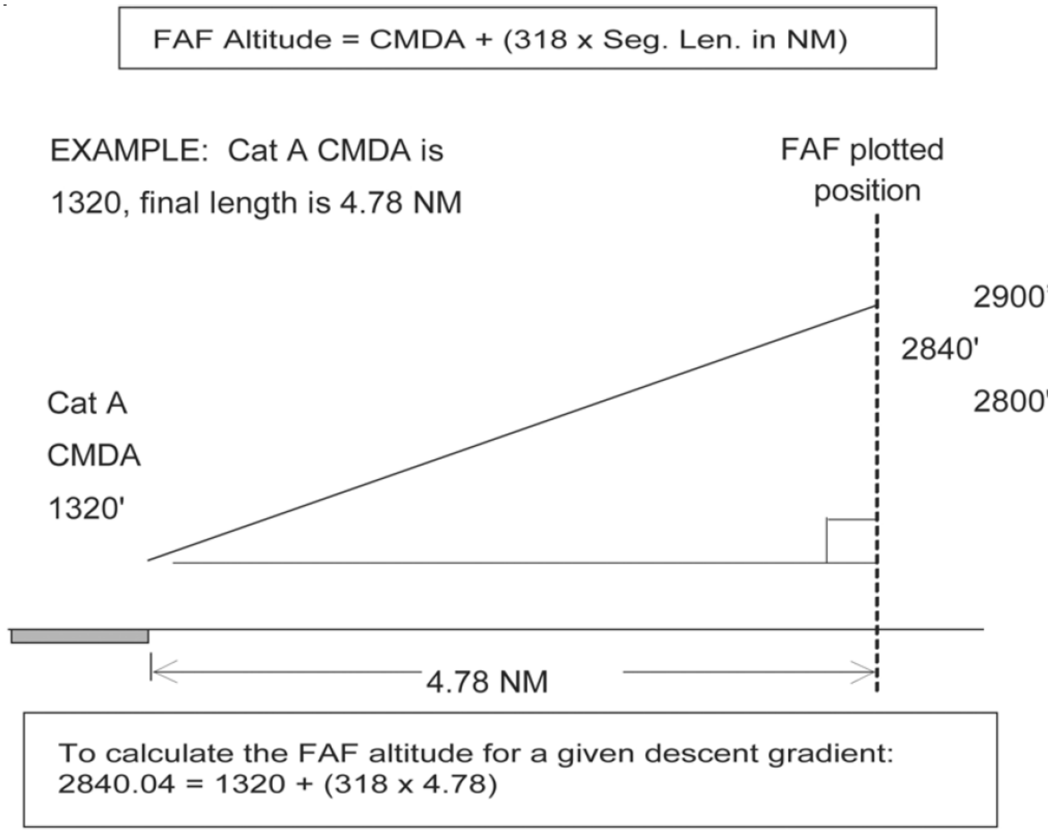
$$SL = 29423.11$$

Figure 2-14-9: Final Length Given FAF Altitude. Para 252.b.



FAF to SDF	**SDF to TCH**
$Descent_{GRADIENT} = \frac{(1600 - 980)}{3.0}$	$Descent_{GRADIENT} = \frac{980 - (453 + 46)}{1.5}$
$Descent_{GRADIENT} = \frac{620}{3.0} = 206.66667$	$Descent_{GRADIENT} = \frac{481}{1.5} = 320.6667$
Descent Gradient = 207 ft/NM	**Descent Gradient = 321 ft/NM**
$Tan(\theta)^{-1} = \frac{207}{6076.11548}$	$Tan(\theta)^{-1} = \frac{321}{6076.11548}$
$\theta = 1.95°$	$\theta = 3.02°$
Angle is 1.95°	**Angle is 3.02°**

Figure 2-14-10: Descent Gradient And Angle. Para 252.c.(2).



To calculate Descent Gradient and Angle given a FAF altitude and final length

$$Descent_{GRADIENT} = \frac{(2900 - 1320)}{4.78}$$

$$Descent_{GRADIENT} = \frac{1580}{4.78} = 330.54393$$

Descent Gradient = 331 ft/NM

$$Tan(\theta)^{-1} = \frac{331}{6076.11548}$$

$$\theta = 3.12°$$

Angle is 3.12°

Figure 2-14-11: Circling Approach Maximum Descent Angle. Para 252.d.

SECTION 6. CIRCLING APPROACH

260. Circling Approach Area

This is the obstacle clearance area, which shall be considered for aircraft maneuvering to land on a runway, which is not aligned with the FAC of the approach procedures, or for an approach where the final segment descent gradient does not meet criteria.

a. Alignment and Area. The size of the circling area varies with the approach category of the aircraft, as shown in Table 2-4. To define the limits of the circling area for the appropriate category, draw an arc of suitable radius from the centre of the end of each usable runway. Join the extremities to the adjacent arcs with lines drawn tangent to the arcs. The area thus enclosed is the circling approach area (see Figue 2-15).

Approach Category	Radius (NM)
A	1.3
B	1.5
C	1.7
D	2.3
E	4.5

Table 2-4: Circling Approach Area Radii (NM). Para 260a.

b. Obstacle Clearance. A minimum of 300 feet of obstacle clearance shall be provided in the circling approach area. There is no secondary obstacle clearance for the circling approach. See Para 322 for standard circling MDA.

261. Circling Approach Area Not Considered For Obstacle Clearance

It is permissible to eliminate from consideration, a particular sector where prominent obstacles exist in the circling approach area, provided the landing can be made without maneuvering over this sector and further provided that a note to this effect is included in the procedure. When a sector is eliminated from the obstacle clearance area, the area within which circling is permitted will be expanded to include a portion of the sector eliminated. The expanded portion of the obstacle clearance area shall begin at the threshold and splay 10° from the runway edge. Sectors within which circling is not permitted shall be clearly identified by runway centrelines, and where necessary, illumination of certain runway lights may be required. Circling restrictions shall be noted on the procedure.

262—269. Reserved

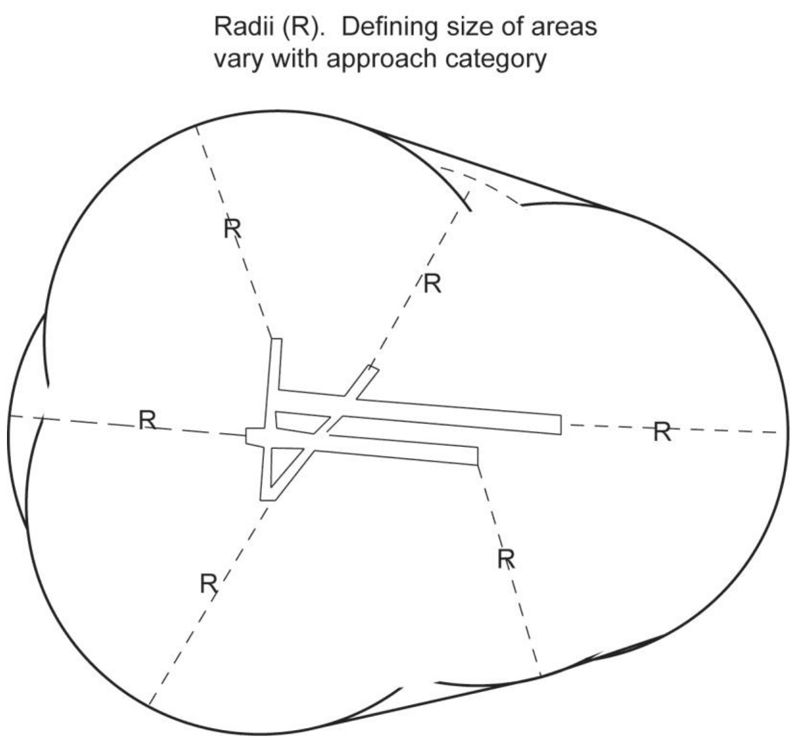


Figure 2-15: Construction Of Circling Approach Area. Para 260.a.

SECTION 7. MISSED APPROACH

270. Missed Approach Segment

(See ILS and PAR chapters for special provisions). A missed approach procedure shall be established for each IAP. The missed approach shall be initiated at the decision height (DH) in precision approaches or missed approach point (MAP) in non-precision approaches. The missed approach procedure must be simple, specify an altitude, and a clearance limit. The missed approach altitude specified in the procedure shall be sufficient to permit holding or en route flight. This means that the missed approach altitude must provide sufficient ROC to allow the pilot to hold at the missed approach holding fix (using the appropriate holding template), or must provide sufficient ROC to allow the pilot to proceed enroute. Where the missed approach altitude is below an initial approach altitude or enroute altitude, the 40:1 OIS must be assessed beyond the missed approach holding fix. If a climb in hold is required, it shall be assessed in accordance with Chapter 18, Holding Criteria. A note indicating that a shuttle is required prior to proceeding on course shall be included in the missed approach instructions. Example: Shuttle climb to 5000' BPOC.

Design alternate missed approach procedures using the criteria in this section. The area considered for obstacles has a width equal to that of a final approach area at the MAP and expands uniformly to the width of the initial approach segment at a point 15 nautical miles from the MAP (see Figure 2-16). When PCG is available, a secondary area for the reduction of obstacle clearance is identified within the missed approach area, which has the same width as the final approach segment area at the MAP, and which expands uniformly to a width of 2 NM at a point 15 NM from the MAP (see Figure 2-16). Where PCG is not available beyond this point, expansion of the area continues until PCG is achieved or segment terminates. Where PCG is available beyond this point, the area tapers at a rate of 30° inward relative to the course until it reaches initial segment width.

Note: Only the primary missed approach procedure shall be included on the published chart.

271. Missed Approach Alignment

Wherever practical, the missed approach course should be a continuation of the FAC. Turns are permitted, but should be minimized in the interest of safety and simplicity.

272. Missed Approach Point (MAP)

The MAP specified in the procedure may be the point of intersection of an electronic glide path with a DA, a navigation facility, a fix, or a specified distance from the FAF. The specified distance may not be more than the distance from the FAF to the usable landing surface. Specific criteria for the MAP are contained in the appropriate facility chapters.

273. Straight Missed Approach Area

When the missed approach course is within 15° of the final approach course, it is considered a straight missed approach (see Figure 2-16). The area considered for obstacle clearance is specified in Para 270.

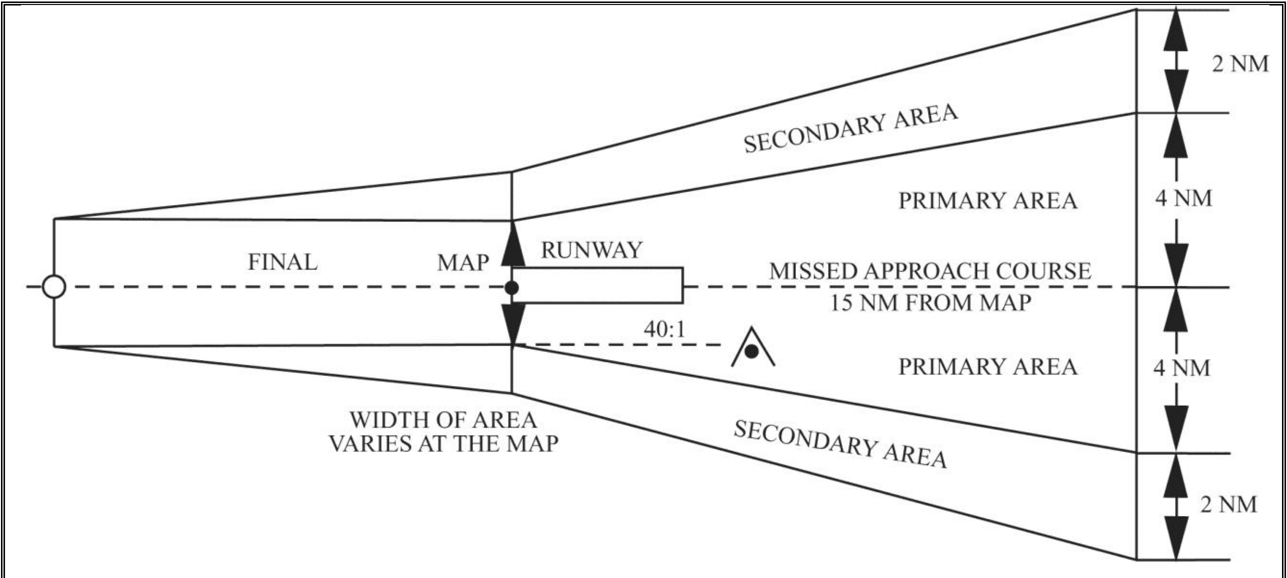


Figure 2-16: Straight Missed Approach Area. Para 273.

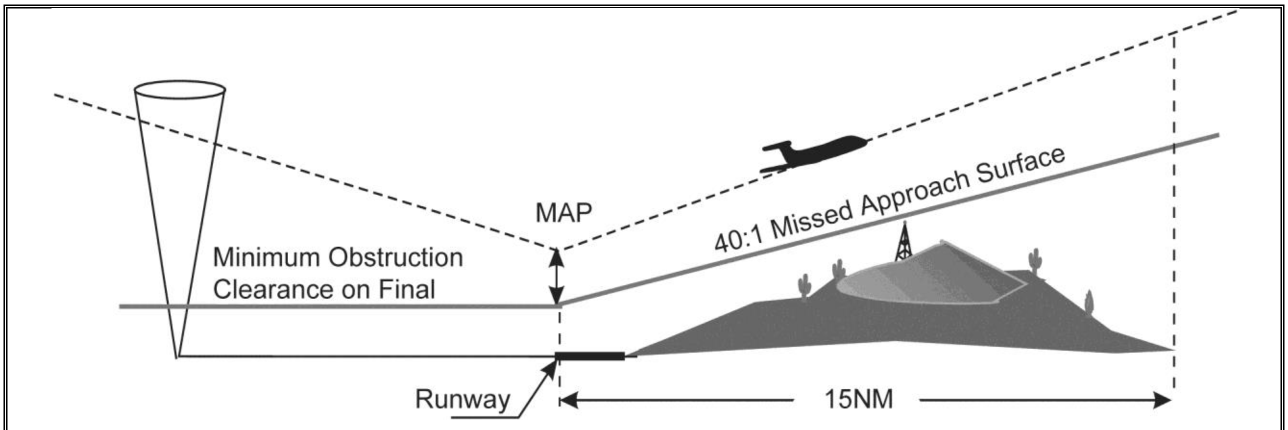


Figure 2-17: Straight Missed Approach Obstacle Clearance. Para 274.

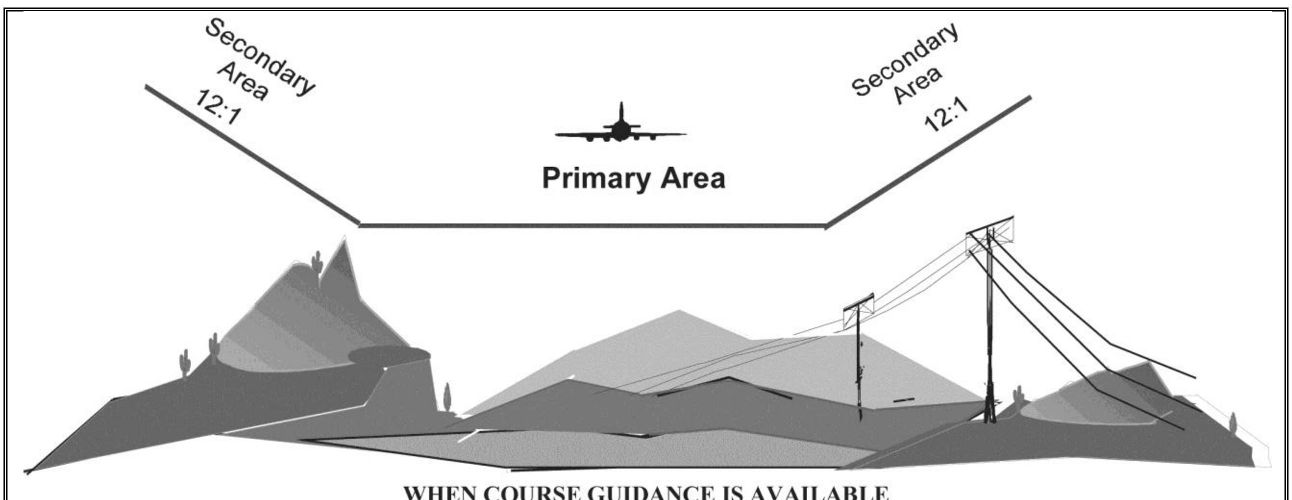


Figure 2-18: Missed Approach Cross-Section. Para 274.

274. Straight Missed Approach Obstacle Clearance

Within the primary missed approach area, no obstacle shall penetrate the missed approach surface. This surface begins over the MAP at a height determined by subtracting the required final approach primary area ROC and any minima adjustments, in accordance with Para 323, from the MDA. It rises uniformly at a rate of 1 foot vertically for each 40 feet horizontally (40:1) (see Figure 2-17). Where the 40:1 surface reaches a height of 1,000 feet below the missed approach altitude (Para 270), further application of the surface is not required. In the secondary area, no obstacle shall penetrate a 12:1 slope that extends outward and upward from the 40:1 surface at the inner boundaries of the secondary area (see Figure 2-18). Evaluate the missed approach segment to ensure obstacle clearance is provided.

a. Evaluate the 40:1 surface from the MAP to the clearance limit (end of the missed approach segment). The height of the missed approach surface over an obstacle is determined by measuring the straight-line distance from the obstacle to the nearest point on the line defining the origin of the 40:1 surface. If obstacles penetrate the surface, take action to eliminate the penetration.

b. The preliminary charted missed approach altitude is the highest of the minimum missed approach obstruction altitude, minimum holding altitude (MHA) established in accordance with Para 1820.a, or the lowest airway minimum en route altitude (MEA) at the clearance limit. To determine the minimum missed approach obstruction altitude for the missed approach segment, identified the highest obstacle in the primary area; or if applicable, the highest equivalent obstacle in the secondary area. Then add the appropriate ROC (plus adjustments), for holding or en route to the highest obstacle elevation. Round the total value to the nearest hundred-foot value, provided the ROC is not penetrated.

c. Determine if a climbing in holding pattern (climb-in-hold) evaluation is required (see Para 1822). If a climb in hold is intended at the clearance limit, a climb-in-hold evaluation is mandatory.

(1) Calculate the elevation of the 40:1 surface at the end of the segment (clearance limit). The 40:1 surface starts at the same elevation as it does for obstacle evaluations. Compute the 40:1 rise from a point on the line defining the origin of the 40:1 surface in the shortest distance and perpendicular to the end-of-segment line at the clearance limit.

(2) Compute the ROC surface elevation at the clearance limit by subtracting the appropriate ROC (plus adjustments) from the preliminary charted missed approach altitude.

(3) Compare the ROC surface elevation at the clearance limit with the 40:1 surface elevation.

(a) If the computed 40:1 surface elevation is equal to or greater than the ROC surface elevation, a climb-in-hold evaluation is NOT required.

(b) If computed 40:1 surface elevation is less than the ROC surface elevation, a climb-in-hold evaluation IS required. TP308/GPH209, Chapter 18, Holding Pattern Criteria, Para 1820 specifies higher speed groups and, therefore, larger template sizes are usually necessary for the climb-in-hold evaluation. These templates may require an increase in minimum holding altitude (MHA) under TP308/GPH209 Chapter 18, Para 1801.c. Minimum Holding Altitude (MHA). If this evaluation requires an increase in the MHA, evaluate the new altitude using the higher speed group specified in Para 1822. This sequence of review shall be used until the MHA does not increase, then the 40:1 surface is re-evaluated. If obstacles penetrate the 40:1 surface, take action to eliminate the penetration.

(c) The charted missed approach altitude is the higher of the preliminary charted missed approach altitude or the MHA established under Para 274.c.3.b.

Approach Category	**Obstacle Clearance Radius (R)**	**Flightpath Radius (R_1)**
A	2.6	1.30
B	2.8	1.40
C	3.0	1.50
D	3.5	1.75
E	5.0	2.50

Table 2-5: Turning Missed Approach Radii (Nautical Miles). Para 275.

275. Turning Missed Approach Area

(See Volume 3 for special provisions.) If a turn of more than 15° from the FAC is required, a turning missed approach area must be constructed.

Note: If the HAT value associated with the DH/MDA is less than 400 feet, construct a combination straight and turning missed approach (see Para 277) to accommodate climb to at least 400 feet above the TDZE or Airport elevation prior to turn.

a. The dimensions and shape of this area are affected by three variables:

(1) Width of final approach area at the MAP.

(2) All categories of aircraft authorized to use the procedure (the obstacle area for each aircraft category, authorized to fly the procedure, shall be assessed); and

(3) Number of degrees of turn required by the procedure.

b. Secondary areas for the reduction of obstacle clearance are permitted when PCG is provided. The secondary area begins where a line perpendicular to the straight flightpath, originating at the point of completion of the turn, intersects the outer boundaries of the missed approach segment. The width of the secondary area expands uniformly from 0 (zero) to 2 NM at the 15 NM flight track point.

c. Primary areas. Figures 2-19 to 2-24 show the manner of construction of some typical turning missed approach areas. The following radii are used in the construction of these areas:

(1) **90° Turn or Less**. Narrow final approach area at MAP (see Figure 2-19). To construct the area:

(a) Draw an arc with the radius (R_1) from the MAP. This line is then extended outward to a point 15 NM from the MAP, measured along the line. This is the assumed flight path. (see Table 2-5).

(b) Establish Points "A_2" and "B_1" by measuring 6 NM perpendicular to the flight path at the 15 mile point.

(c) Now connect "A_2" and "B_1" with a straight line.

(d) Draw an arc with the radius (R) from Point "A" to "A_1". ("A_1" is defined as the point where a line from "A_2" becomes tangent to the obstacle clearance "R" radius.) This is the edge of the obstacle clearance area.

(e) Establish Point "B" by measuring backward on the edge of the final approach secondary area a distance of 1 mile or a distance equal to the fix error PRIOR to the FAF, whichever is greater.

(f) Connect Points "A_1" and "A_2", and Points "B" and "B_1" with straight lines.

(2) **90° Turn or Less**. Wide final approach area at MAP (see Figure 2-20). To construct the area:

(a) Draw an arc with the appropriate radius (R_1) from the MAP. This line is then extended outward to a point 15 NM from the MAP, measured along the line. This is the assumed flight path.

(b) Establish Points "A_2" and "B_1" by measuring 6 NM perpendicular to the flight path at the 15-mile point.

(c) Now connect Points "A_2" and "B_1" with a straight line.

(d) Draw an arc with the appropriate radius (R) from Point "A" to "A_1". ("A_1" is defined as the point where a line from "A_2" becomes tangent to the obstacle clearance "R" radius.) This is the edge of the obstacle clearance area.

(e) Establish Point "B" by measuring backward on the edge of the final approach secondary area a distance of 1 mile or a distance equal to the fix error PRIOR to the FAF, whichever is greater.

(f) Connect Points "A_1", and "A_2" and Points "B" and "B_1" with straight lines.

(3) **More Than a 90° Turn**. NARROW FINAL approach area at MAP (see Figure 2-21). To construct the area:

(a) Draw an arc with the radius (R_1) from the MAP through the required number of degrees and then continue outward to a point 15 NM from the MAP, measured along this line, which is the assumed flight path.

(b) Establish Points "A_2" and "C_1" by measuring 6 NM on each side of the assumed flight path and perpendicular to it at the 15 mile point.

(c) Now connect Points "A_2" and "C_1" with a straight line.

(d) Draw an arc with the radius (R) from Point "A" to Point "A_1" (Figure 2-21 uses 135°). ("A_1" is defined as the point where a line from "A_2" becomes tangent to the obstacle clearance "R" radius.) This is the outer edge of the obstacle clearance area.

(e) Locate Point "C" at the inner edge of the final approach secondary area opposite the MAP. (Point "A" and Point "C" will be coincident when the MAP is the facility.)

(f) Connect Points "A_1" and "A_2" and Points "C" and "C_1" with straight lines.

(4) More Than 90° Turn. WIDE FINAL approach area at MAP (see Figure 2-22). To construct the area:

(a) Draw the assumed flightpath, which is an arc with the radius (R_1), from the MAP the required number of degrees to the desired flightpath or course.

(b) Establish Points "A_4" and "C_1" by measuring 6 NM on each side of the assumed flight path and perpendicular to it at the 15-mile point.

(c) Connect Points "A_4" and "C_1" with a straight line.

(d) Draw a 90° arc with the appropriate radius (R) from Point "A" to Point "A_1". Note that when the width of the final approach area at the MAP is greater than the appropriate radius (R), the turn is made in two increments when constructing the obstacle clearance area.

(e) Draw an arc with the radius (R) from Point "D" (edge of final approach secondary area opposite MAP) the required number of degrees from Point "A_2" to Point "A_3". (Point “A_3”is defined as the point where a line from "A_4" becomes tangent to the obstacle clearance "R" radius from Point "D"). Compute the number of degrees by subtracting 90° from the total turn magnitude.

(f) Connect Points "A_1" and "A_2" with a straight line.

(g) Locate Point "C" at the inner edge of the final approach secondary area opposite the MAP.

(h) Connect Point "A_3" with Point "A_4" and connect Point "C" with Point "C_1" using straight lines.

(5) 180° Turn. Narrow final approach area at MAP (see Figure 2-23). To construct the area:

(a) Draw an arc with the radius (R_1) from the MAP through 180°, and then continue outward to a point 15 NM from the MAP, measured along this line, which is the assumed flight path.

(b) Establish Points "A_2" and "C_1" by measuring 6 NM on each side of the assumed flight path, and perpendicular to it at the 15 mile point.

(c) Now connect Point "A_2" and Point "C_1" with a straight line.

(d) Locate Point "C" at the inner edge of the final approach secondary area opposite the MAP. (Point "A" and Point "C" will be coincident when the MAP is the facility.)

(e) Draw an arc with the radius (R) from Point "A" to Point "A_1" (180°). This is the outer edge of the obstacle clearance area.

(f) Connect Points "A_1" and "A_2" and Points "C" and "C_1" by straight lines. (The line "A_1-A_2" joins the arc tangentially.)

(6) 180° Turn. Wide Final Approach area at MAP (see Figure 2-24). To construct the area:

(a) Draw the flightpath arc with the radius (R_1) from the MAP and then continue the line outward to a point 15 NM from the MAP, measured along the assumed flightpath.

(b) Establish Points "A_4" and "C_1" by measuring 6 NM on each side of the flight path and perpendicular to it at the 15-mile point.

(c) Now connect Points "A_4" and "C_1" with a straight line.

(d) Draw a 90° arc with the appropriate radius (R) from Point "A" to Point "A_1". Note that when the width of the final approach area at the MAP is greater than the appropriate radius (R), the turn is made in two increments when constructing the obstacle clearance area.

(e) Draw an arc with the radius (R) from Point "D" (edge of final approach secondary area opposite MAP) the required number of degrees from Point "A_2" to Point "A_3". Compute the number of degrees by subtracting 90° from the total turn magnitude.

(f) Connect Points "A_1" and "A_2" with a straight line.

(g) Locate Point "C" at the inner edge of the final approach secondary area opposite the MAP.

(h) Connect Points "A_3" and "A_4" and Points "C" and "C_1" with straight lines. (The line "A_3-A_4" joins the arc tangentially.)

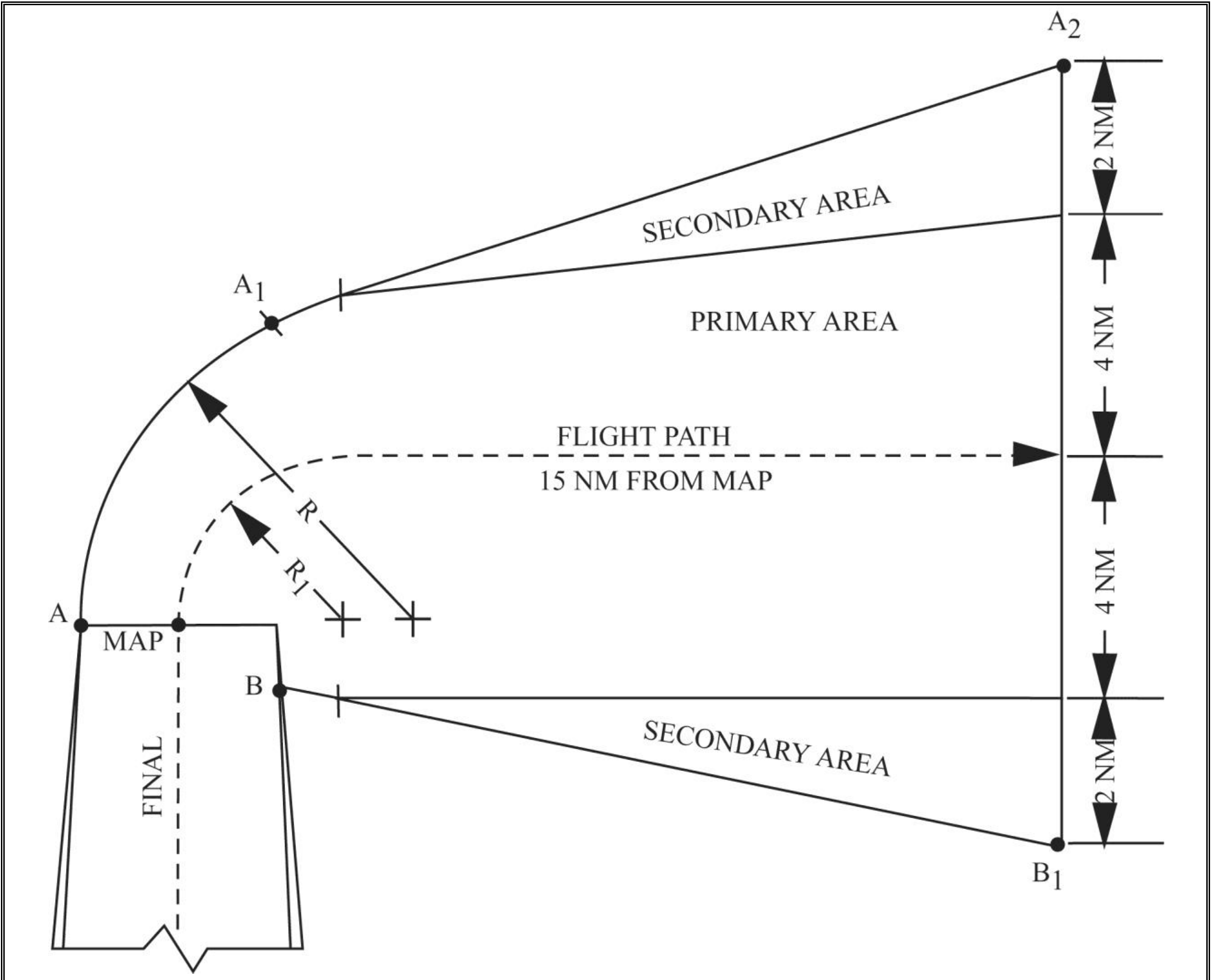


Figure 2-19: Turning Missed Approach Area. 90 Degree Turn Or Less. Narrow Final Approach At MAP. Para 275.c.(1).

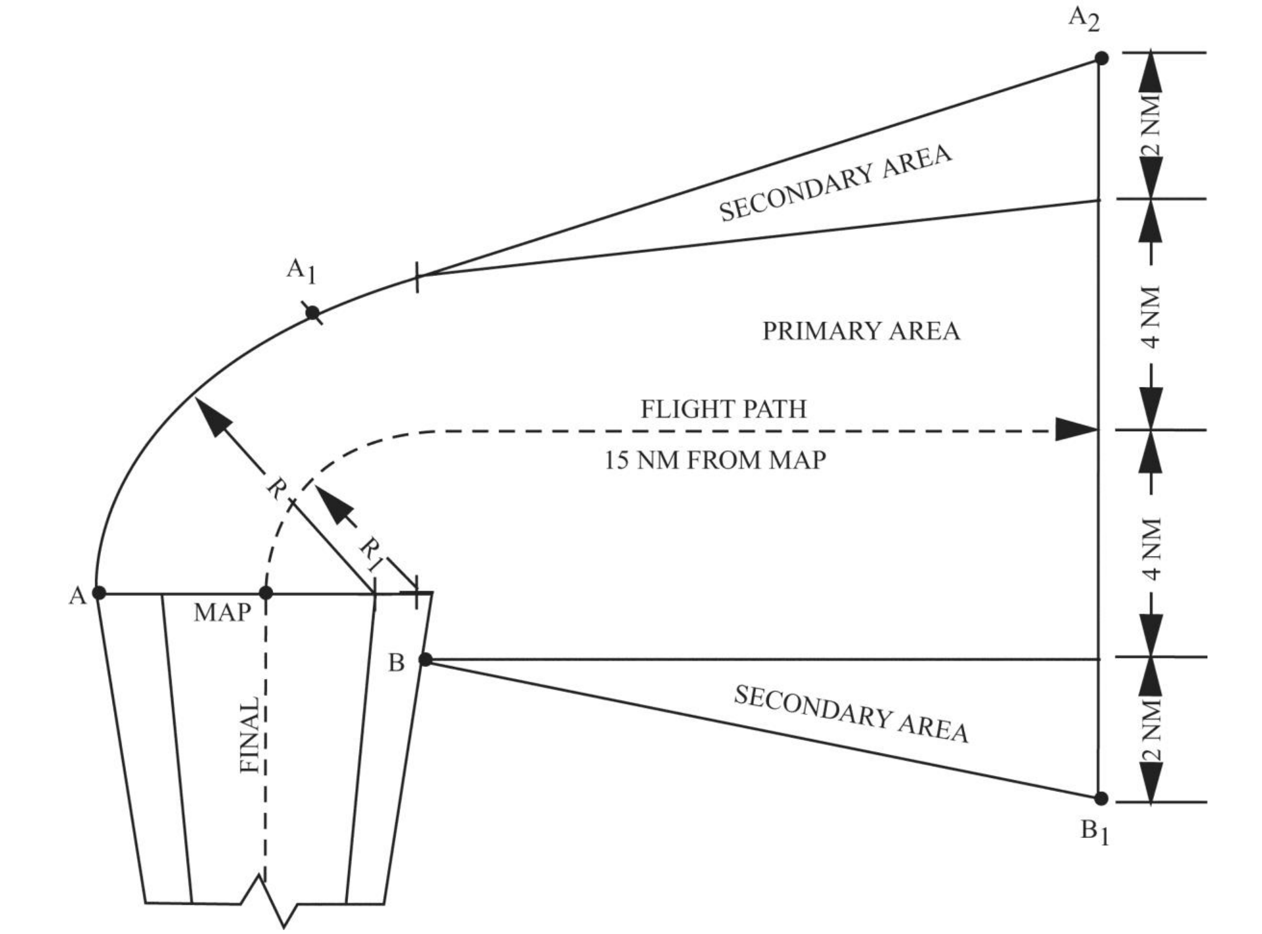


Figure 2-20: Turning Missed Approach Area. 90 Degree Turn Or Less. Wide Final Approach Area At MAP. Para 275.c.(2).

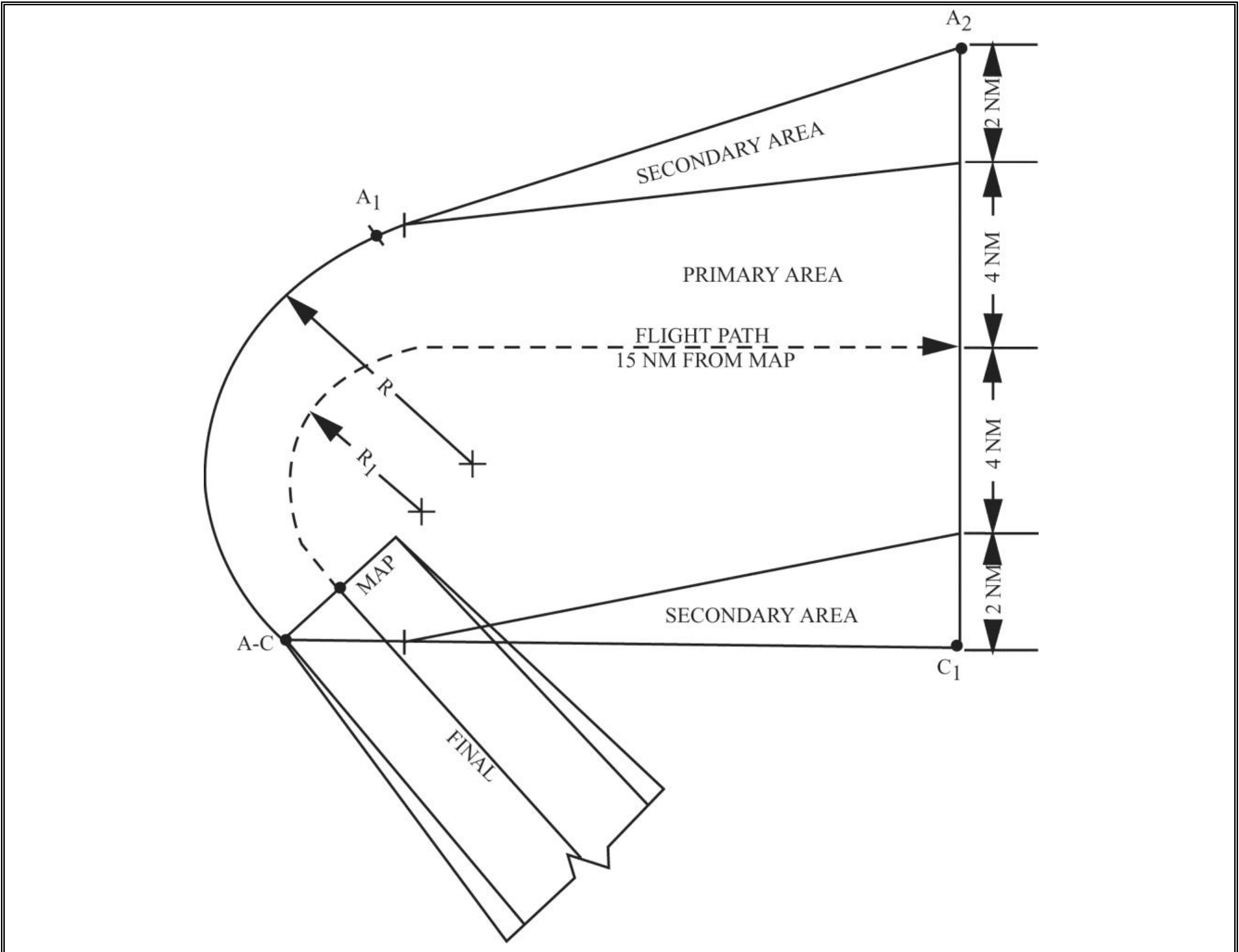


Figure 2-21: Turning Missed Approach Area. More Than 90 Degree Turn. Narrow Final Approach At MAP. Para 275.c.(3).

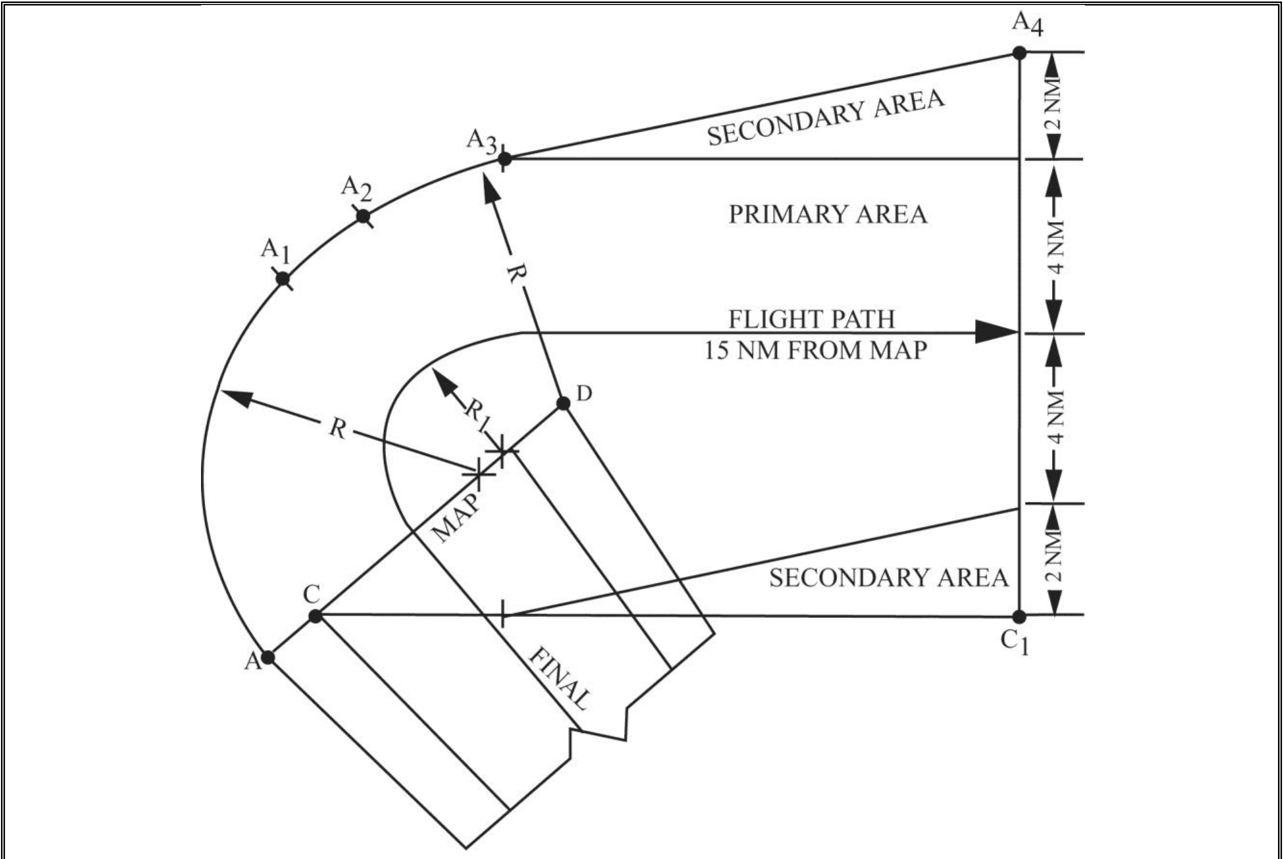


Figure 2-22: Turning Missed Approach Area. More Than 90 Degree Turn. Wide Final Approach At MAP. Para 275.c.(4).

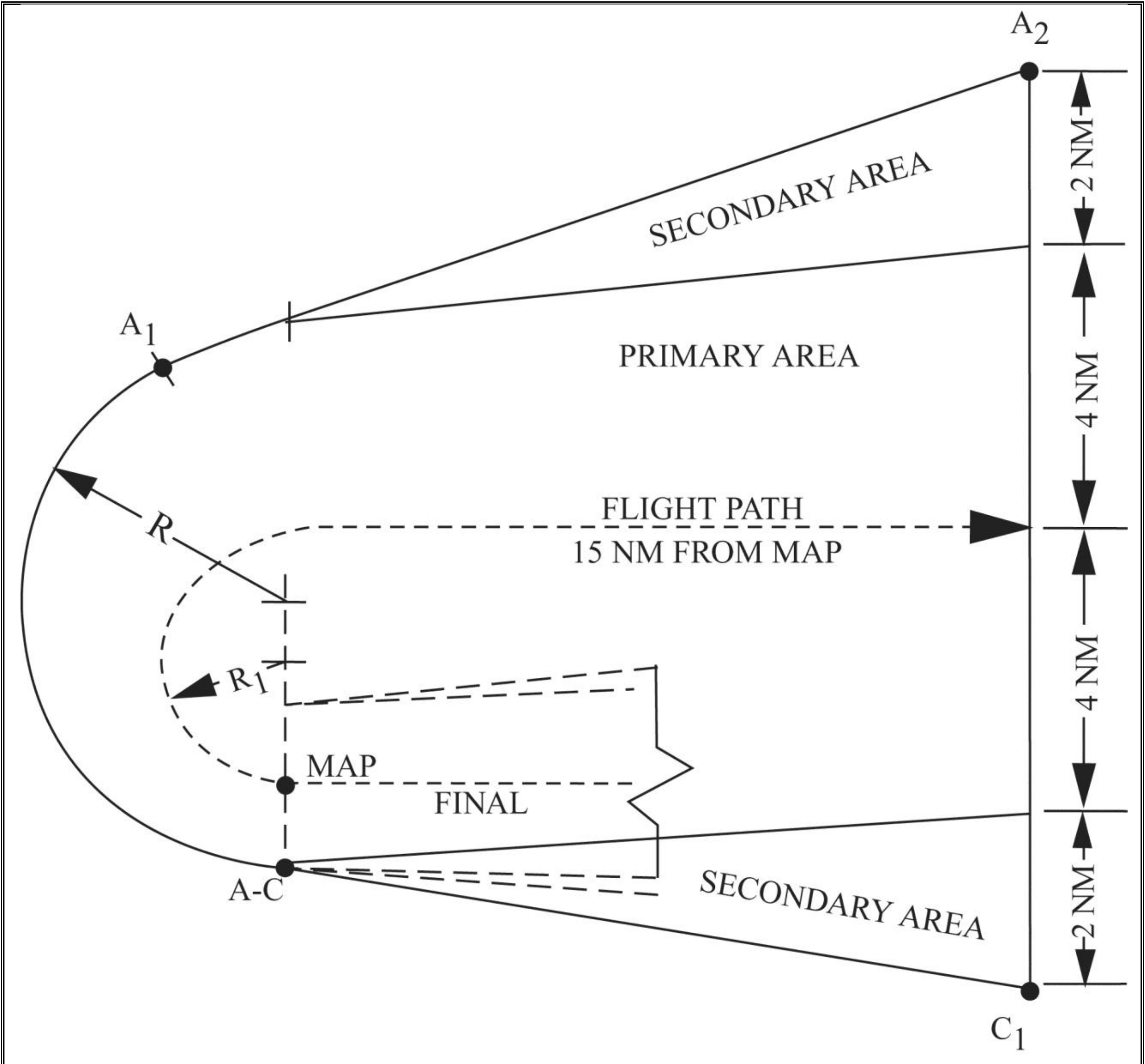


Figure 2-23: Turning Missed Approach Area. 180 Degree Turn. Narrow Final Approach Area At MAP. Para 275.

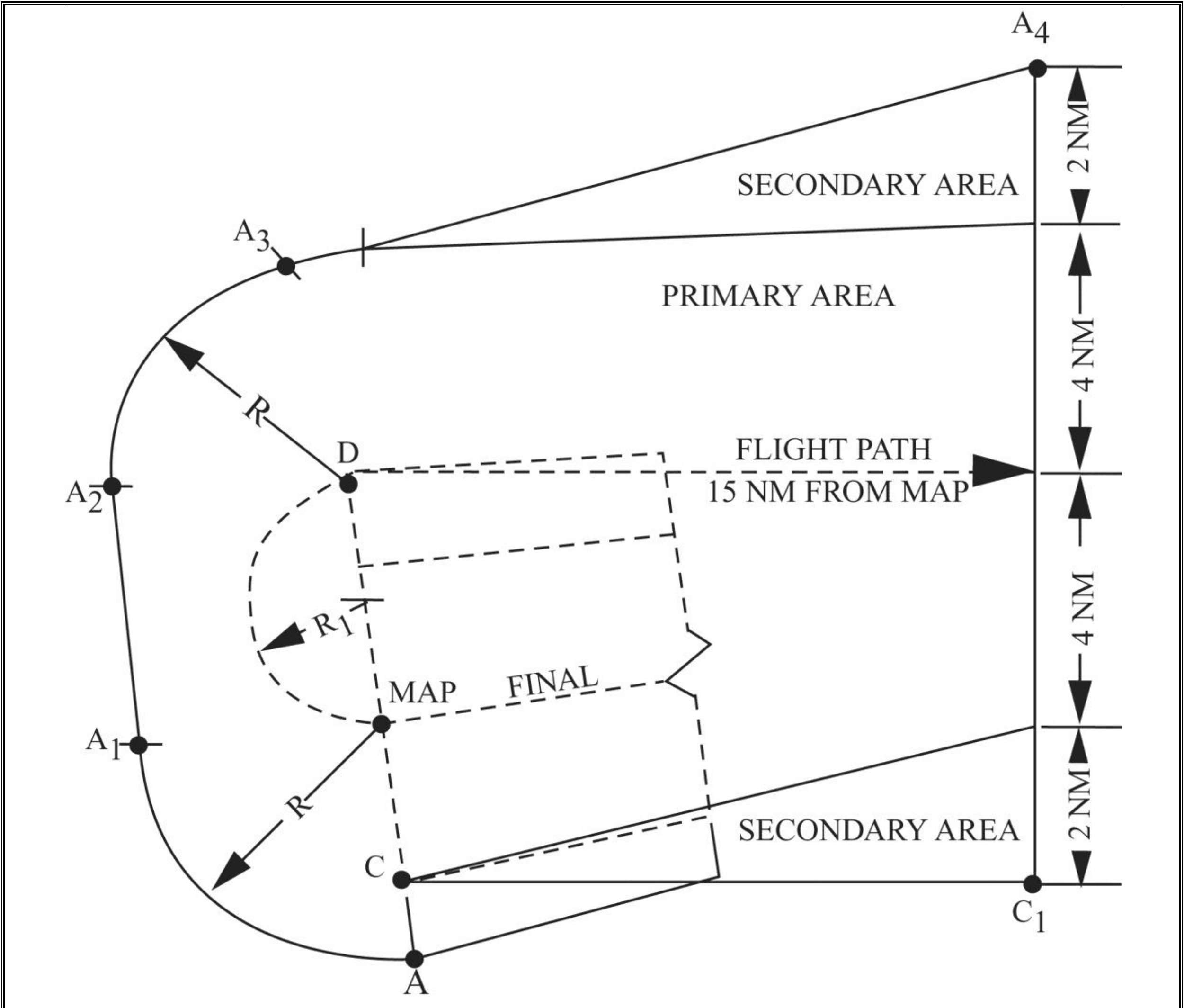


Figure 2-24: Turning Missed Approach Area. 180-Degree Turn. Wide Final Approach Area At MAP. Para 275.c.(6).

276. Turning Missed Approach Obstacle Clearance

The methods of determining the height of the 40:1 missed approach surface over obstacles in the turning missed approach area vary with the amount of turn involved. Evaluate the missed approach segment to ensure the 40:1 obstacle identification surface (OIS) is not penetrated.

a. 90° Turn or Less (see Figure 2-25). Zone 1 is a 1.6-mile continuation of the final approach secondary area, and has identical obstacle clearance requirements. Zone 2 is the area in which the height of the missed approach surface over an obstacle must be determined. To do this, first identify line "A-D-B". Point "B" is located by measuring backward on the edge of the final approach area a distance of 1 mile or a distance equal to the fix error prior to the MAP, whichever is greater. This is to safeguard the short-turning aircraft. Thus, the height of the missed approach surface over an obstacle in Zone 2 is determined by measuring the straight-line distance from the obstacle to the nearest point on line "A-D-B" and computing the height based on the 40:1 ratio. The height of the missed approach surface over the MAP is the same as specified in Para 274. When an obstacle is in a secondary area, measure the straight-line distance from the nearest point on the line "A-D-B" to the point on the inner edge of the secondary area which is nearest the obstacle. Compute the height of the missed approach surface at this point, using the 40:1 ratio. Then apply the 12:1 secondary area ratio from the height of the surface for the remaining distance to the obstacle.

b. More than 90° Turn (see Figure 2-26). In this case a third zone becomes necessary. Zone 3 is defined by extending a line from Point "B" to the extremity of the missed approach area perpendicular to the FAC. Zone 3 will encompass all of the missed approach area not specifically within Zones 1 and 2. All distance measurements in Zone 3 are made from point "B". Thus the height of the missed approach surface over an obstacle in Zone 3 is determined by measuring the distance from the obstacle to point "B" and computing the height based on the 40:1 ratio. The height of the missed approach surface over Point "B" for Zone 3 computations is the same as the height of the MDA. For an obstacle in the secondary area, use the same measuring method prescribed in Para 276.a except that the original measuring point shall be point "B".

c. Secondary Area. In the secondary area no obstacles may penetrate a 12:1 slope, which extends outward and upward from the 40:1 surface from the inner to the outer boundary lines of the secondary area.

d. Evaluate the missed approach segment from the MAP to the clearance limit. Terminate the 40:1 obstacle clearance surface (OCS) at an elevation corresponding to enroute ROC below the missed approach altitude.

(1) If the 40:1 0CS terminates prior to the clearance limit, continue the evaluation using a level OIS at the height that the 40:1OCS was terminated.

(2) If the clearance limit is reached before the 40:1 OCS terminates, continue a climb-in-hold evaluation at the clearance limit.

e. The preliminary charted missed approach altitude is the highest of the minimum missed approach obstruction altitude, MHA established in accordance with Chap 18, Para 1820.c, or lowest airway MEA at the clearance limit. To determine the minimum missed approach obstruction altitude for the missed approach segment, identify the highest obstacle in the primary area; or if applicable, the highest equivalent obstacle in the secondary area. Then add the appropriate ROC (plus adjustments) for holding or en route to the highest obstacle elevation. Round the total value to the nearest hundred-foot level, provided the ROC is not violated.

f. Determine if a climb-in-hold evaluation is required (see Chap 18, Para 1822.a(2)).

(1) Calculate the elevation of the 40:1 surface at the end of the segment (clearance limit). The 40:1 surface starts at the same elevation as it does for obstacle evaluations. Compute the 40:1 rise from a point on the "A-D-B" line in the shortest distance to the end-of-segment line at the clearance limit.

(2) Compute the ROC surface elevation at the clearance limit by subtracting the appropriate ROC (plus adjustments) from the preliminary charted missed approach altitude.

(3) Compare the ROC surface elevation at the clearance limit with the 40:1 surface elevation.

(a) If the computed 40:1 surface elevation is equal to or greater than the ROC surface elevation, a climb hold evaluation is NOT required, or

(b) If the computed 40:1 surface elevation is less than the ROC surface elevation, a climb-in-hold evaluation IS required. Chap 18 Holding Criteria, Para 1822, specifies higher speed groups and therefore, larger template sizes are usually necessary for the climb-in-hold evaluation. These templates may require an increase in MHA under Para 1801.c. If this evaluation requires an increase in the MHA, evaluate the new altitude using the higher speed group specified in Para 1822. This sequence of review shall be used until the MHA does not increase, then the 40:1 surface is re-evaluated. If obstacles penetrate the 40:1 surface, take action to eliminate the penetration.

g. The charted missed approach altitude is the higher of the preliminary charted missed approach altitude or the MHA established under Para 274.c.3.b.

277. Combination Straight And Turning Missed Approach Area

If a straight climb to a specific altitude followed by a turn is necessary to avoid obstacles, a combination straight and turning missed approach area must be constructed. The straight portion of this missed approach area is Section 1. The portion in which the turn is made is Section 2. Evaluate the missed approach segment to ensure obstacle clearance is provided.

a. Straight Portion. Section 1 is a portion of the normal straight missed approach area and is constructed as specified in Para 273. Obstacle clearance is provided as specified in Para 274 except that secondary area reductions do not apply. The length of Section 1 is determined as shown in Figure 2-27 and relates to the need to climb to a specified altitude prior to commencing the turn. Point A_1 marks the end of Section 1. Point B_1 is one nautical mile from the end of Section 1 (see Figure 2-27).

b. Turning Portion. Section 2 is constructed as specified in Para 275 except that it begins at the end of Section 1 instead of at the MAP. To determine the height, which must be attained before commencing the missed approach turn, first identify the controlling obstacle on the side of Section 1 to which the turn is to be made. Then measure the distance from this obstacle to the nearest edge of the Section 1 area. Using this distance as illustrated in Figure 2-27, determine the height of the 40:1 slope at the edge of Section 1. This height plus the appropriate final ROC, (the sum rounded up to the next higher 100-foot increment) is the height at which the turn should be started. Obstacle clearance requirements in Section 2 are the same as those specified in Para 276 except that Zone 1 is not considered and Section 2 is expanded to start at point "B" if no fix exists at the end of Section 1, or if no course guidance is provided in Section 2 (see Figure 2-27).

c. **Evaluate** the 40:1 surface from the MAP to the clearance limit (end of the missed approach segment). If obstacles penetrate the surface, take action to eliminate the penetration.

d. The preliminary charted missed approach altitude is the lowest of the minimum missed approach obstruction altitude, MHA established in accordance with Chapter 18, Para 1820.c, or lowest airway MEA at the clearance limit. To determine the minimum missed approach obstruction altitude for the missed approach segment, identify the highest obstacle in the primary area; or if applicable, the highest equivalent obstacle in the secondary area. Then add the appropriate ROC (plus adjustments) for holding or en route to the highest obstacle elevation. Round the total value to the next higher hundred-foot level.

e. **Determined** if a climb-in-hold evaluation is required (see Chapter 18, Para 1822).

(1) Calculate the elevation in the 40:1 surface at the end of the segment (clearance limit). The 40:1 surface starts at the same elevation as it does for obstacle evaluations, plus minima adjustments in accordance with Para 323.

(2) Compute the ROC surface elevation at the clearance limit by subtracting the appropriate ROC (plus adjustments) from the preliminary charted missed approach altitude.

(3) Compare the ROC surface elevation at the clearance limit with the 40:1 surface elevation.

(a) If the computed 40:1 surface elevation is equal to or greater than the ROC surface elevation, a climb-in-hold evaluation is NOT required.

(b) If the computed 40:1 surface elevation is less than the ROC surface elevation, a climb-in-hold evaluation IS required. TP 308 Holding Criteria, Para 1822, specifies higher speed groups and therefore, larger template sizes are usually necessary for the climb-in-hold evaluation. These templates may require an increase in MHA under Para 1801.c. If this evaluation requires an increase in the MHA, evaluate the new altitude using the higher speed group specified in Para 1822. This sequence of review shall be used until the MHA does not increase, then the 40:1 surface is re-evaluated. If obstacles penetrate the 40:1 surface, take action to eliminate the penetration.

f. The charted missed approach altitude is the higher of the preliminary charted missed approach altitude or the MHA established under Para 274.c.3.b.

278. End of Missed Approach

Aircraft shall be assumed to be in the initial approach or en route environment upon reaching minimum obstacle clearance altitude (MOCA) or minimum en route altitude (MEA). Thereafter, the initial approach or the en route obstacle clearance criteria apply. This means that the missed approach altitude must provide sufficient ROC to allow the pilot to hold at the missed approach holding fix (using the appropriate holding template), or must provide sufficient ROC to allow the pilot to proceed enroute. Where the missed approach altitude is below an initial approach altitude or enroute altitude, the 40:1 OIS must be assessed beyond the missed approach holding fix. If a climb in hold is required, it shall be assessed in accordance with Chapter 18, Holding Criteria. A note indicating that a shuttle is required prior to proceeding on course shall be included in the missed approach instructions. Example: Shuttle climb to 5000' BPOC.

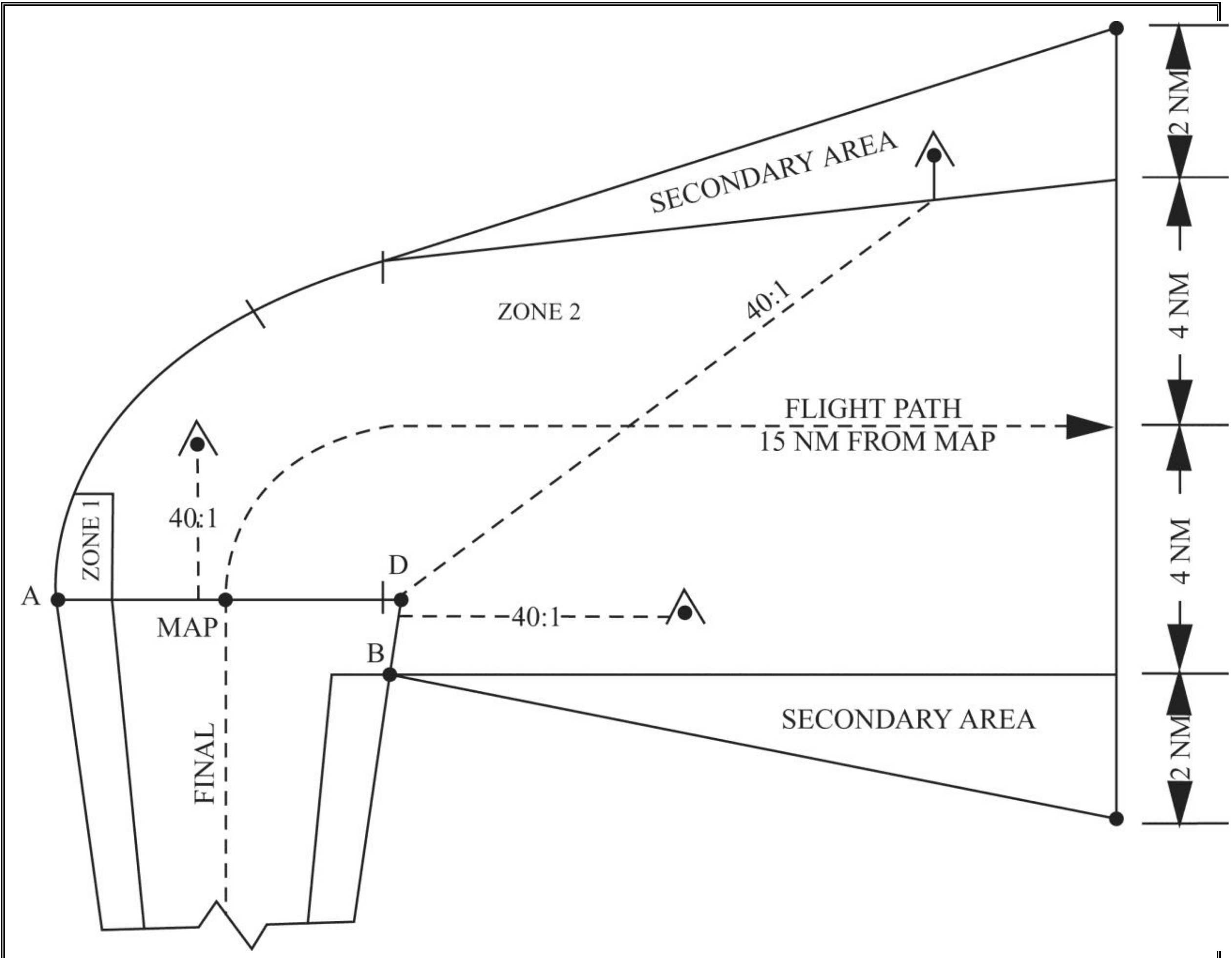


Figure 2-25: Turning Missed Approach Obstacle Clearance. 90 Degree Turn Or Less. Para 276.

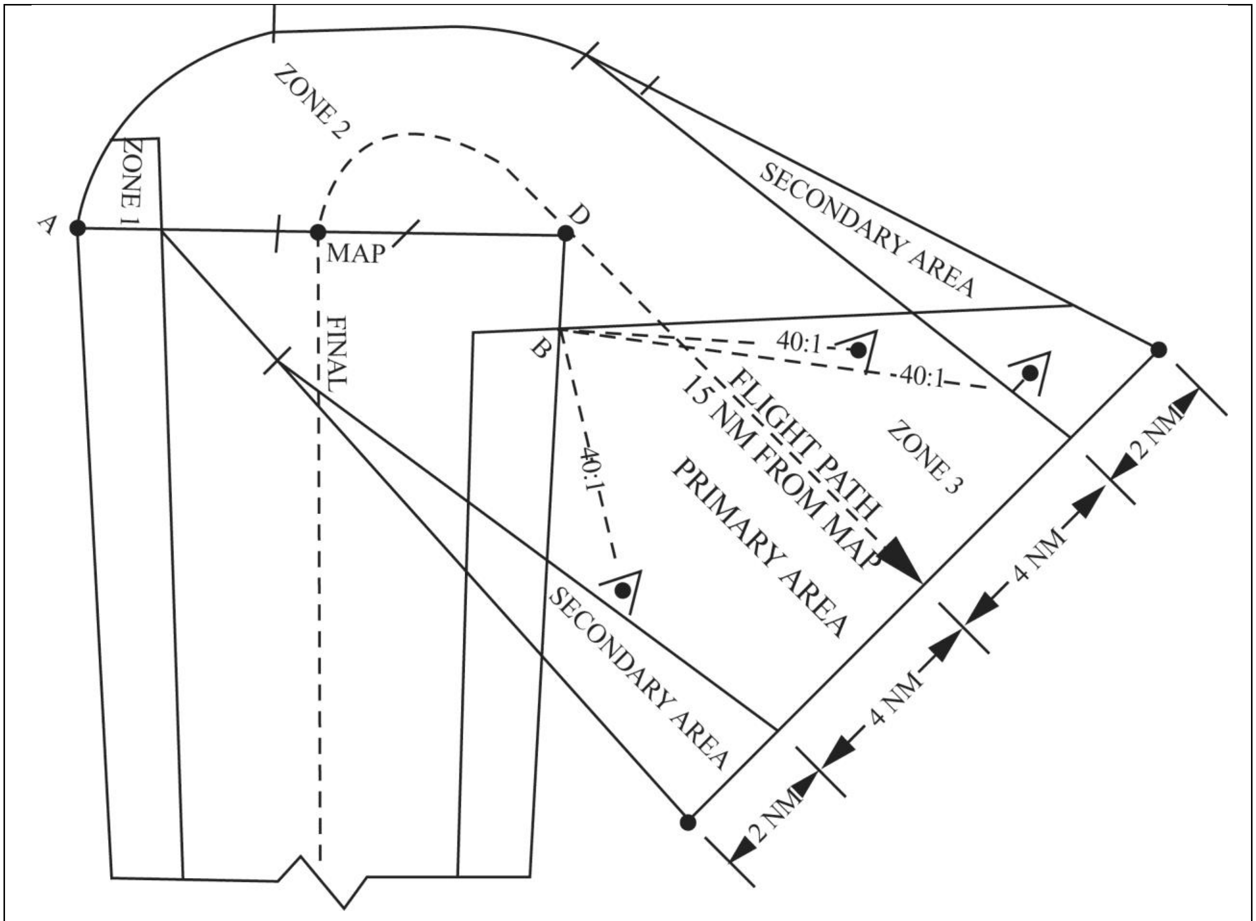
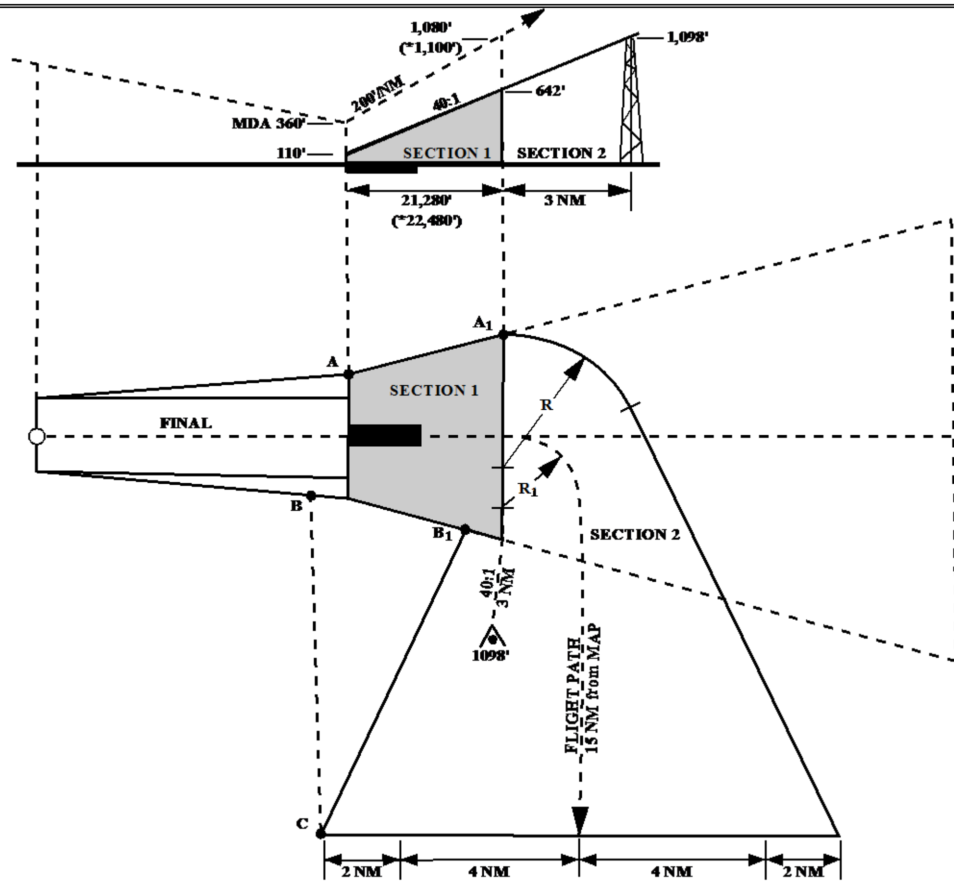


Figure 2-26: Turning Missed Approach Obstacle Clearance. More Than 90 Degree Turn. Para 276.



EXAMPLE

GIVEN:

1. MDA ....360’ MSL
2. Obstacle height ....1098’ MSL
3. Obstacle is section 2, 3 NM from near edge of section 1

FIND:

1. Require length of Section 1
2. Minimum altitude at which aircraft can start turn

SOLUTION:

1. Find height MSL at near edge
   ObstHt – (Dist x 6076 / 40)
   1098 – (3 x 6076 / 40) = **642’**
2. Find HMAS
   HMAS = MDA – (ROC + Adjustments)
   HMAS = 360 – 250 = **110’**
3. Find the rise from MAP to the end of Section 1
   642 – 110 = **532’**

ANSWER 1:

- Length of Section1 = 532 x 40 = **21,280 feet (* see note)**

ANSWER 2:

- Minimum altitude at which aircraft can turn: (21280 / 6076) x 200) + 360 = **1060’ MSL**
- Round results to next higher **100 foot** increment
- Missed approach instructions: “**Climb to 1100’** before starting right turn to …”

Notes: 1. *Section 1 must be lengthened to accommodate the rounding up to 1100’. In this example, the aircraft will climb an extra 40’ (from 1060’ to 1100’) at 200’/NM, therefore traveling an extra 1200’ (40x30) from the previous section 1 calculation. The required length of section 1 for the turn at 1100’ MSL is 22,480 (21280 + 1200)

Notes: 2. Line BC becomes the boundary of Section 2 if:

- No Fix exists at the end of section 1, or
- No course guidance is provided in Section 2

Figure 2-27: Combined Missed Approach Area. Para 277.a.

279. Missed Approach Climb Gradient

Where the OCS is penetrated and the lowest minima is required, a missed approach climb gradient (CG) greater than the standard 200 ft/NM (or 400 ft/NM for COPTER procedures) may be specified. Gradients greater than 425 ft/NM (or 600 ft/NM for COPTER procedures) require Flight Standards approval.

SECTION 8. TERMINAL AREA FIXES

280. General

Terminal area fixes include, but are not limited to the FAF, the IF, the IAF, the holding fix, and when possible, a fix to mark the MAP. Each fix is a geographical position on a defined course. Terminal area fixes should be based on similar navigation systems. For example, TACAN, VORTAC, and VOR/DME facilities provide Radial/DME fixes. NDB facilities provide bearings. VOR facilities provide VOR radials. The use of integrated (VHF/NDB) fixes shall be limited to those intersection fixes where no satisfactory alternative exists.

281. Fixes Formed By Intersection

A geographical position can be determined by the intersection of courses or radials from two stations. One station provides the course the aircraft is flying and the other provides a crossing indication that identifies a point along the course that is being flown. Because all stations have accuracy limitations, the geographical point which is identified is not precise, but may be anywhere within a quadrangle which surrounds the plotted point of intersection. Figure 2-28 illustrates the intersection of an arc and a radial from the same DME facility, and the intersection of two radials or courses from different navigation facilities. The area encompassed by the sides of the quadrangle formed in these ways is referred to in this publication as the "fix displacement area".

282. Course/Distance Fixes

A DME fix is formed by a DME reading on a positive navigational course. The information should be derived from a single facility with collocated azimuth and DME antennas. However, when a unique operational requirement indicates a need for DME information from other than collocated facilities, an individual IAP that specifies DME may be approved, provided the angular divergence between the signal sources at the fix does not exceed 23° (see Figure 2-28). For limitation on use of DME with ILS, see Volume 3, Para 2.9.1.

283. Fixes Formed By Radar

Where ATC can provide the service, Airport Surveillance Radar (ASR) may be used for any terminal area fix. PAR may be used to form any fix within the radar coverage of the PAR system. Air Route Surveillance Radar (ARSR) may be used for initial approach and intermediate approach fixes.

284. Fix Displacement Area

The areas portrayed in Figure 2-28 extend along the flight course from Point "A" to Point "C". The fix error is a plus-or-minus value, and is represented by the lengths from "A" to "B" and "B" to "C". Each of these lengths is applied differently. The fix error may cause the fix to be received early (between "A" and "B"). Because the fix may be received early, protection against obstacles must be provided from a line perpendicular to the flight course at point “A".

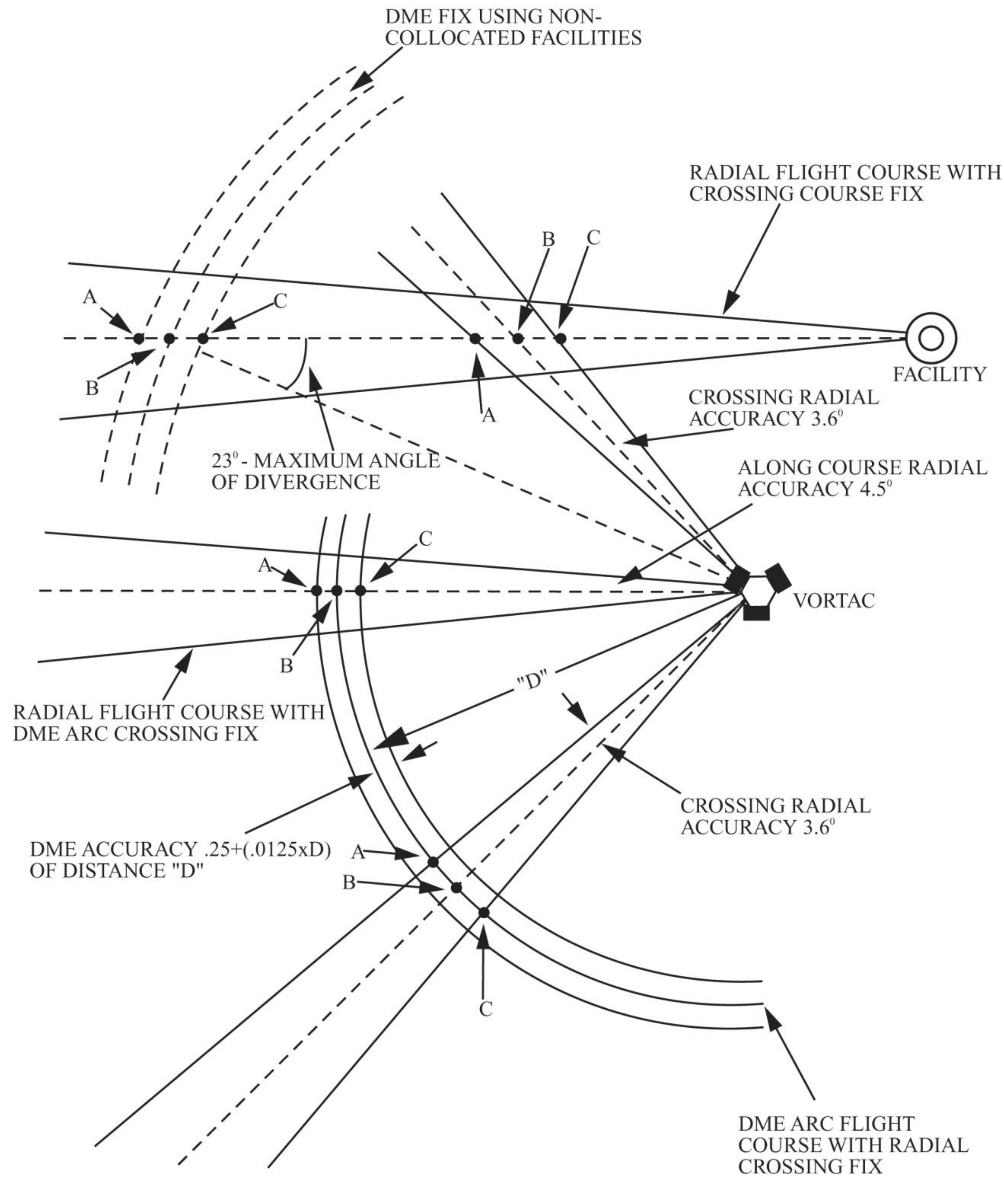


Figure 2-28: Intersection Fix Displacement. Paras 281, 282, and 284.

285. Intersection Fix Displacement Factors

The intersection fix displacement area is determined by the system use accuracy of the navigation fixing systems (see Figure 2-28). The system use accuracy in VOR and TACAN type systems is determined by the combination of ground station error, airborne receiving system error, and flight technical error (FTE). En route VOR data have shown that the VOR system accuracy along radial 4.5°, 95 percent of occasions, is a realistic, conservative figure. Thus, in normal use of VOR or TACAN intersections, fix displacement factors may conservatively be assessed as follows:

a. Along-Course Accuracy.

(1) VOR/TACAN radials, plus-or-minus 4.5°.

(2) Localizer course, plus-or-minus 1°.

(3) NDB courses or bearings, plus-or-minus 5°.

Note: The plus-or-minus 4.5° (95 percent) VOR/TACAN figure is achieved when the ground station course signal error, the FTE, and the VOR airborne equipment error are controlled to certain normal tolerances. Where it can be shown that any of the three error elements is consistently different from these assumptions (for example, if flight inspection shows a consistently better VOR signal accuracy or stability than the one assumed, or if it can be shown that airborne equipment error is consistently smaller than assumed), VOR fix displacement factors smaller than those shown above may be utilized under Para 141.

b. Crossing Course Accuracy.

(1) VOR/TACAN radials, plus-or-minus 3.6°.

(2) Localizer course, plus-or-minus 0.5°.

(3) NDB courses or bearings, plus-or-minus 5°.

Note: The plus-or-minus 3.6° (95 percent) VOR/TACAN figure is achieved when the ground station course signal error and the VOR airborne equipment error are controlled to certain normal tolerances. Since the crossing course is not flown, FTE is not a contributing element. Where it can be shown that either of the error elements is consistently different, VOR displacement factors smaller than those shown above may be utilized in accordance with Para 141.

286. Other Fix Displacement Factors

a. Radar. Plus-or-minus 500 feet or 3 percent of the distance to the antenna, whichever is greater.

b. DME. Plus-or-minus 0.25 NM plus 0.0125 of the distance to the antenna.

c. Overheading a Station. The fix error involved in station passage is not considered significant in terminal applications. The fix is therefore considered to be at the plotted position of the navigation facility. The use of TACAN station passage as a fix is NOT acceptable for holding fixes or high altitude IAF’s.

287. Satisfactory Fixes

a. Intermediate, Initial or Feeder Fix. To be satisfactory as an intermediate or initial or feeder approach fix, the fix error must not be larger than 50 percent of the appropriate segment distance that follows the fix. Measurements are made from the plotted fix position (see Figure 2-29).

b. Holding Fixes. Any terminal area fix except overheading a TACAN may be used for holding. The following conditions shall exist when the fix is an intersection formed by courses or radials:

(1) The angle of divergence of the intersecting courses or radials shall not be less than 45°.

(2) If the facility that provides the crossing course, is NOT an NDB, it may be as much as 45 NM from the point of intersection.

(3) If the facility that provides the crossing course is an NDB, it must be within 30 NM of the intersection point.

(4) If distance stated in Para 287.b.(2) or (3) are exceeded, the minimum angle of divergence of the intersecting courses must be increased at the following rate:

(a) If an NDB facility is involved, 1° for each mile over 30 NM.

(b) If an NDB facility is NOT involved, ½° for each mile over 45 NM.

c. FAF. For a fix to be satisfactory for use as a FAF, the fix error should not exceed plus-or-minus 1 mile (see Figures 2-31-1 and 2-31-2). It may be as large as plus-or-minus 2 NM when:

(1) The MAP is marked by overheading an air navigation facility; OR

(2) A buffer of equal length to the excessive fix error is provided between the published MAP and the point where the missed approach surface begins (see Figure 2-32)

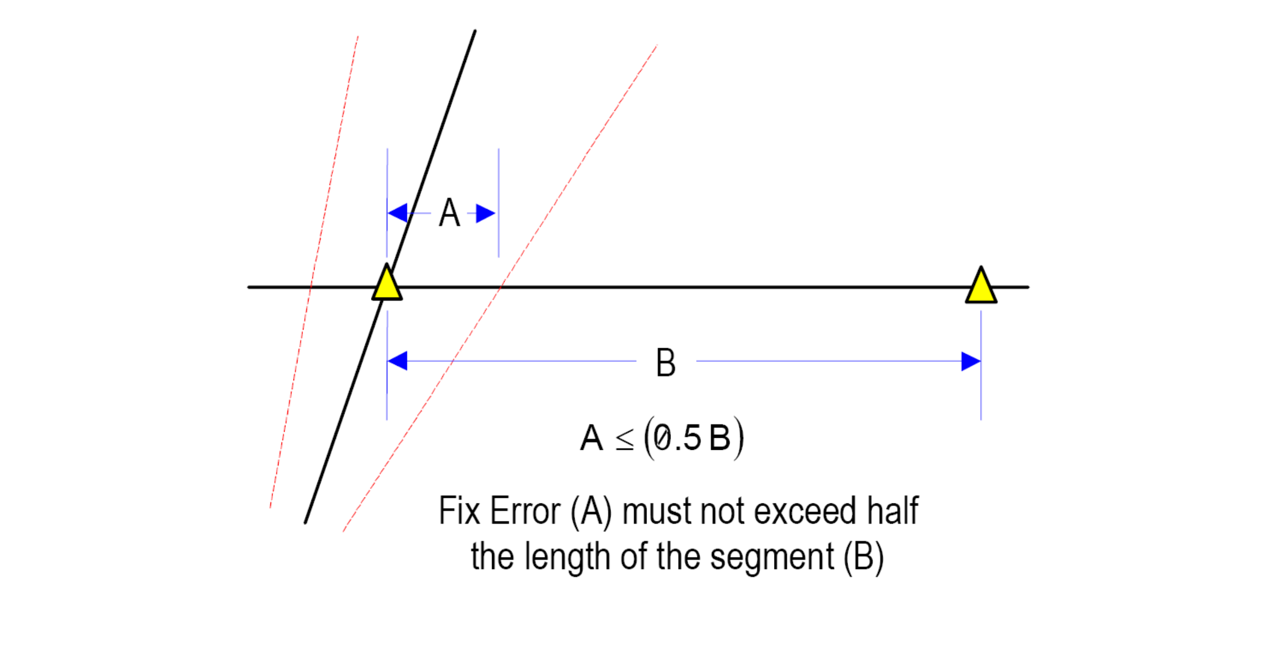


Figure 2-29: Intermediate, Initial, or Feeder Approach Fix Errors. Para 287.

Note: B segment from IF to FAF.

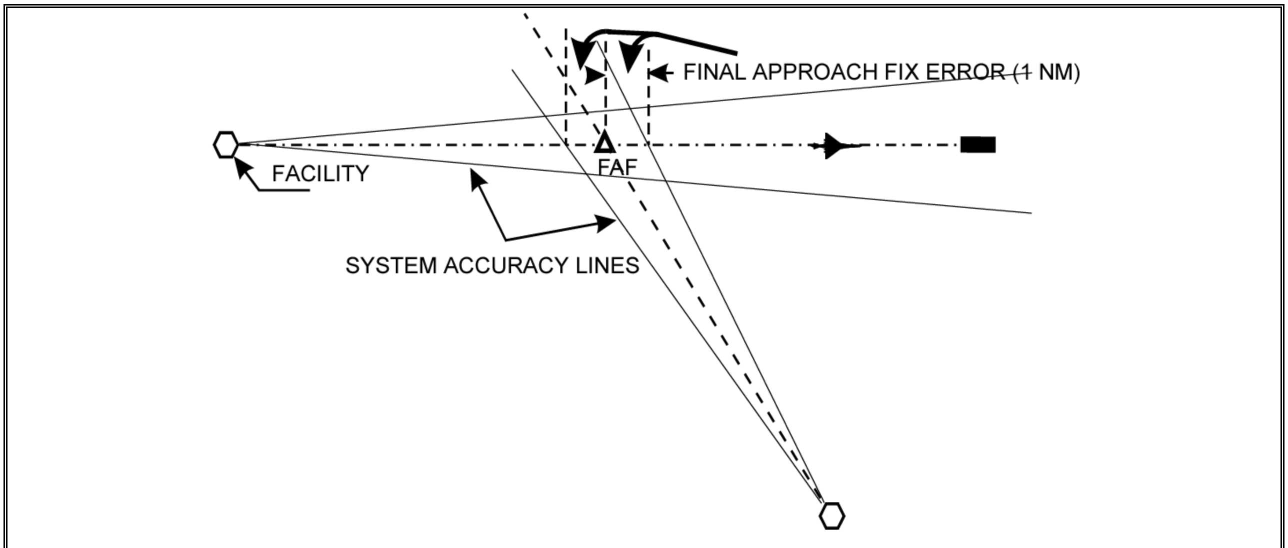
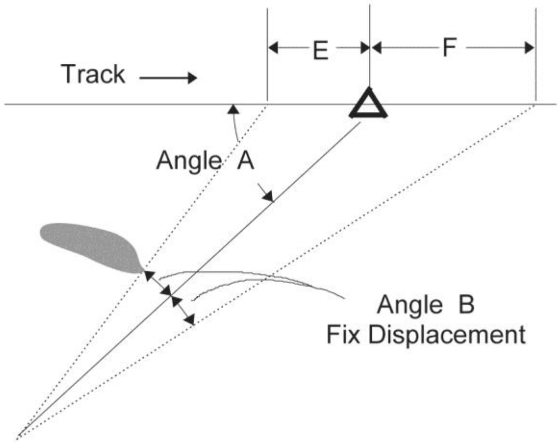


Figure 2-31-1: Measurement Of FAF Error. Para 287.c.

Calculate fix displacement using the following formulas:



Formula	Example
$E = \frac{6076.11548 \times D \times \sin B}{\sin (A + B)}$	$E = \frac{6076\text{-}11548 \times 30 \times \sin 3.6^\circ}{\sin (50^\circ + 3.6^\circ)}$
	E =14220.10
$F = \frac{6076.11548 \times D \times \sin B}{\sin (A - B)}$	$F \quad \frac{6076.11548 \times 30 \times \sin 3.6^\circ}{\sin (50^\circ - 3.6^\circ)}$
	F =15805.19

Figure 2-31-2: Fix Displacement Calculations. Para 287.c.

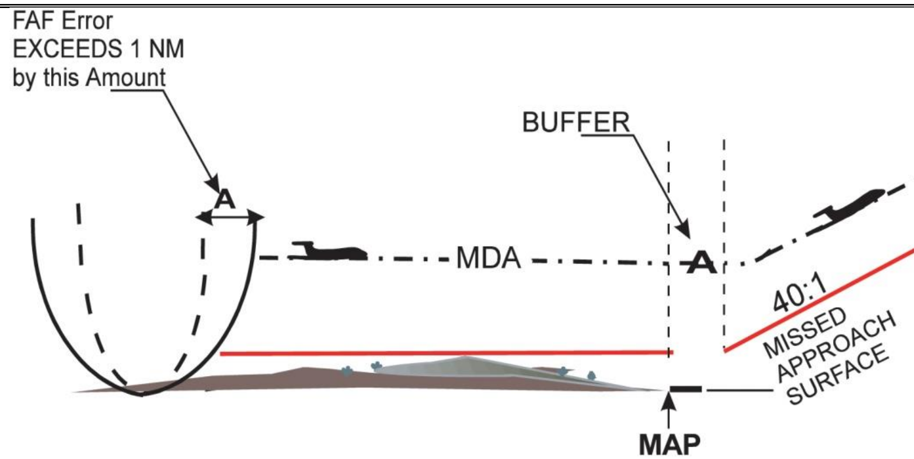


Figure 2-32: FAF Error Buffer. Para 287.c.(2).

288. Using Fixes For Descent

a. Distance Available for Descent. When applying descent gradient criteria applicable to an approach segment (initial, intermediate or final approach areas), the measuring point is the plotted position of the fix (see Figure 2-33).

b. Obstacle Clearance After Passing a Fix. It is assumed that descent will begin at the earliest point the fix can be received. Full obstacle clearance shall be provided from this point to the plotted point of the next fix. Therefore, the altitude to which descent is to be made at the fix must provide the same clearance over obstacles in the fix displacement area as it does over those in the approach segment that is being entered (see Figures 2-34-1 and 2-34-2).

c. Step-down Fixes (see Figure 2-35).

(1) DME or Radar Fixes. Except in the intermediate segment within a procedure turn (see Para 244), there is no maximum number of step-down fixes in any segment when DME or radar is used. DME may be denoted in tenths of a mile. The distance between fixes shall not be less than 1 mile.

(2) Intersection Fixes.

(a) Only one step-down fix is permitted in the final and intermediate segments.

(b) If an intersection fix forms a FAF, IF, or IAF:

(i) The same crossing facility shall be used for the step-down fix(es) within that segment.

(ii) All fixes from the IF to the last step-down fix in final shall be formed using the same crossing facility.

(c) Table 2-5A shall be used to determine the number of step-down fixes permitted in the initial segment. The distance between fixes shall not be less than 1 mile.

(3) **Altitude at the Fix**. The minimum altitude at each step-down fix shall be specified in 100-foot increments, except the altitude at the last step-down fix in the final segment may be specified in a 20-foot increment.

(4) **In the Final Segment**:

(a) A step-down fix shall not be established unless a decrease of at least 60 feet in MDA or a reduction in the visibility minimum is achieved.

(b) The last step-down fix error shall not exceed plus-or-minus 2 NM or the distance to the MAP whichever is less. The fix error for other step-down fixes in final shall not exceed 1 NM.

(c) Minimums shall be published both with and without the last step down fix, except for procedures requiring DME or NDB procedures that use a VOR radial to define the step down fix.

Supplementary Note: Step down fix maybe lower than one or more circling minima.

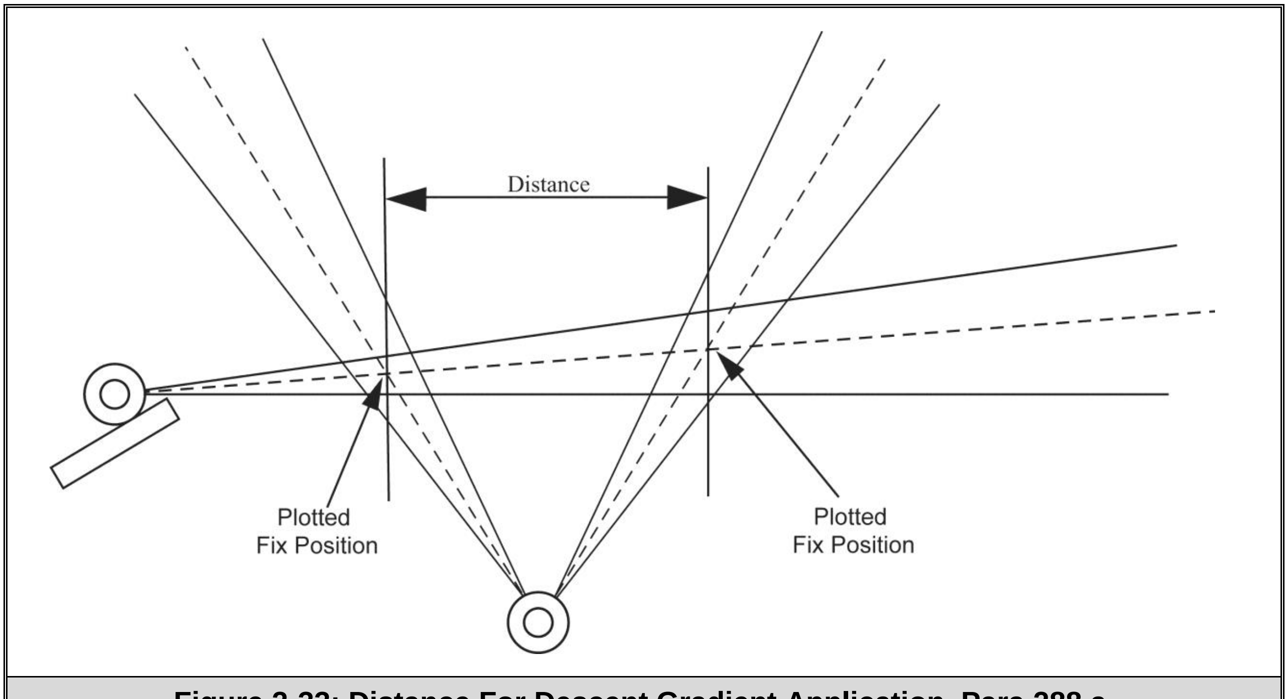


Figure 2-33: Distance For Descent Gradient Application. Para 288.a.

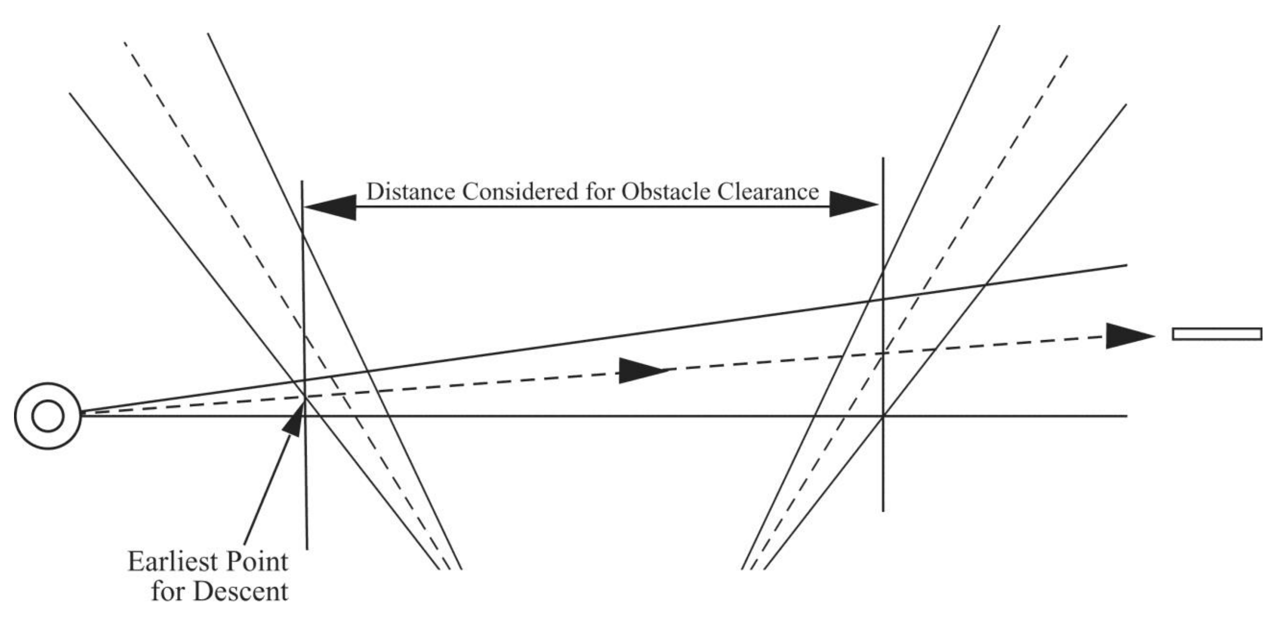


Figure 2-34-1: Obstacle Clearance Area Between Fixes. Para 288.b.

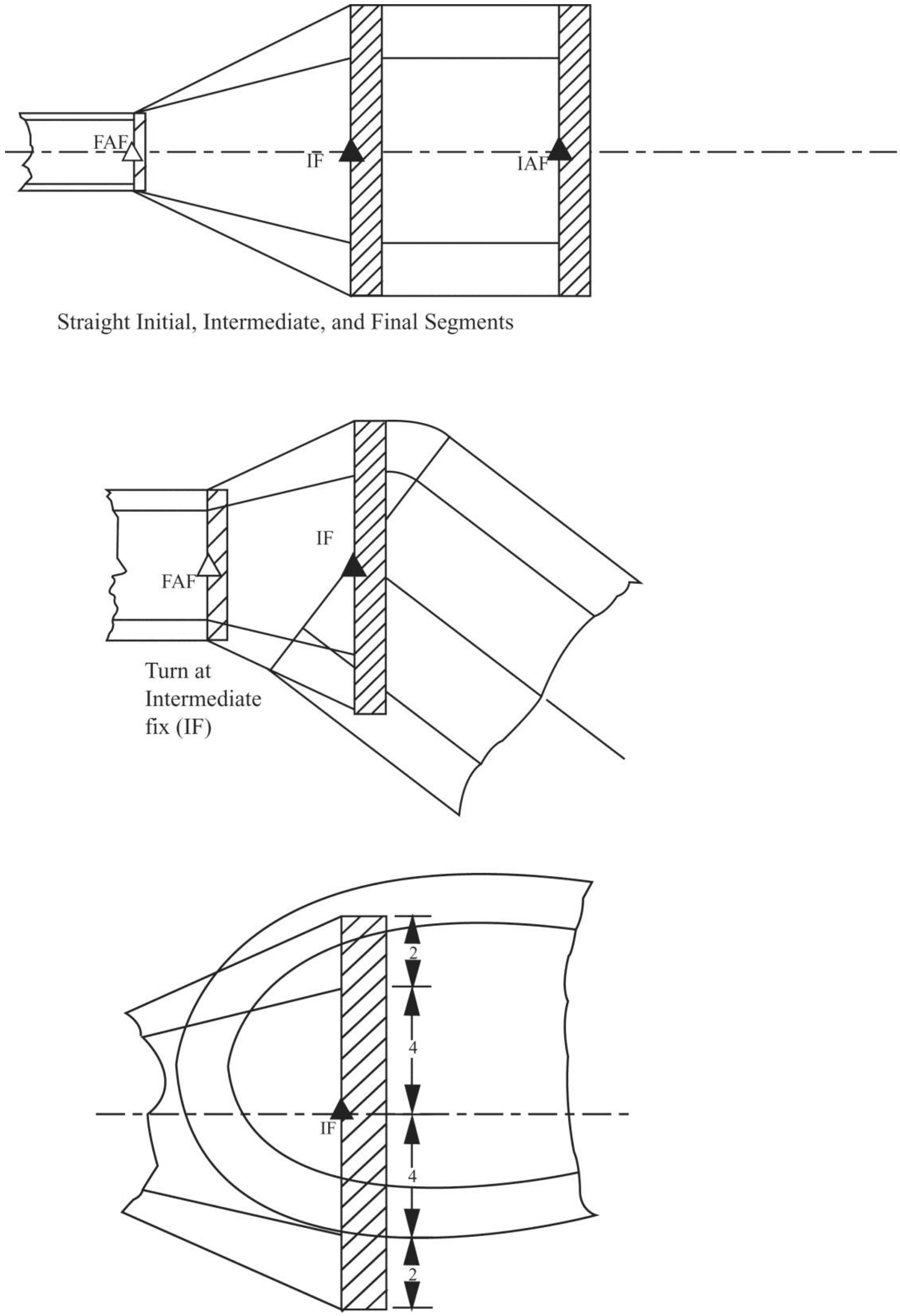


Figure 2-34-2: Construction Of Fix Displacement Area For Obstacle Clearance. Para 288.b.

289. Obstacles Close To a FAF or SDF

Existing obstacles close to a FAF or SDF may be eliminated from consideration if the following conditions are met:

a. The obstacle is in the final approach trapezoid within 1 NM past the point the FAF/SDF can first be received, AND

b. The obstacle does not penetrate the 7:1 obstacle identification surface (OIS). The surface begins at the earliest point the fix can be received and extends toward the MAP 1 NM. The beginning surface height is determined by subtracting the final segment ROC (and adjustments from Para 323., as applicable) from the minimum altitude required at the fix. The surface slopes downward 1 foot vertically for each 7 feet horizontally toward the MAP.

c. Obstacles eliminated from consideration by application of this paragraph shall be noted on the procedure.

The following formulas may be used to determine the OIS height at the obstacle or the minimum fix altitude based on applying the surface to an obstacle, which must be eliminated.

Fix Alt =	MSL altitude at the fix (round up in accordance with Para 288.c.3)
Obst Dist =	Distance from earliest fix reception to obstacle (ft)
ROC =	Required Obstacle Clearance (plus adjustments) (ft)
Obst Elev =	MSL obstacle elevation

$$\mathrm{OIS_{Height}} = \mathrm{FixAlt} - \mathrm{ROC} - \left(\frac{\mathrm{ObstDist}}{7}\right)$$

$$\mathrm{MinFixAlt} = \mathrm{ObsElev} + \mathrm{ROC} + \left(\frac{\mathrm{ObstDist}}{7}\right)$$

See Figures 2-36a, b and c. To determine fix error, see Para 284, 285, and 286.

Supplementary Note: Round $\frac{\mathrm{OBST\ DIST}}{7}$ up to next foot.

Length of Segment	Number of Fixes
5 – 10 NM	1 stepdown fix
over 10 – 15 NM	2 stepdown fixes
over 15 NM	3 stepdown fixes

Table 2-5A: Stepdown Fixes In Initial Segment. Para 288c(2)(c).

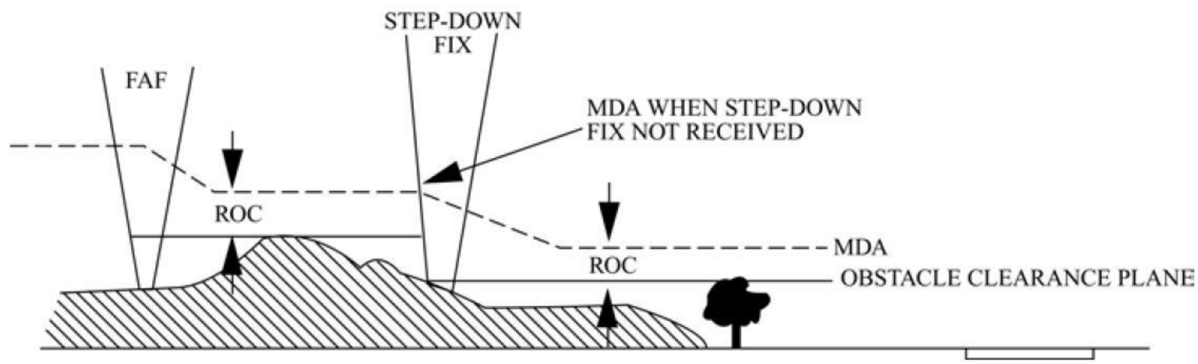
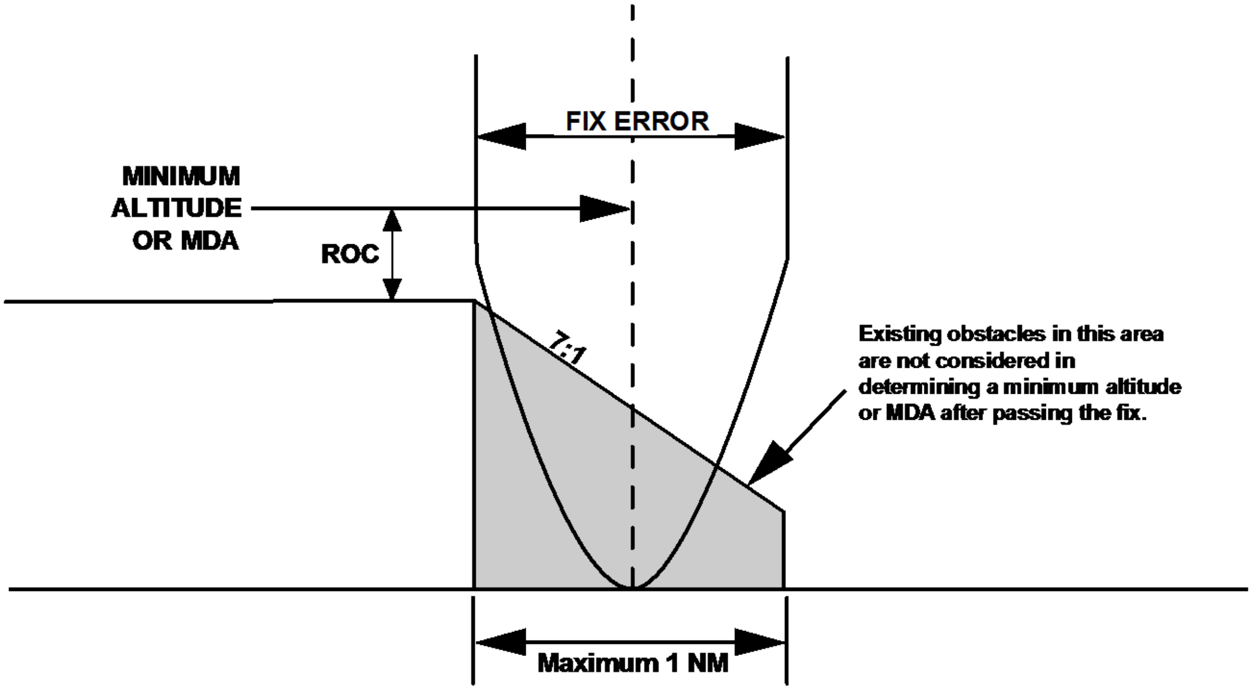


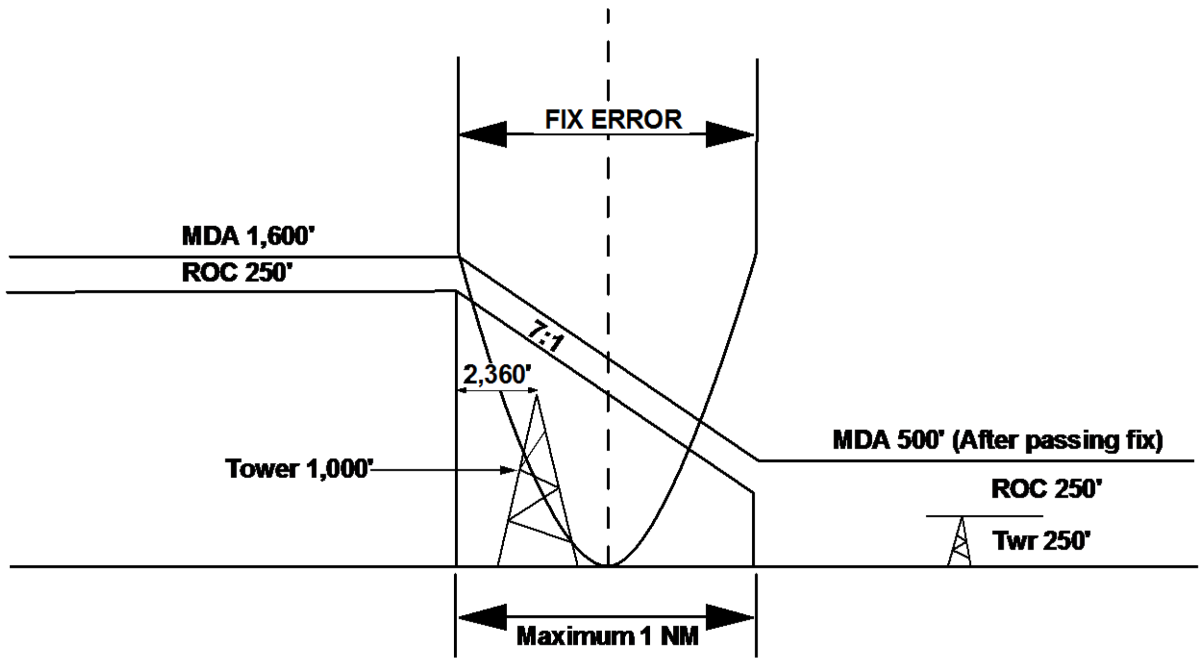
Figure 2-35: Final Segment Step down Fix, Para 288.c.



Obstacles close to a fix (FAF or stepdown) may be eliminated from consideration as an obstacle when the following conditions exist:

1. Must be located in the final approach area, within 1 mile past the point where the fix can be first received,
2. Obstacle does not penetrate a 7:1 descent gradient, which starts at the point where the fix is first received. (7:1 means 1 foot vertically for each 7 feet horizontally.),
3. The height at the start of the 7:1 slope is determined by subtracting the ROC from the minimum altitude required, and
4. Any obstacle eliminated because of the 7:1 descent gradient will be noted on the procedure.

Figure 2-36a: Obstacle Close-In To A Fix. Para 289.



Height at start of 7:1 Slope = MDA – ROC
= 1,600 – 250 = **1,350'**
Height Loss (ft) of 7:1 slope at d = Dist to Obstacle / 7
= 2,360 / 7 = **337.143' (rounded to 338')**
Height of 7:1 slope at Obstacle = Height at Start – Height Loss
= 1,350 – 338 = **1,012'**

Obstacle does not penetrate 7:1 slope

Figure 2-36b: Example Of Obstacle Close In To Fix. Para 289.

	Location	**SUMSPOT INTL., AB (CYSS)**	
	Procedure	**RNAV (GNSS) RWY 02**	
	Fix	**BEKIE**	
	Note:	The fix must be located in the final approach area, within 1 mile past the point where the fix can be first received.	
PART I: General		**Primary**	**Secondary**
1	Obstacle #	**WT "A7"**	**WT "B3"**
2	**(MDA)** MDA (before 7:1 slope):	**1740.00**	**1740.00**
3	**(Adjust)** Adjustments (Vol 1, para 323)	**130.00**	**130.00**
PART II: Obstruction Assessment		**Primary**	**Secondary**
4	Basic ROC (before 7:1) **Basic ROC_P**(Primary), **Basic ROC_S**(Secondary)	**250.00**	**250.00**
5	**(W_S)** Width of secondary at obstacle (ft)	n/a	**4800.00**
6	**(d_S)** distance (ft) of obstruction in secondary (from edge of primary)	n/a	**3600.00**
7	**(ROC_S)** Secondary ROC at obstacle: ROC_S = (Basic ROC_S + adjust) x ([W_S - d_S] / W_S)	n/a	**95.00**
8	**(ROC_P)** Primary ROC (before 7:1): ROC_P = Basic ROC_P + Adjust	**380.00**	n/a
9	Altitude (ASL) of Primary/Secondary OIS (before 7:1) ALT_{POIS} = MDA – ROC_P ALT_{SOIS} = MDA – ROC_S	ALT_{POIS} **1360.00**	ALT_{SOIS} **1645.00**
10	**(d)** Distance (ft) from start of 7:1 Slope to obstacle	**200.00**	**300.00**
11	**(HL)** Height Loss (ft) of 7:1 slope at d HL = d / 7 (Round to next higher foot)	**28.57 (29.00)**	**42.86 (43.00)**
12	**(ALT_{slope})** 7:1 Slope Altitude (ASL) at d ALT_{slope} = ALT_{POIS} – HL (and/or) ALT_{slope} = ALT_{SOIS} – HL	**1331.43**	**1602.14**
13	**(ALT_{obs})** Obstruction Altitude (ASL)	**1209.00**	**1248.00**
14	Clearance = ALT_{slope} - ALT_{obst}	**122.43**	**354.14**
15	Penetration ? (Negative Value = Penetration)	**No**	**No**
16	Minimum MDA (before 7:1): For obstacle elimination. ALT_{obs} + HL + ROC_P (and/or) ALT_{obs} + HL + ROC_s	**1617.57**	**1385.86**
17	Round Value to next 100 foot value	**1700**	**1400**

Figure 2-36c: 7:1 Slope Worksheet (Example)

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CHAPTER 3. TAKE-OFF AND LANDING MINIMA

300. Application

The minima specified in this section are the lowest that can be approved at any location for the type of facility concerned.

301—309. Reserved

SECTION 1. GENERAL INFORMATION

310. Establishment

The minimums established for a particular airport shall be the lowest permitted by the criteria contained in this document. Each procedure shall specify minima for the various conditions stated in the procedure; i.e., straight-in, circling and take-off, as required. The elements of minima are the Minimum Descent Altitude (MDA) or Decision Altitude (DA) and a visibility. The minima shall include the visibility required by the procedure. The height of the MDA or DA above the highest elevation in the touchdown zone (or above the aerodrome elevation for circling approaches) shall be shown on the procedure. Alternate and take-off minima may be specified in separate directives established by the appropriate authority.

311. Publication

Minima shall be published for each approach category that can be accommodated at the aerodrome. Where the aerodrome landing surface is not adequate, or other restrictions exist which prohibit certain approach categories, "Not Authorized" or "NA" shall be entered in lieu of minima values. Approach Category "E" minima should normally be published only on high altitude procedures, except where special requirements exist for their publication on other procedures.

312—319. Reserved

SECTION 2. ALTITUDES

320. Minimum Descent Altitude (MDA)

The MDA is the lowest altitude to which descent shall be authorized in procedures not using a glide slope. The MDA shall be expressed in feet above MSL and is determined by adding the required obstacle clearance to the MSL height of the controlling obstacle in the final approach segment and circling approach area for circling procedures.

321. MDA For Straight-In Approach

The MDA for a straight-in approach shall provide at least the minimum required clearance over obstacles in the final approach segment. It shall also be established high enough to ensure that obstacles in the missed approach area do not penetrate the 40:1 missed approach surface (see Vol 1, Para 274). The MDA shall be rounded up to the next higher 20-foot increment. Example: 2,104 feet becomes 2,120.

322. MDA For Circling Approach

The height of the circling MDA above the aerodrome (HAA) shall not be less than the minima referred to in Para 351. In addition, the MDA shall provide at least the minimum required final obstacle clearance in the final approach segment and the minimum required circling obstacle clearance in the circling approach area. It shall also meet the missed approach requirements specified in Para 321. The MDA shall be rounded to the next higher 20-foot increment. For example, 2,109 feet shall become 2,120. The published circling MDA shall not be above the FAF altitude or below the straight-in MDA.

323. Minima Adjustments

Raising the MDA or DA above that required for obstacle clearance may be necessary under the following conditions:

a. For PA/APV approaches, determine the minimum HATh based on glidepath angle for each aircraft category using table 3-5.

b. Precipitous Terrain. When procedures are designed for use in areas characterized by precipitous terrain, in or outside of designed mountainous areas, consideration must be given to induced altimeter errors and pilot control problems which result when winds of 20 knots or more move over such terrain. Where these conditions are known to exist, required obstacle clearance in the final approach segment should be increased. Procedure specialists and approving authorities should be aware of such hazards involved and make appropriate addition, based on their experience and good judgment, to limit the time in which an aircraft is exposed to lee-side turbulence and other weather phenomena associated with precipitous terrain. This may be done by increasing the minimum altitude over the intermediate and final approach fixes so as to preclude prolonged flight at low altitudes. User comments should be solicited to obtain the best available local information.

Note: An allowance for precipitous terrain should also be considered for initial segments (including dead reckoning) and procedure turns as per paragraphs 232.c, 233.c and 234.c.

c. Remote Altimeter Setting Source (RASS). When the altimeter setting is obtained from a source more than 5 NM from the airport reference point (ARP) for an airport, or the heliport reference point (HRP) for a heliport or vertiport, the ROC shall be increased by the amount of RASS adjustment for the final (except precision final), step-down, circling and intermediate segments. For precision finals, the DH shall be increased by the amount of RASS adjustment. When two altimeter sources are used, RASS shall be applied to the missed approach climb-to-altitude. RASS adjustment does not apply to MSA, initials, en route, feeder routes or segment/areas based upon en route criteria. A remote altimeter-setting source is not authorized for a remote distance that is greater then 75 NM or for an elevation differential between the RASS and the landing area that is greater than 6,000 feet. To determine which adjustment shall apply, evaluate the terrain between the RASS and the airport/heliport/vertiport for adverse atmospheric pressure pattern effects. Comments should be solicited from Environment Canada in order to obtain the best available climatological information.

(1) Where intervening terrain does not adversely influence atmospheric pressure patterns, the following formula shall be used to compute the basic adjustment in feet:

RASS Adjustment = $2.3\ d_R + 0.14e$

where: "d_R" = the horizontal distance in nautical miles from the altimeter source to the ARP/HRP, and

"e" = the elevation differential in feet between the elevation of the RASS and the elevation of the airport/heliport/vertiport. (see Figure 3-37B).

(2) Where intervening terrain adversely influences atmospheric pressure patterns, an elevation differential area (EDA) shall be evaluated. The EDA is defined as the area within 5 NM each side of a line connecting the ARP/HRP and the RASS, and includes a circular area enclosed by a 5 NM radius at each end of this line. (see Figure 3-37C. The following formulas shall be used to compute the basic adjustment:

RASS Adjustment = $2.3\ d_R + 0.14E$

where: "d_R" = the horizontal distance in nautical miles from the altimeter source to the ARP/HRP, and

"E" = the terrain elevation differential in feet between the lowest and the highest terrain elevation points contained with the EDA. (see Figure 3-37C).

(3) For the intermediate segment, use 60 per cent of the basic adjustment from Para 323.c (1) or (2), and increase the intermediate segment ROC by the amount this value exceeds 200 feet.

Example:	RASS adjustment (100%) = 420 ft
	RASS adjustment (60%) = 420 ft x 0.6 = 252 ft
Since 60% value is > 200 ft, then:	
	Intermediate adjustment = 252 ft – 200 ft = 52 ft
Therefore	
	Primary ROC for intermediate segment = 500 ft + 52 ft = 552 ft

(4) For a missed approach climb-to-altitude when two altimeter sources are available and the climb-to-altitude is less than the missed approach clearance limit altitude, apply RASS adjustment to the climb-to-altitude or to Section 2 and Zone 2/3 40:1 surface height as follows:

(a) Decrease the starting height of the 40:1 surface for Section 2 and Zone 2/3 by the difference between the RASS adjustments for the two remote altimeter sources. (Where one altimeter is local, subtract the full RASS adjustment.) Do not decrease these surface-starting heights to less than the height of the 40:1 surface at the MAP.

(b) If the application of Para 323.c(4)(a) results in a 40:1 surface penetration that cannot be resolved by other methods, provide a second climb-to-altitude using the least accurate altimeter source by adding the difference between the RASS adjustments to the climb-to-altitude and rounding to the next higher 20-foot increment. DO NOT lower the Section 2 and Zone 2/3 40:1 surfaces. This application shall not increase the climb-to-altitude above the missed approach clearance limit altitude.

For example: "MISSED APPROACH: Climb to 5,900 (6,100 when using Kelowna altimeter setting) then … "

(5) Point-In-Space Approach (PINSA). When the MAP is more than 5 NM from the PINSA altimeter-setting source, RASS adjustment shall be applied. For application of the RASS formula, define "d_R" as the distance from the altimeter setting source to the MAP, and define "e" or "E" as in Para 323.c.(1) or (2).

(6) Minimum Reception Altitude (MRA). Where a minimum altitude is dictated by the MRA, the MRA shall be increased by the amount of the RASS adjustment factor.

(7) When the procedure is based on a remote altimeter source, the procedure shall be annotated, as follows:

(a) Full Time Remote - "Use Ottawa Intl altimeter setting." In this case, the adjustment shall be included in the published altitudes.

(b) Part Time Remote - "When using Ottawa Intl altimeter setting, add **XXX** feet to all procedure altitudes."

(8) The calculated RASS adjustment value shall be rounded to the nearest 10-foot increment.

d. Excessive Length of Final Approach. When a final approach fix is incorporated in the procedure, and the distance from that fix to the nearest landing surface exceeds 6 NM, the required obstacle clearance in the final approach segment shall be increased at the rate of 5 feet for each one-tenth NM over 6 miles. Where a step-down fix is incorporated in the final approach segment, the basic obstacle clearance may be applied between the step-down fix and the MAP, provided the fix is within 6 NM of the landing surface. These criteria are applicable to non-precision approach procedures only.

324. Decision Altitude (DA)

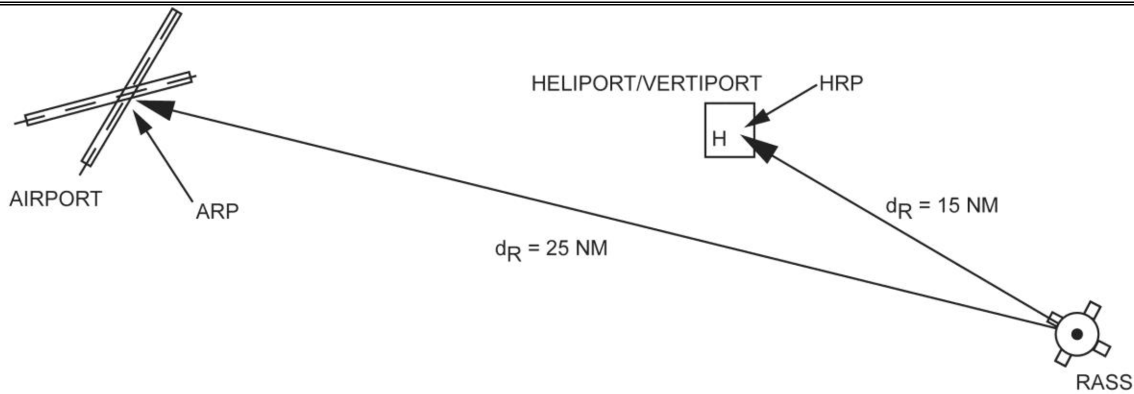
The DA applies to approach procedures where the pilot is provided with glidepath deviation information; e.g., ILS, MLS, TLS, LPV, GLS, Baro VNAV, or PAR. The DA is the barometric altitude, specified in feet above MSL, at which a missed approach shall be initiated if the required visual reference has not been established. DA's shall be established by using the appropriate criteria in this document.

325. Decision Height (DH)

The DH is the value of the DA expressed in feet above the highest runway elevation in the touchdown zone. This value is also referred to as **HAT**.

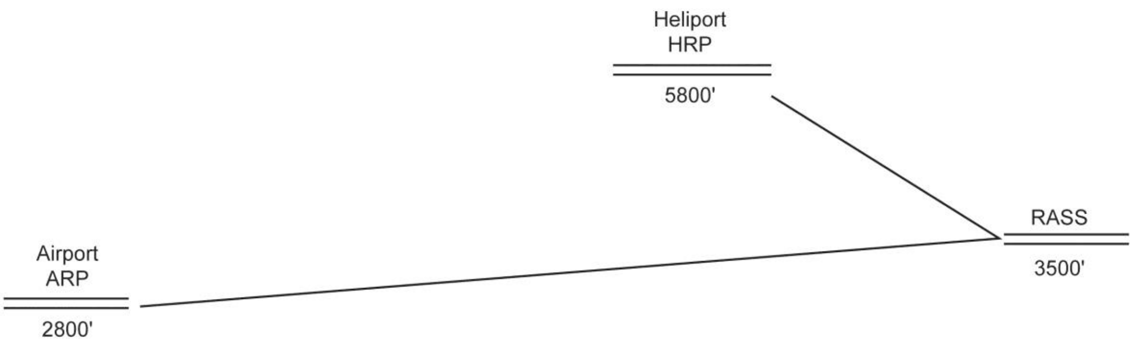
326—329. Reserved

Figure 3-1 TO 3-37a: Reserved



Distances:

- Airport: d_R = 25 nm
- Heliport: d_R = 15 nm



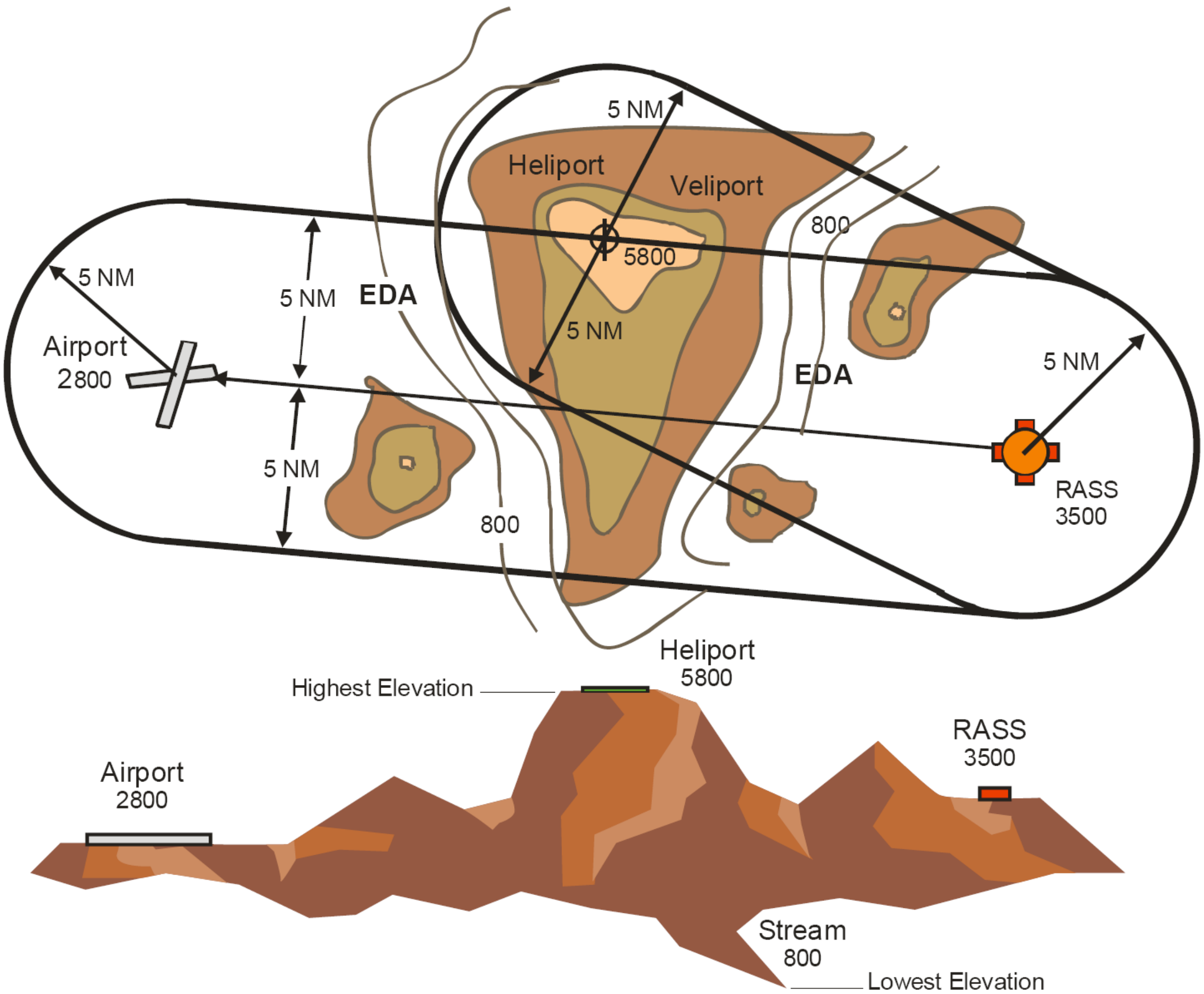
Elevations:

- Airport: e = (3,500' – 2,800') = 700 feet
- Heliport: e = (5,800' – 3,500') = 2,300 feet

Examples:

RASS Adjustment — Airport:	RASS Adjustment — Heliport:
RASS = 2.3 dR + 0.14 e	RASS = 2.3 dR + 0.14 e
= 2.3 (25) + 0.14 (700)	= 2.3 (15) + 0.14 (2300)
= 57.5 + 98	= 34.5 + 322
= 155.5 feet	= 356.5 feet

Figure 3-37b: Distance Remoted (d_R) And Elevation (e). Para 323.c.



EXAMPLE – ELEVATION DIFFERENCE

AIRPORT – E = 2800’ – 800’ = 2000’ x .14 = 280’
HELIPORT/VERTIPORT – E = 5800’ – 800’ = 5000’ x .14 = 700’

Figure 3-37c: Elevation Differential Area (EDA) Where Intervening Terrain Influences Atmospheric Pressure Patterns. Para 323.c.

SECTION 3. VISIBILITIES

330. Establishment Of Visibility Minima

a. **NON-PRECISION** Straight-in minima shall be established for an approach category when:

(1) The final approach course-runway alignment criteria have been met; AND

(2) The height of the DA or MDA above the touchdown zone (TDZ) and the associated visibility are within the tolerances specified in Para 331; AND

(3) The descent gradient from the final approach fix to the runway does not exceed the maximum specified in the applicable facility chapter of this document.

b. **PRECISION** Straight-in minima shall be established for an approach category when the final approach course alignment criteria have been met.

c. The minimum visibility prior to applying credit for lights shall not be less than;

(1) the visibility required in Para 331; or

(2) the MAP to threshold distance (where the MAP is reached before the threshold), whichever is greater.

d. When straight-in minima are not authorized, only circling MDAs and visibilities will be established. In establishing circling visibility minima, Para 331 applies. These minima shall be no lower than those specified in Para 351.

e. Circling minima shall NOT be lower than straight-in landing minima.

331. Effect Of HAA/HAT And Facility Distance On Straight-In And Circling Visibility Minima/Advisory Visibility

The minimum standard visibility required for the pilot to establish visual reference in time to descend safely from the DA or MDA is dependent upon the HAT/HAA. The minimum standard visibility is specified in Table 3–2.

332. Effect Of DA On Precision Visibility Minima/Advisory Visibility

The minimum standard visibility required for the pilot to establish reference in time to descend safely from the DA is dependent upon the HAT. The minimum standard visibility is specified in Table 3–3.

333. Runway Visual Range (RVR)

An RVR sensor system is used for measuring the visibility along the runway. It is an instrumentally derived value that represents the horizontal distance a pilot will see down the runway from the approach end. It is based on the sighting of either high intensity runway lights or the visual contrast of other targets; whichever yields the greater visual range.

334. Reserved

335. Comparable Values Of RVR And Ground Visibility

If RVR minima for take-off or landing are prescribed in an instrument approach procedure but RVR is not reported for the runway of intended operation, the RVR minima shall be converted to ground visibility in accordance with Table 3–4, and observed as the applicable visibility minimum for take-off or landing on that runway.

336—339. Reserved

SECTION 4. VISIBILITY CREDIT FOR LIGHTS

340—342. Reserved

343. Visibility Reduction

Standard visibility requirements are computed by applying the criteria contained in Para 331. These requirements may be reduced by giving credit for appropriate light systems as shown in Table 3–2.

> **Note:** No credit is given for approach light systems for circling approaches.

344—349. Reserved

SECTION 5. STANDARD MINIMA

350. Standard Straight-In Minima

Table 3–1 specifies the lowest minima which may be prescribed for various combinations of electronic and visual navigation aids. Lower minima based on special equipment or aircrew qualifications may be authorized only by TC HQ or DND HQ, as applicable. Higher minima shall be specified where required by application of criteria contained elsewhere in this document.

351. Standard Circling Minima

Table 3–1 specifies the lowest minima which may be prescribed for circling approaches. See also Para 330.c. The MDA established by application of the minima specified in this paragraph shall be rounded to the next higher 20-foot increment.

352—359. Reserved

SECTION 6. ALTERNATE MINIMA

360. Alternate Weather Minima

Determining the weather requirements for an alternate is the responsibility of the pilot-in-command based upon criteria detailed in the Canada Air Pilot and A.I.P. Canada. For military procedures, see BGA-100-001/AA-000.

361—369. Reserved

SECTION 7. DEPARTURES

370. Take-Off Minima

All take-off minima shall be determined by applying Vol 1, Chap 12 of this document to all conventional departure procedures and Standard Instrument Departures (SIDs). The appropriate RNAV criteria shall be applied for all RNAV Departures and SIDs. Published minima are detailed in the Canada Air Pilot and appropriate Military publications.

371—399. Reserved

TYPE OF APPROACH		MINIMA		
		HEIGHT	VISIBILITY (SM)	RVR
ILS CAT III		NA	NA	06
ILS CAT II		HAT 100 FT	NA	12
PAR, ILS CAT I, LPV CAT I		HAT 200 FT	1/2	26
HIAL INOP		HAT 250 FT	1	50
RNP-AR RNAV (LPV, LP, LNAV/VNAV, LNAV) LOC, LOC BACK COURSE VOR/DME, TACAN VOR WITH FAF		HAT 250 FT	1	50
VOR WITHOUT FAF		HAT 300 FT	1	50
NDB WITH FAF		HAT 300 FT	1	50
NDB WITHOUT FAF		HAT 350 FT	1	50
CIRCLING	CAT A and B	HAA 500 FT	1 1/2	NA
	CAT C	HAA 500 FT	2	NA
	CAT D and E	HAA 600 FT	2	NA

Note: All calculated minima values shall be rounded to whole number increments as follows:

DA – next higher 1’ increment (i.e., 196.2’ = 197’)
TCH – next lower 1’ increment (i.e., 46.75’ = 46’)
MDAs – next higher 20-foot increment (i.e., 414’ = 420’)
Sector Altitudes – next higher 100-foot increments (i.e., 2036’ = 2100’)
HAT – next higher 1-foot increment (i.e., 257.2’ = 258’)
HAA – next higher 1-foot increment (i.e., 414.4’ = 415’)

Table 3-1: Standard Straight-In And Circling Minima. Para 350 and 351.

HAT/HAA RANGE	VISIBILITY (SM)
250' – 347'	1
348' – 434'	1 ¼
435' – 521'	1 ½
522' – 608'	1 ¾
609' – 695'	2
696' – 782'	2 ¼
783' – 869'	2 ½
870' – 956'	2 ¾
957' and above	3

Note: If the landing runway is served by an operational high intensity (HIAAIL), MALSR (AM) or SSALR (AN) approach lighting system, the visibility may be reduced by ½ SM, but at no time to a value less than 1 SM or that shown in Table 3-1, whichever is higher. On circling approaches, no visibility credit will be given for approach lights.

**Table 3-2: Non-Precision Minima Visibility Matrix.
Para 331 and 343.**

HAT	VISIBILITY (SM)
100' – 199'	RVR down to 1200
200' – 249'	½
≥ 250'	use Table 3-2

Table 3-3: Precision Minima Visibility Matrix. Para 332.

RVR	VISIBILITY (SM)
1200	¼
2600	½
4000	¾
5000	1

**Table 3-4: Comparable Values Of RVR And Ground Visibility.
Para 335.**

GPA	Aircraft Category A	B	C	D & E
2.50° - 2.99° (DND only)	200			
3.00° - 3.10°	200			
3.11° - 3.30°	200		250	**NA**
3.31° - 3.60°	200		270	**NA**
3.61° - 3.80°	200		**NA**	
3.81° - 4.20°	200	250	**NA**	
4.21° - 5.00°	250	**NA**		
5.01° - 5.70°	300	**NA**		
5.71° - 6.40° Airspeed NTE 80 knots	350	**NA**		

Note: LPV GPA > 3.5° = 250 minimum

Table 3-5. Minimum HAT for PA and APV Approach Procedures as a function of GPA. Para 323.a.

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CHAPTER 4. ON-AIRPORT VOR (NO FAF)

400. General

This chapter is divided into two sections; one for low altitude procedures and one for high altitude teardrop penetration procedures. These criteria apply to procedures based on a VOR facility located on an airport in which no final approach fix (FAF) is established. These procedures must incorporate a procedure or a penetration turn. An ON-AIRPORT facility is one that is located:

a. For Straight-in Approach. Within one mile of the nearest portion of the landing runway.

b. For Circling Approach. Within one mile of the nearest portion of the usable landing surface of the airport.

401—409. Reserved

SECTION 1. LOW ALTITUDE PROCEDURES

410. Feeder Routes

Criteria for feeder routes are contained in Para 220.

411. Initial Approach Segment

The initial approach fix is received by overheading the navigation facility. The initial approach is a procedure turn. The criteria for the procedure turn areas are contained in Para 234.

412. Intermediate Approach Segment

This type of procedure has no intermediate segment. Upon completion of the procedure turn, the aircraft is on final approach.

413. Final Approach Segment

The final approach begins where the procedure turn intersects the final approach course inbound.

a. Alignment. The alignment of the final approach course with the runway centreline determines whether a straight-in or circling approach may be established.

(1) Straight-in. The angle of convergence of the final approach course and the extended runway centreline shall not exceed 30 degrees. The final approach course should be aligned to intersect the extended runway centreline 3,000 feet outward from the runway threshold. When an operational advantage can be achieved this point of intersection may be established at any point between the runway threshold and a point 5,200 feet outward from the runway threshold. Also, where an operational advantage can be achieved, a final approach course which does not intersect the runway centreline, or intersects it at a distance greater than 5,200 feet from the threshold, may be established provided such a course lies within 500 feet laterally of the extended runway centreline at a point 3,000 feet outward from the runway threshold. Straight-in category C, D, and E minimums are not authorized when the final approach course intersects the extended runway centreline at an angle greater than 15° and a distance less than 3,000 feet (see Figure 4-38).

(2) Circling Approach. When the final approach course alignment does not meet the criteria for straight-in landing, only a circling approach shall be authorized, and the

course alignment should be made to the centre of the landing area. When an operational advantage can be achieved, the final approach course may be aligned to pass through any portion of the usable landing surface. See Figure 4-39.

b. Area. Figure 4-40 illustrates the final approach primary and secondary areas. The primary area is longitudinally centred on the final approach course, and is 10 miles long. The primary area is 2 miles wide at the facility and expands uniformly to 6 miles at 10 mile from the facility. A secondary area is on each side of the primary area. It is zero miles wide at the facility and expands uniformly to 1.34 miles on each side of the primary area at 10 miles from the facility. When the 5 mile procedure turn is used, only the inner 5 miles of the final approach area need be considered.

c. Obstacle Clearance.

(1) **Straight-in**. The minimum obstacle clearance in the primary area is 300 feet. In the secondary area, 300 feet of obstacle clearance shall be provided at the inner edge, tapering uniformly to zero feet at the outer edge.

(2) **Circling Approach**. In addition to the minimum requirements specified in Para 413.c.(1), obstacle clearance in the circling area shall be as prescribed in Chapter 2, Section 6.

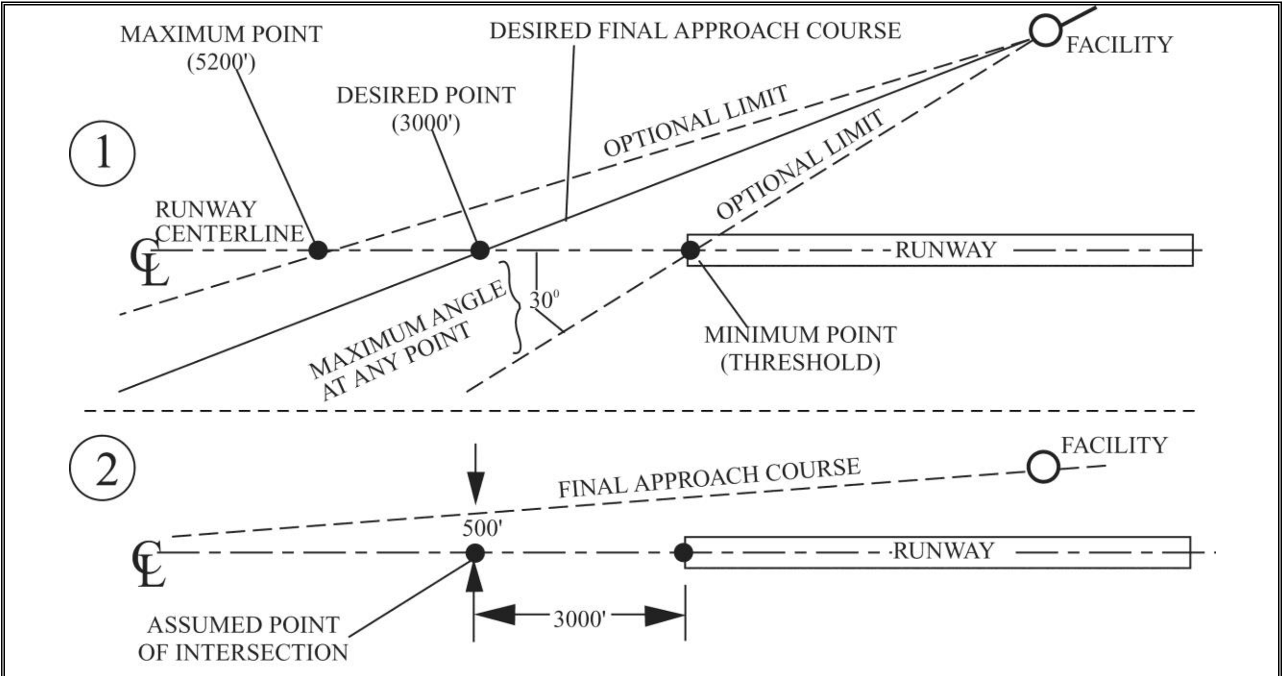
d. Procedure Turn Altitude (Descent Gradient). The procedure turn completion altitude shall be within 1,500 feet of the MDA (1,000 feet with a 5-mile procedure turn), provided the distance from the facility to the point where the final approach course intersects the runway centreline (or the first usable portion of the landing area for "circling only" procedures) does not exceed 2 miles. When this distance exceeds 2 miles, the maximum difference between the procedure turn completion altitude and the MDA shall be reduced at the rate of 25 feet for each one tenth of a mile in excess of 2 miles. See Figure 4-41.

Note: For those procedures in which the final approach does NOT intersect the extended runway centreline within 5,200 feet of the runway threshold (see Para 413.a.(1)) the assumed point of intersection for computing the distance from the facility shall be 3,000 feet from the runway threshold. See Figure 4-38.

e. Use of Step-down Fix. Use of the step-down fix (Para 288.c) is permitted provided the distance from the facility to the step-down fix does not exceed 4 miles. The descent gradient between PT completion altitude and stepdown altitude shall not exceed 150 ft/NM. The descent gradient will be computed based upon the difference in PT completion altitude minus stepdown fix altitude, divided by the specified PT distance, minus the facility to stepdown fix distance. Obstacle clearance may be reduced to 250 feet from the stepdown fix to the MAP/FEP. See Figure 4-42, Para 252.

f. Minimum Descent Altitude. Criteria for determining the MDA are contained in Chapter 3.

Figure 4-1 TO 4-37: Reserved



Note: Note: Straight-in category C, D, and E minimums are not authorized when the final approach course intersects the extended runway centerline at an angle greater than 15° and a distance less than 3,000 feet.

Figure 4-38: Alignment Options For Final Approach Course. On-Airport VOR, No FAF, Straight-In Approach Procedure. Para 413.a.(1).

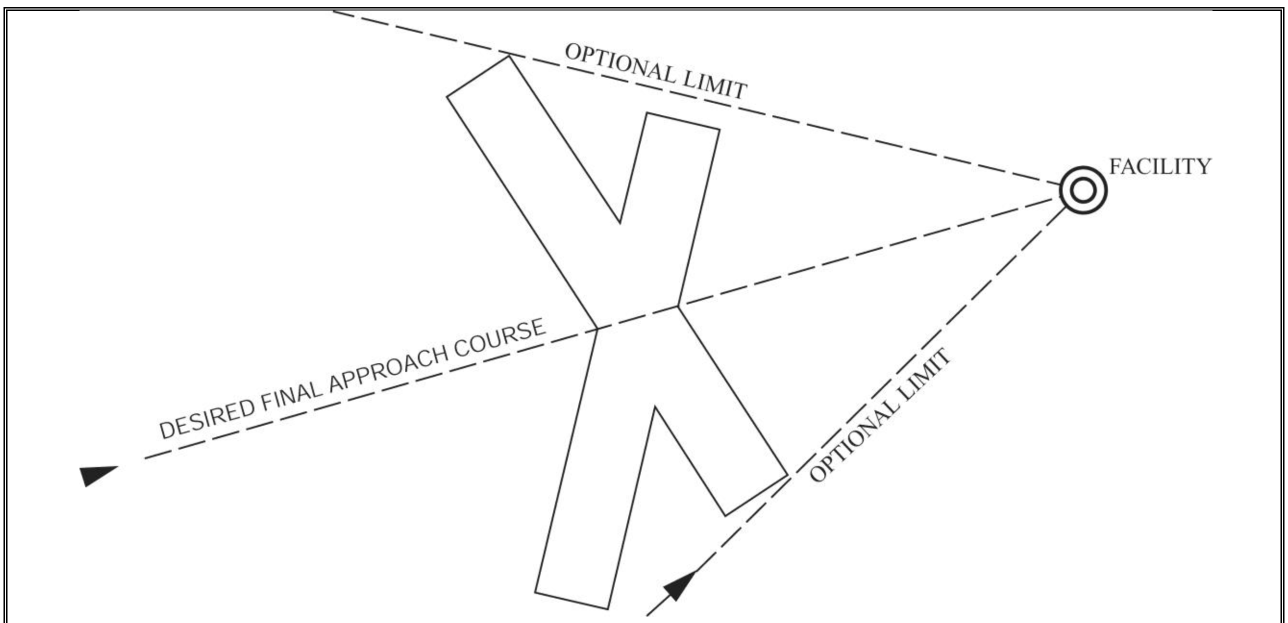


Figure 4-39: Alignment Options For Final Approach Course. On Airport VOR, No FAF, Circling Approach Procedure. Para 413.a.(2).

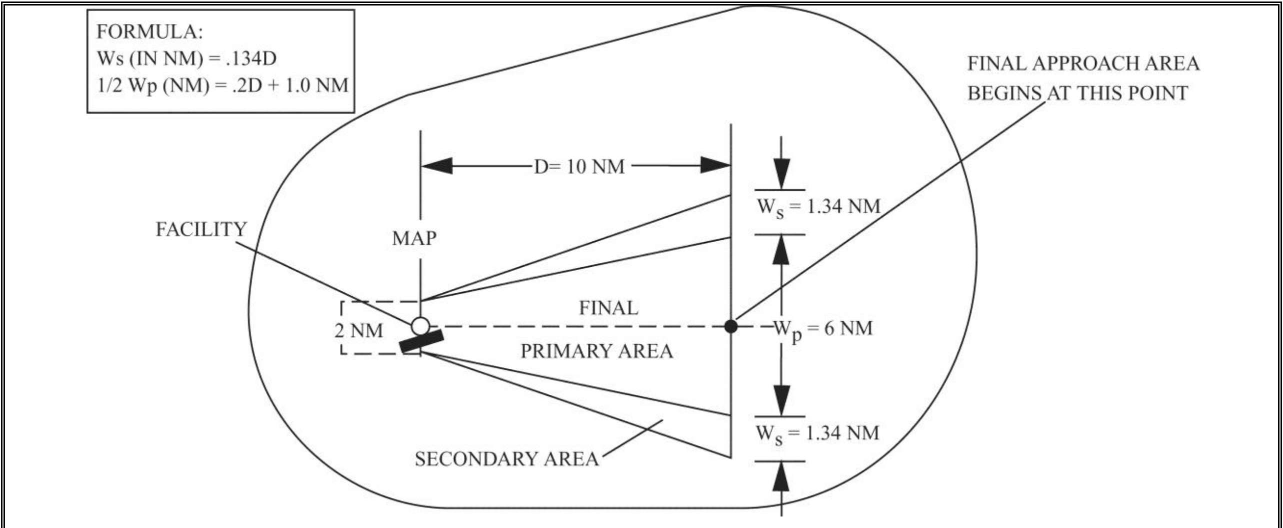


Figure 4-40: Final Approach Primary And Secondary Areas. On-Airport VOR, No FAF. Para 413.b.

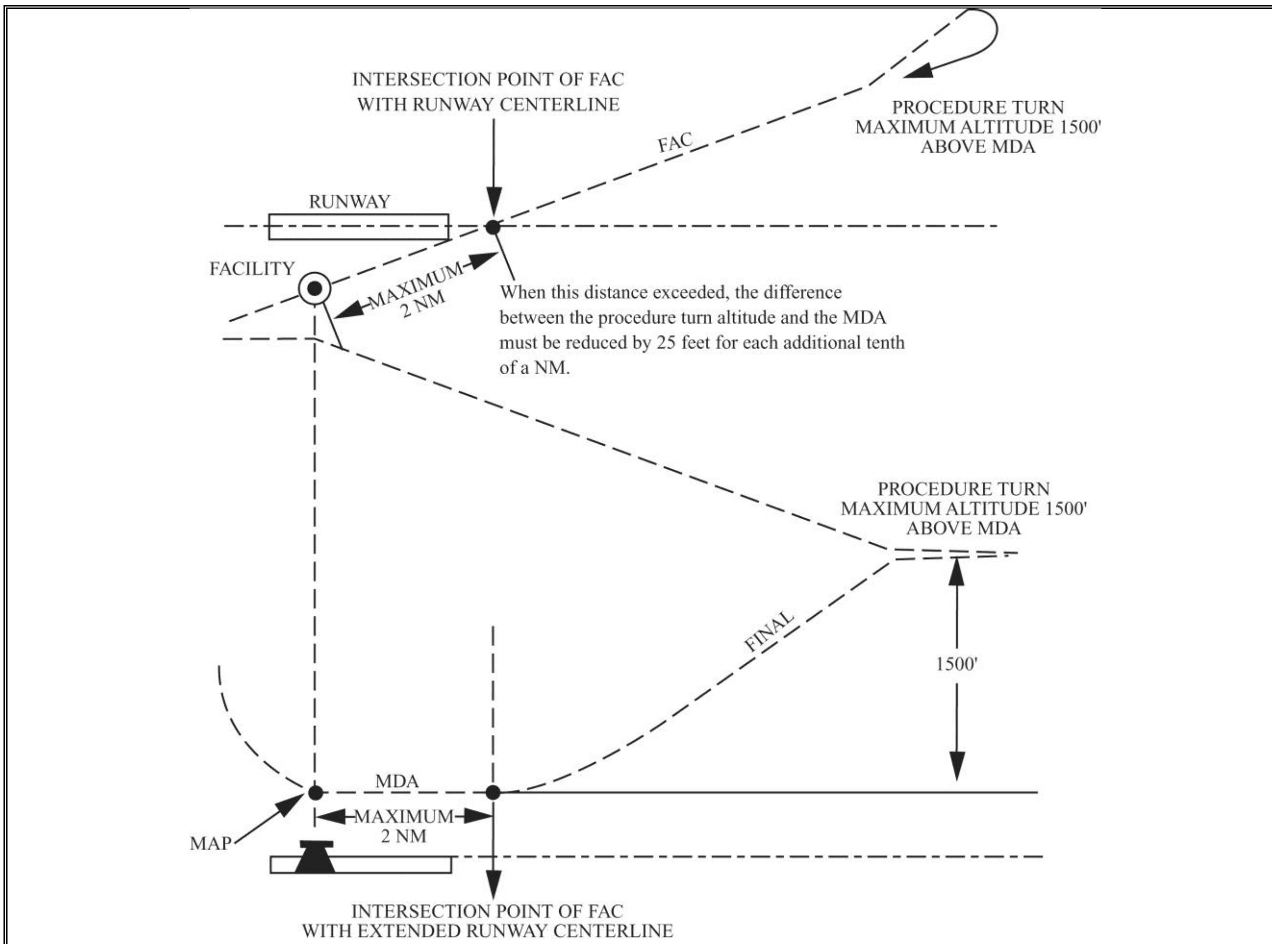


Figure 4-41: Procedure Turn Altitude. On-Airport VOR, No FAF. Para 413.d.

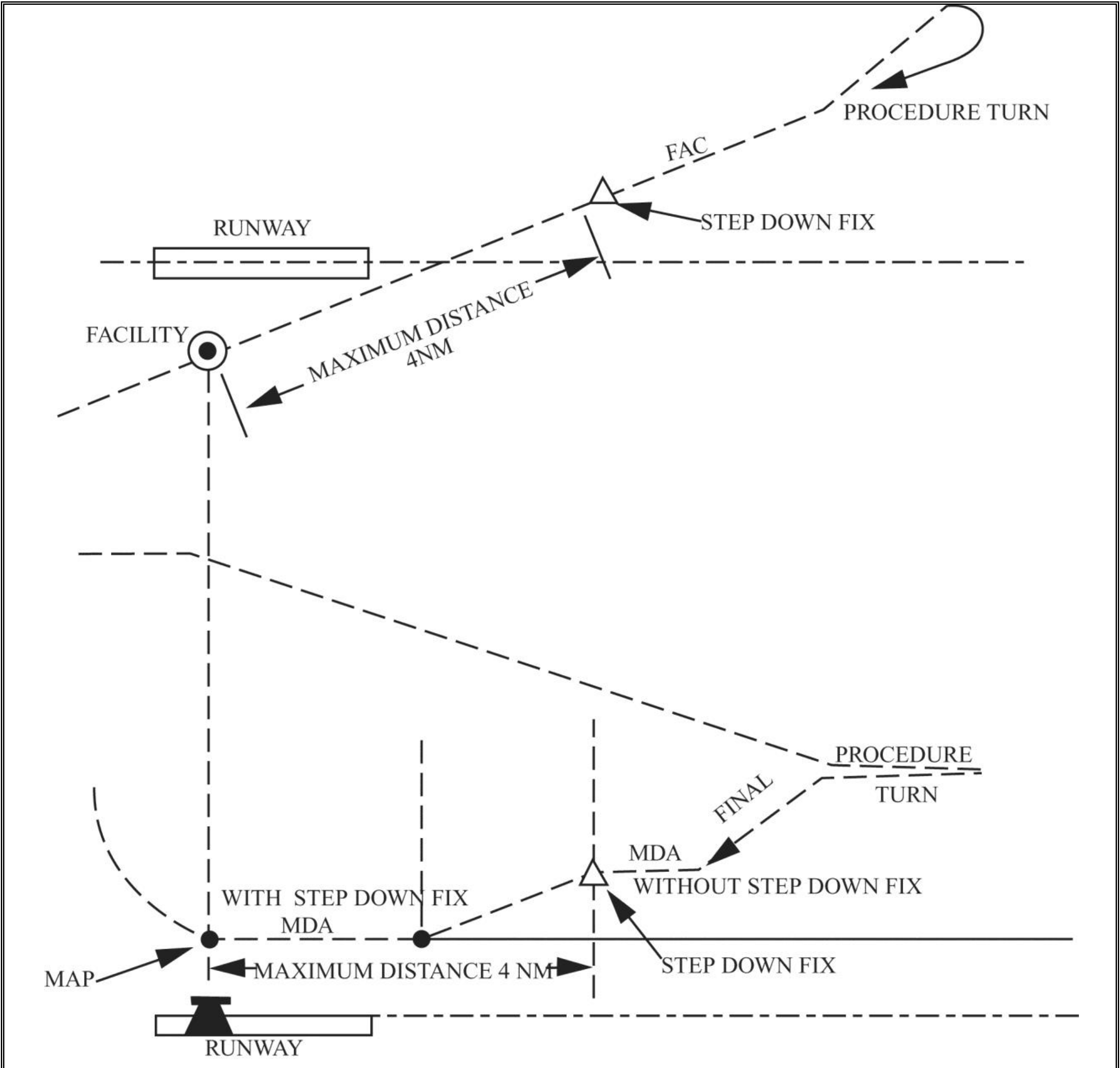


Figure 4-42: Use Of Step-Down Fix. On-Airport VOR, No FAF. Para 413.e.

414. Missed Approach Segment

Criteria for the missed approach segment are contained in Chapter 2, Section 7. The missed approach point is the facility. See Figure 4-42. The missed approach surface shall commence over the facility at the required height. See Para 274.

415—419. Reserved

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SECTION 2. HIGH ALTITUDE TEARDROP PENETRATIONS

420. Feeder Routes

Criteria for feeder routes are contained in Para 220.

421. Initial Approach Segment

The initial approach fix is received by overheading the navigation facility. The initial approach is a teardrop penetration turn. The criteria for the penetration turn are contained in Para 235.

422. Intermediate Approach Segment

This procedure has no intermediate segment. Upon completion of the penetration turn, the aircraft is on final approach.

423. Final Approach Segment

An aircraft is considered to be on final approach upon completion of the penetration turn. However, the final approach segment begins on the final approach course 10 miles from the facility. That portion of the penetration procedure prior to the 10-mile point is treated as the initial approach segment. See Figure 4-6.

a. Alignment. Same as low altitude (Para 413.a).

b. Area. Figure 4-6 illustrates the final approach primary and secondary areas. The primary area is longitudinally centred on the final approach course, and is 10 miles long. The primary area is 2 miles wide at the facility, and expands uniformly to 8 miles at a point 10 miles from the facility. A secondary area is on each side of the primary area. It is zero miles wide at the facility, and expands uniformly to 2 miles each side of the primary area at a point 10 miles from the facility.

c. Obstacle Clearance.

(1) **Straight-in**. The minimum obstacle clearance in the primary area is 500 feet. In the secondary area, 500 feet of obstacle clearance shall be provided at the inner edge, tapering uniformly to zero feet at the outer edge.

(2) **Circling Approach**. In addition to the minimum requirements specified in Para 423.c.(1), obstacle clearance in the circling area shall be as prescribed in Chapter 2, Section 6.

d. Penetration Turn Altitude (Descent Gradient). The penetration turn completion altitude shall be at least 1,000 feet, but not more than 4,000 feet, above the MDA on final approach.

e. Use of Step-down Fix. The use of the step-down fix is permitted provided the distance from the facility to the step-down fix does not exceed 10 miles. See Para 288.c.

f. Minimum Descent Altitude. In addition to the normal obstacle clearance requirement of the final approach segment (see Para 423.c), the MDA specified shall provide at least 500 feet of clearance over obstacles in the portion of the initial approach segment between the final approach segment and the point where the assumed penetration turn track intercepts the inbound course. See Figure 4-43.

424. Missed Approach Segment

Criteria for the missed approach segment are contained in Chapter 2, Section 7. The missed approach point is the facility. See Figure 4-43. The missed approach surface shall commence over the facility at the required height. See Para 274.

425—499. Reserved

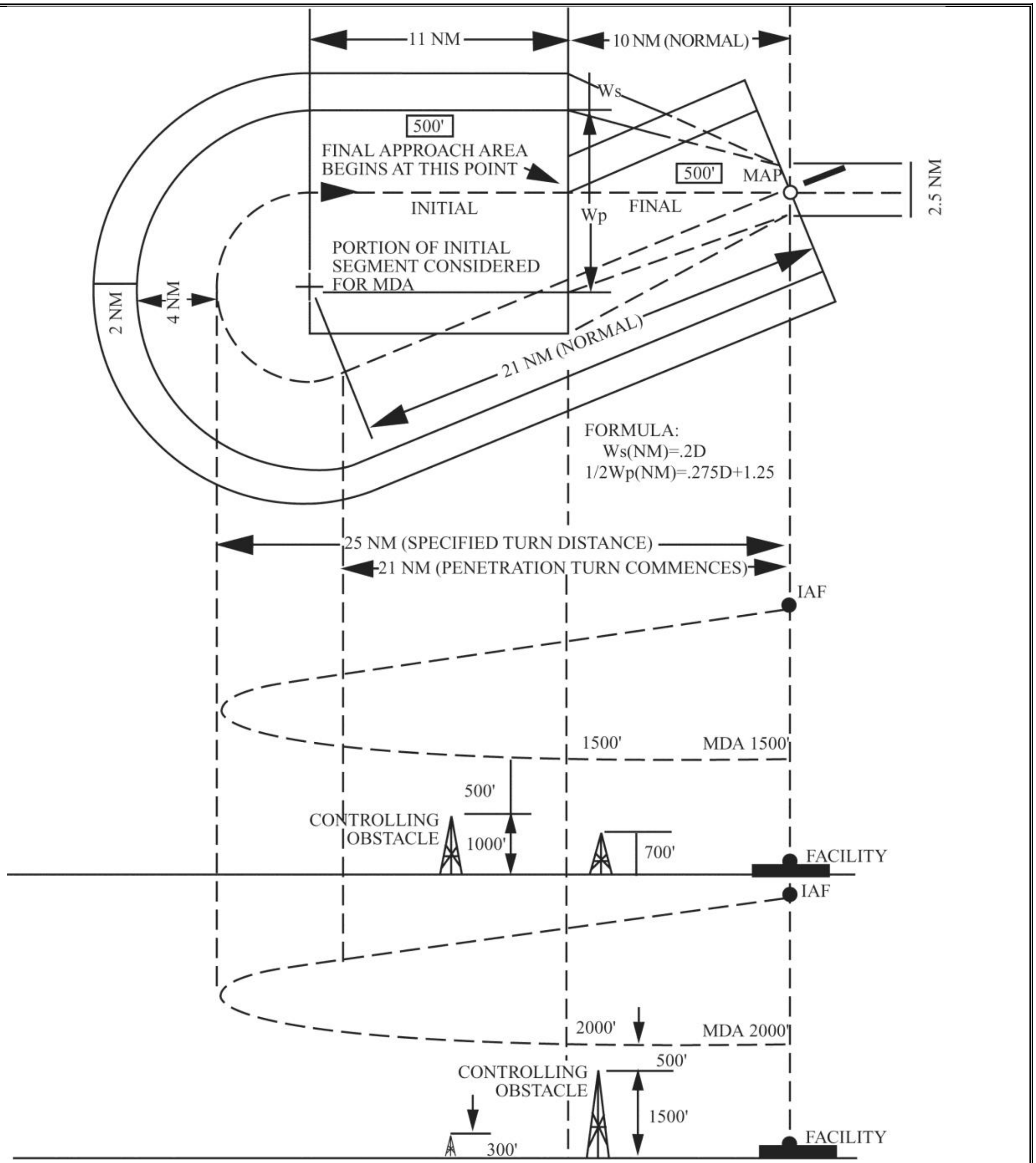


Figure 4-43: Penetration Turn. On Airport VOR, No FAF. Para 423.

CHAPTER 5. TACAN, VOR/DME AND VOR WITH FAF

500. General

This chapter applies to approach procedures based on VOR, VOR/DME, VORTAC or TACAN facilities in which a final approach fix (FAF) is established. The chapter is divided into two sections; Section 1 for VOR procedures that do not use DME as the primary method for establishing fixes, and Section 2 for VOR/DME and TACAN procedures, which use collocated, frequency, paired DME as the sole method of establishing fixes. When both the VOR and TACAN azimuth elements of a VORTAC station will support it, a single procedure, identified as a VOR/DME or TACAN shall be published. Such a procedure may be flown using either a VOR/DME or TACAN airborne receiver and shall satisfy TACAN terminal area fix requirements. See Para 286.c.

501—509. Reserved

SECTION 1. VOR WITH FAF

510. Feeder Routes

Criteria for feeder routes are contained in Para 220.

511. Initial Approach Segment

Criteria for the initial approach segment are contained in Chapter 2, Section 3. (see Figures 5-44a, 5-44b and 5–45.)

512. Intermediate Approach Segment

Criteria for the intermediate approach segment are contained in Chapter 2, Section 4. (see Figures 5–44a, 5-44b and 5–45.)

513. Final Approach Segment

The final approach may be made either FROM or TOWARD the facility. The final approach segment begins at the final approach fix and ends at the runway or missed approach point, whichever is encountered last.

a. Alignment. The alignment of the final approach course with the runway centreline determines whether a straight-in or circling-only approach may be established. The alignment criteria differ depending on whether the facility is OFF or ON the airport. See definitions in Para 400.

(1) Off-airport Facility.

(a) **Straight-in**. The angle of convergence of the final approach course and the extended runway centreline shall not exceed 30 degrees. The final approach course should be aligned to intersect the runway centreline at the runway threshold. However, when an operational advantage can be achieved, the point of intersection may be established to as much as 3,000 feet outward along extended RWY centerline from the runway threshold. (see Figure 5–46.)

(b) **Circling Approach**. When the final approach course alignment does not meet the criteria for a straight-in landing, only a circling approach shall be authorized, and the course alignment should be made to the centre of the landing area. When an operational advantage can be achieved, the final approach course may be aligned to any portion of the usable landing surface. (see Figure 5–47.)

(2) On-airport Facility.

(a) **Straight-in**. The angle of convergence of the final approach course and the extended runway centreline shall not exceed 30 degrees. The final approach course should be aligned to intersect the extended runway centreline 3,000 feet outward from the runway threshold. When an operational advantage can be achieved, this point of intersection may be established at any point between the threshold and a point 5,200 feet outward from the threshold. Also, where an operational advantage can be achieved a final approach course which does not intersect the runway centreline, or which intersects it at a distance greater than 5,200 feet from the threshold, may be established, provided that such a course lies within 500 feet laterally of the extended runway centreline at a point 3,000 feet outward from the runway threshold. (see Figure 5–48.)

(b) **Circling Approach**. When the final approach course alignment does not meet the criteria for a straight-in landing, only a circling approach shall be authorized, and the course alignment should be made to the centre of the landing area. When an operational advantage can be achieved, the final approach course may be aligned to any portion of the usable landing surface. (see Figure 5–49.)

b. Area. The area considered for obstacle clearance in the final approach segment starts at the final approach fix and ends at the runway or missed approach point, whichever is encountered last. It is a portion of a 30 nautical mile long trapezoid (see Figure 5–50), which is made up of primary and secondary areas. The primary area is centred longitudinally on the final approach course. It is 2 nautical miles wide at the facility, and expands uniformly to 5 nautical miles wide at 30 nautical miles from the facility. A secondary area is on each side of the primary area. It is zero miles wide at the facility and expands uniformly to 1 nautical mile on each side of the primary area at 30 nautical miles from the facility. Final approaches may be made to airports, which are a maximum of 30 nautical miles from the facility. (see Figure 5–51.) The OPTIMUM length of the final approach segment is 5 nautical miles. The MAXIMUM length is 10 nautical miles. The MINIMUM length of the final approach segment shall provide adequate distance for an aircraft to make the required descent, and to regain course alignment when a turn is required over the facility. Table 5–14 shall be used to determine the minimum length needed to regain the course.

c. Obstacle Clearance.

(1) **Straight-in Landing**. The minimum obstacle clearance in the primary area is 250 feet. In the secondary area 250 feet of obstacle clearance shall be provided at the inner edge, tapering uniformly to zero feet at the outer edge (see Figure 5-51a). Allowance for adjustments should be considered as specified in Para 323.

(2) **Circling Approach**. In addition to the minimum requirements specified in Para 513.c.(1) above, obstacle clearance in the circling area shall be as prescribed in Chapter 2, Section 6.

d. Descent Gradient. Para 252 applies.

e. Use of Fixes. Criteria for the use of radio fixes are contained in Chapter 2, Section 8. Where a procedure is based on a procedure turn and an on-airport facility is the procedure turn fix, the distance from the facility to the FAF shall not exceed 4 miles.

f. Minimum Descent Altitudes. Criteria for determining the MDA are contained in Chapter 3, Section 2.

514. Missed Approach Segment

Criteria for the missed approach segment are contained in Chapter 2, Section 7. For VOR procedures, the missed approach point and surface shall be established as follows:

a. Off-airport Facilities.

(1) **Straight-in**. The missed approach point is a point on the final approach course, which is not farther from the final approach fix than the runway threshold. (see Figure 5-52.) The missed approach surface shall commence over the missed approach point at the required height. (See Para 274.)

(2) **Circling Approach**. The missed approach point is a point on the final approach course, which is not farther from the final approach fix than the first usable portion of the landing area. The missed approach surface shall commence over the missed approach point at the required height. (See Para 274.)

b. On-airport Facilities. The missed approach point is a point on the final approach course, which is not farther from the final approach fix than the facility. The missed approach surface shall commence over the missed approach point at the required height. (See Para 274.)

515—519. Reserved

SECTION 2. TACAN AND VOR/DME

520. Feeder Routes

Criteria for feeder routes are contained in Para 220.

521. Initial Approach Segment

Due to the fixing capability of TACAN and VOR/DME a procedure turn initial approach may not be required. Criteria for initial approach segments are contained in Chapter 2, Section 3.

522. Intermediate Approach Segment

Criteria for the intermediate segment are contained in Chapter 2, Section 4.

523. Final Approach Segment

TACAN and VOR/DME final approaches may be based either on arcs or radials. The final approach begins at a final approach fix and ends at the missed approach point. The missed approach point is always marked with a fix.

a. Radial Final Approach. Criteria for the radial final approach are specified in Para 513.

b. Arc Final Approach. The final approach arc shall be a continuation of the intermediate arc. It shall be specified in nautical miles and tenths thereof. Arcs closer than 7 miles (15 miles for high altitude procedures) and farther than 30 miles from the facility shall not be used for final approach. No turns are permitted over the final approach fix.

(1) **Alignment**. For Straight-in approaches, the final approach arc shall pass through the runway threshold when the angle of convergence of the runway centreline and the tangent of the arc does not exceed 15 degrees. When the angle exceeds 15 degrees the final approach arc shall be aligned to pass through the centre of the airport and only circling minimums shall be authorized. (see Figure 5–53.)

(2) **Area**. The area considered for obstacle clearance in the arc final approach segments starts at the final approach fix and ends at the runway or missed approach point, whichever is encountered last. It should not be more than 5 miles long. It shall be divided into primary and secondary areas. The primary area is 8 miles wide, and extends 4 miles on either side of the arc. A secondary area is on each side of the primary area. The secondary areas are 2 miles wide on each side of the primary area. (see Figure 5–54.)

(3) **Obstacle Clearance**. The minimum obstacle clearance in the primary area is 500 feet. In the secondary area, 500 feet of obstacle clearance shall be provided at the inner edge, tapering uniformly to zero feet at the outer edge (see Figure 5-54a). Allowance for adjustments should be considered as specified in Para 323.

(4) **Descent Gradient**. Criteria for descents are specified in Para 252.

(5) **Use of Fixes**. Fixes along an arc are restricted to those formed by radials from the VORTAC facility which provides the DME signal. Criteria for such fixes are contained in Chapter 2, Section 8.

(6) **Minimum Descent Altitude**. Straight-in MDAs shall not be specified lower than circling for arc procedures. Criteria for determining the circling MDA are contained in Chapter 3, Section 2.

524. Missed Approach Segment

Criteria for the missed approach segment are contained in Chapter 2, Section 7. The missed approach point shall be a radial/DME fix. The missed approach surface shall commence over the fix and at the required height. (Also see Para 514.)

Note: The arc missed approach course may be a continuation of the final approach arc.

525—599. Reserved

Figure 5-1 TO 5-44: Reserved

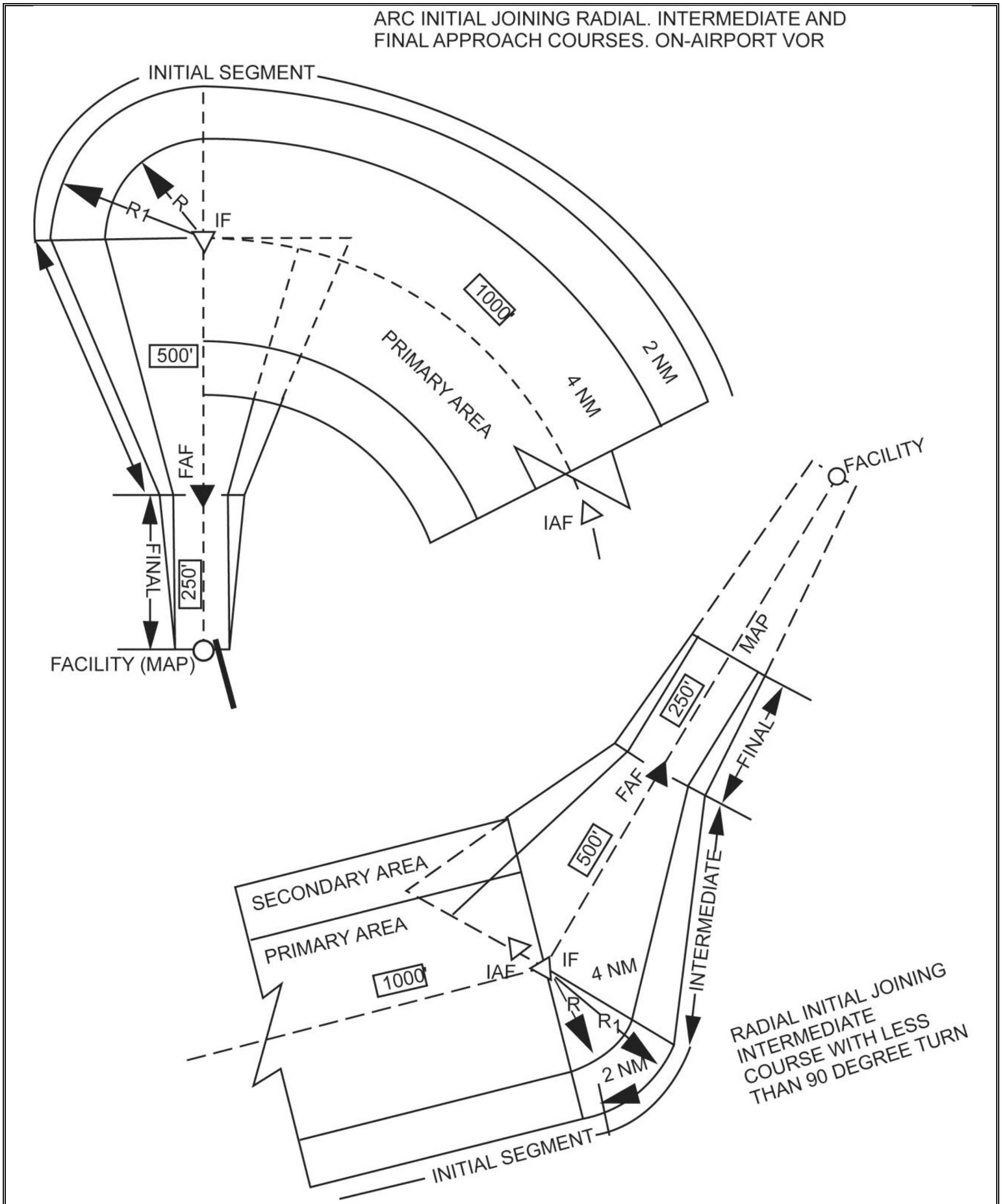


Figure 5-44a: Typical Low Alt Approach Segments. VOR with FAF. Para 511 & 512.

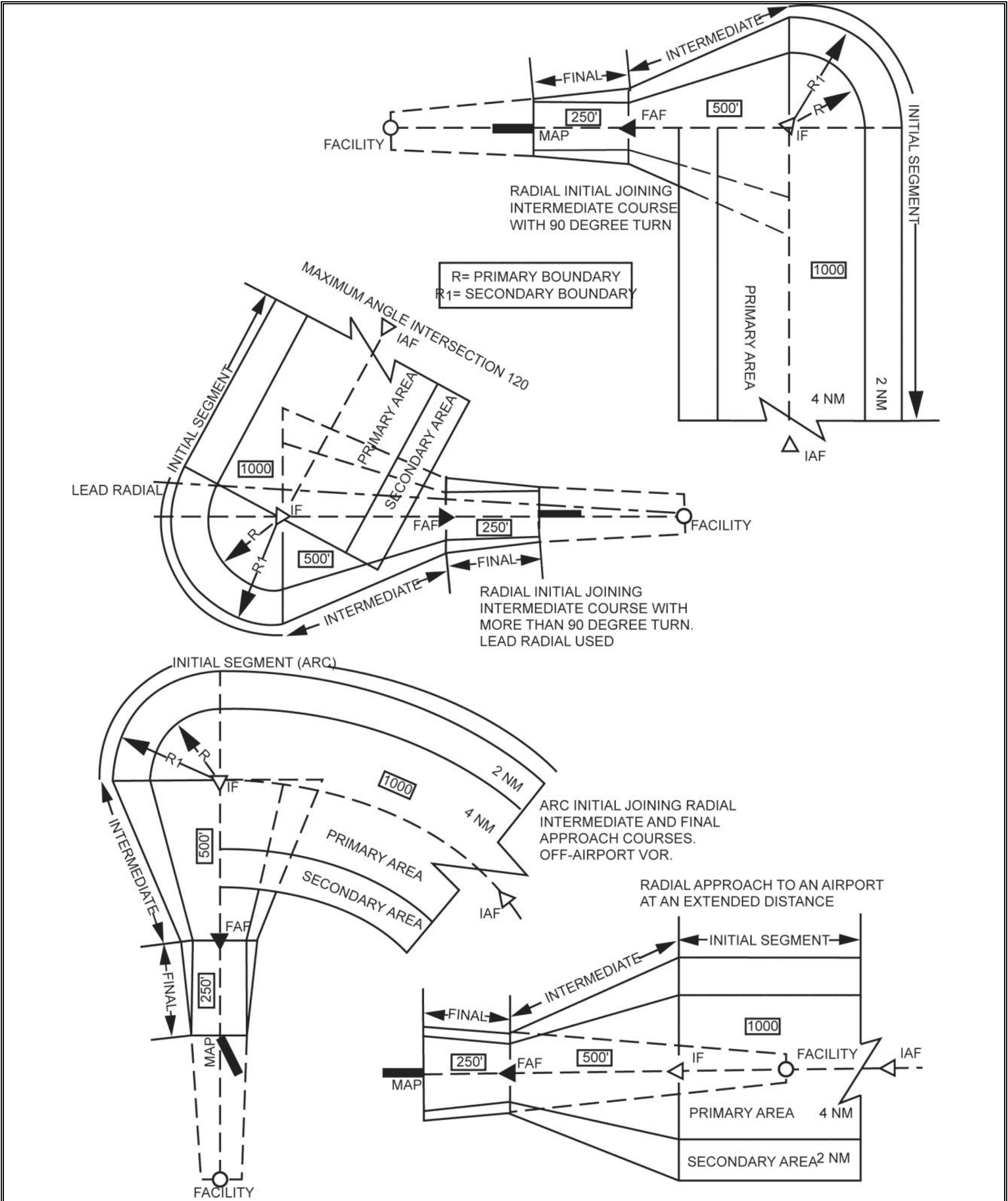


Figure 5-44b: Typical Low Alt Approach Segments. VOR with FAF. Para 511 & 512.

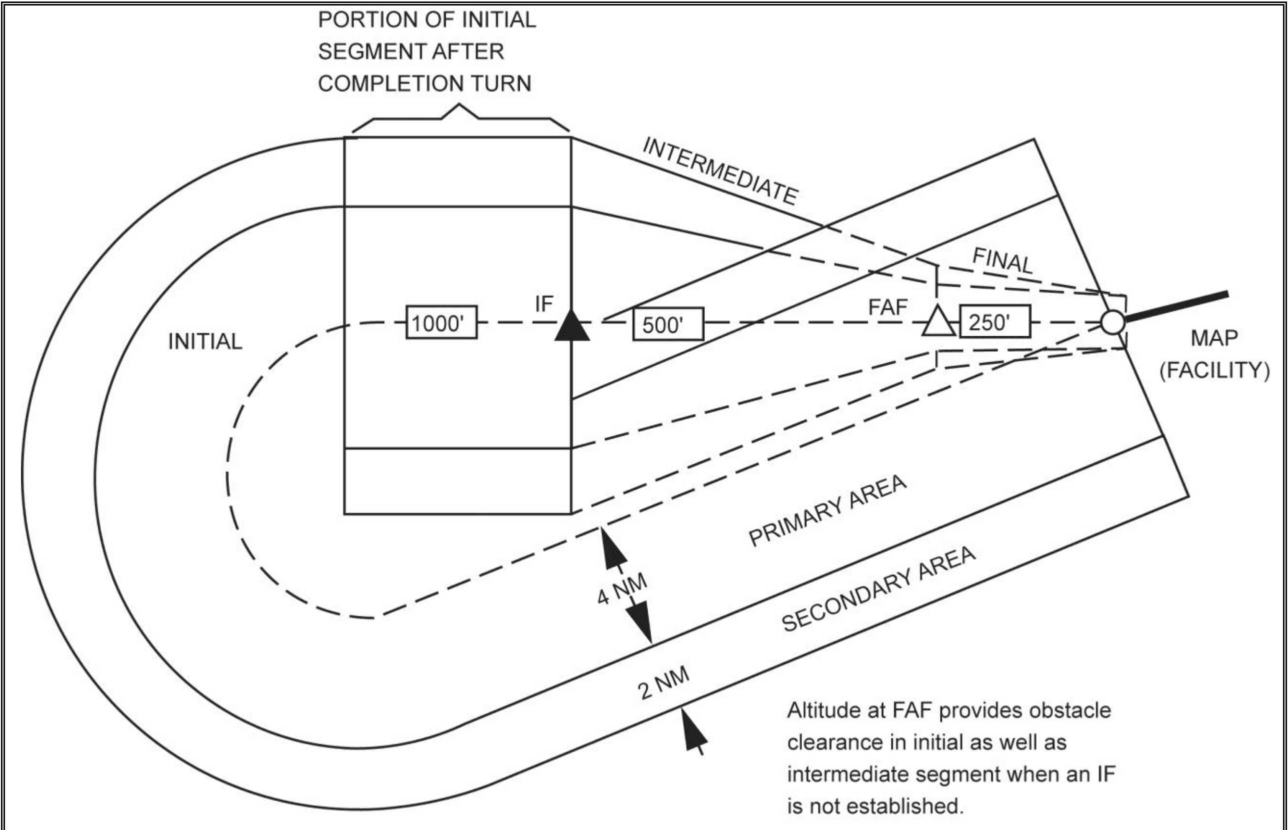


Figure 5-45: Typical High Altitude Segments. VOR with FAF. Para 511 & 512.

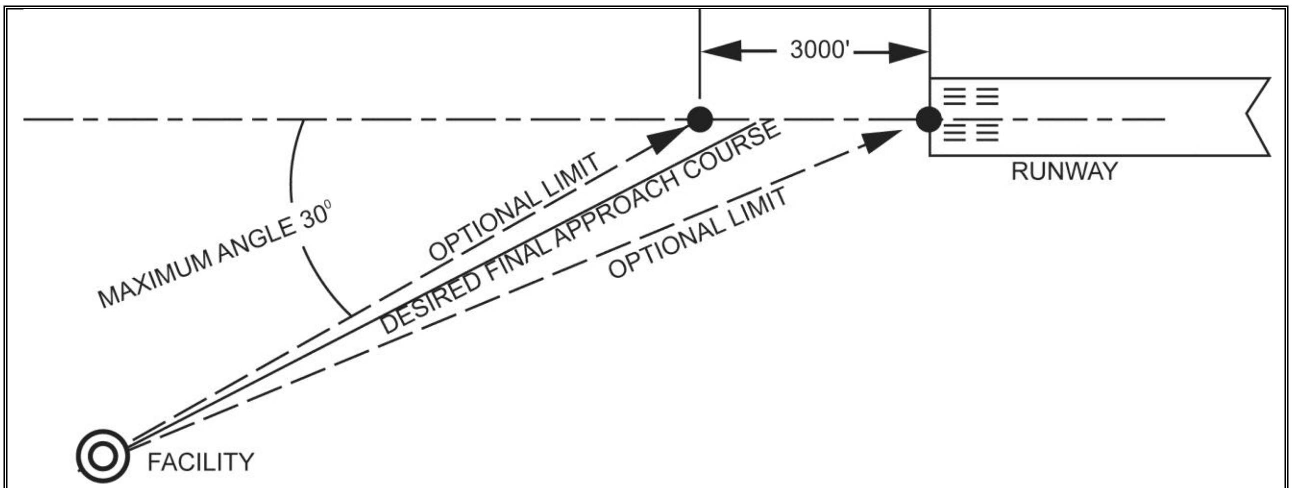


Figure 5-46: Alignment Options For Final Approach Course. Off-airport VOR with FAF. Straight-in approach. Off-airport Para 513.1.(1)(a).

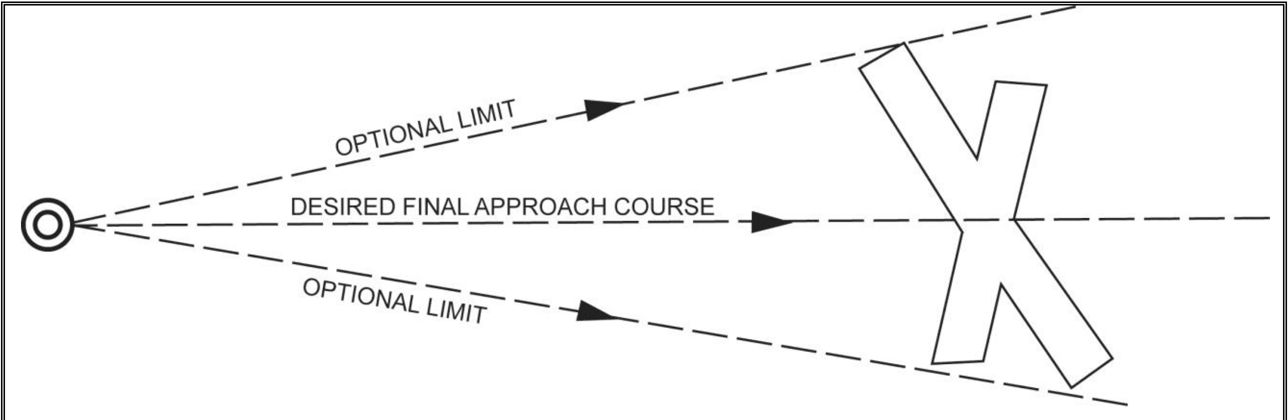


Figure 5-47: Alignment Options For Final Approach Course. Off-airport VOR with FAF. Circling Approach. Para 513.a.(1)(b).

Tables 5–1 TO 5–13: Reserved

Approach Category	Magnitude of Turn over the Facility (Degrees)		
	10°	20°	30°
A	1.0	1.5	2.0
B	1.5	2.0	2.5
C	2.0	2.5	3.0
D	2.5	3.0	3.5
E	3.0	3.5	4.0

Note: This table may be interpolated. If turns of more than 30° are required, or if the minimum lengths specified in the table are not available, straight-in minima are not authorized. See Figure 5-51 for typical straight-in final approach areas.

Table 5-14: Minimum Length Of Final Approach Segment - VOR (NM). Para 513.b.

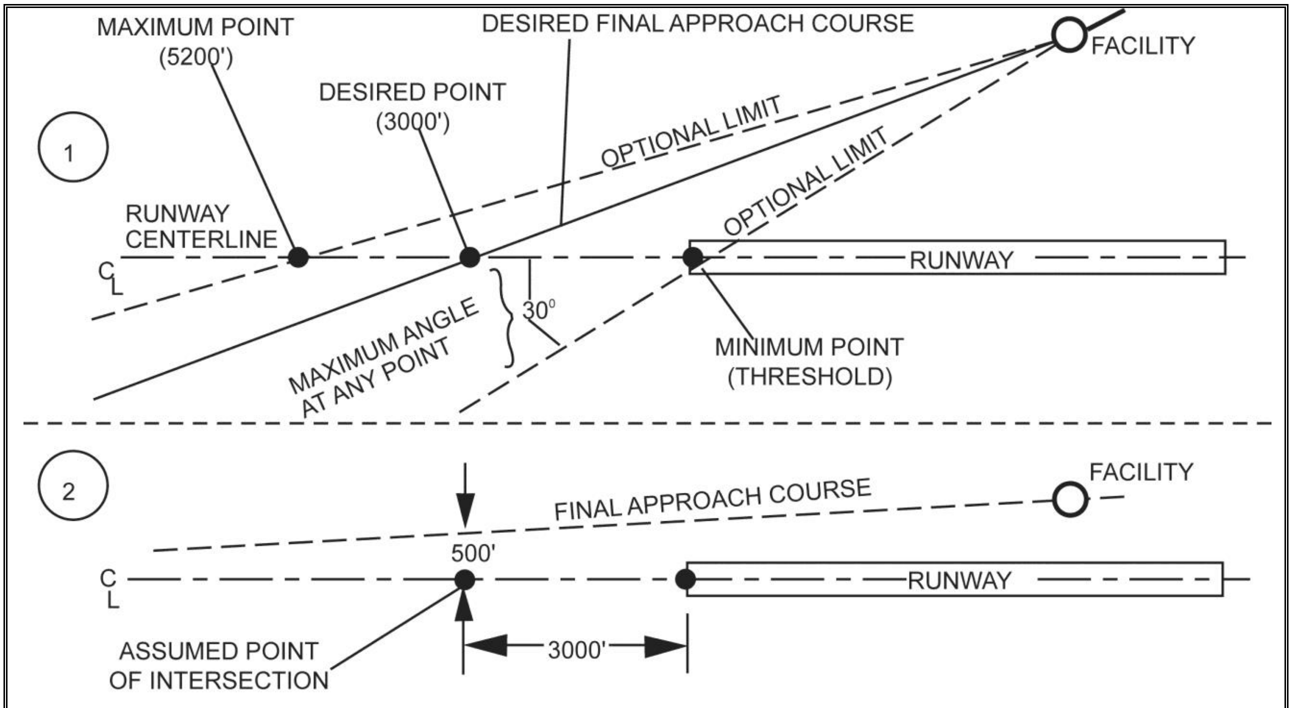


Figure 5-48: Alignment Options For Final Approach Course. On-Airport VOR, with FAF, Straight-In Approach Procedure. Para 513.a.(2)(a).

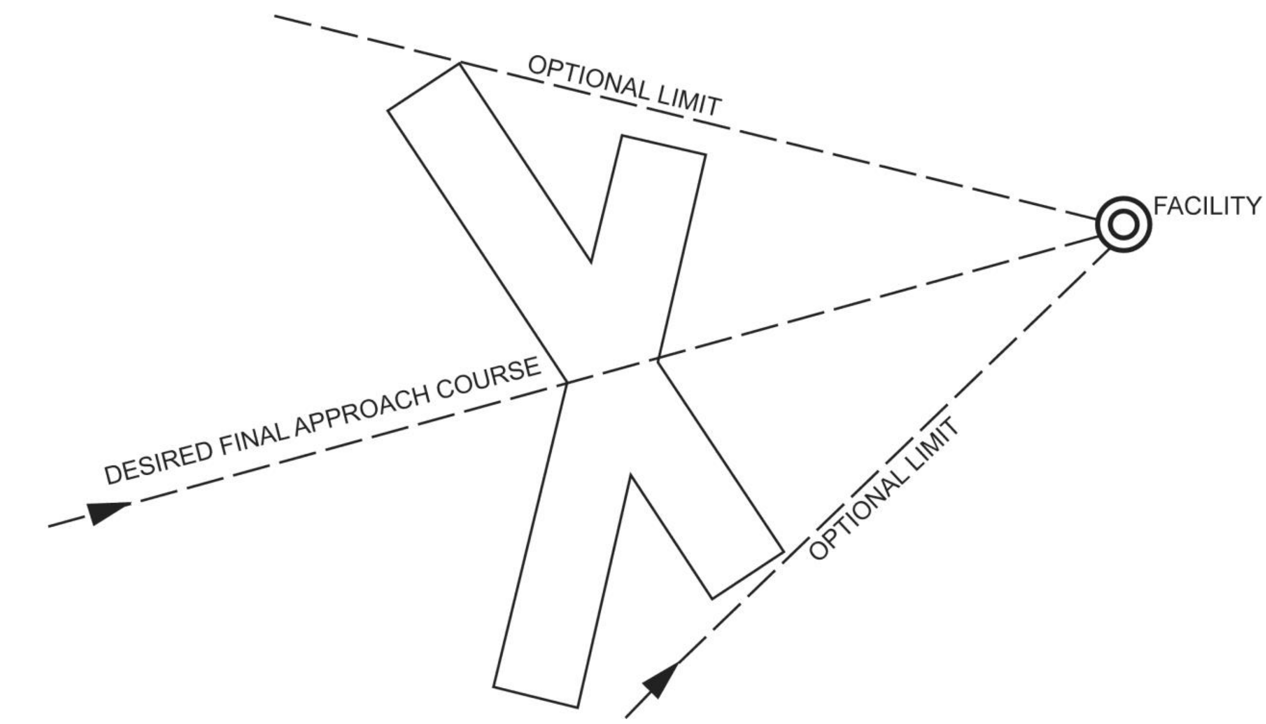


Figure 5-49: Alignment Options For Final Approach Course. On Airport VOR with FAF, Circling Approach Procedure. Para 513.a.(2)(b).

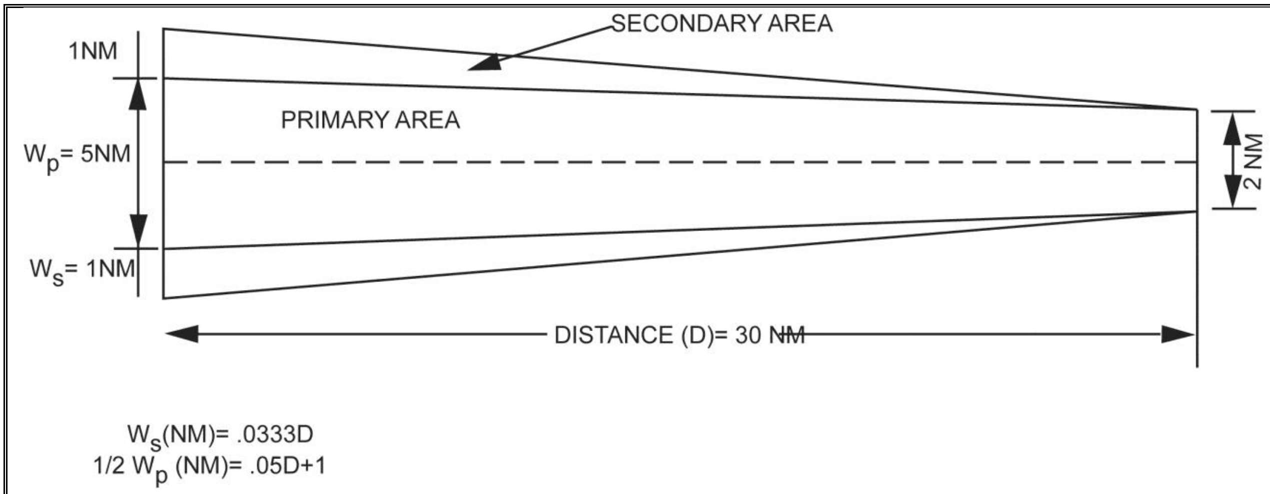


Figure 5-50: Final Approach Trapezoid. VOR with FAF. Para 513.b.

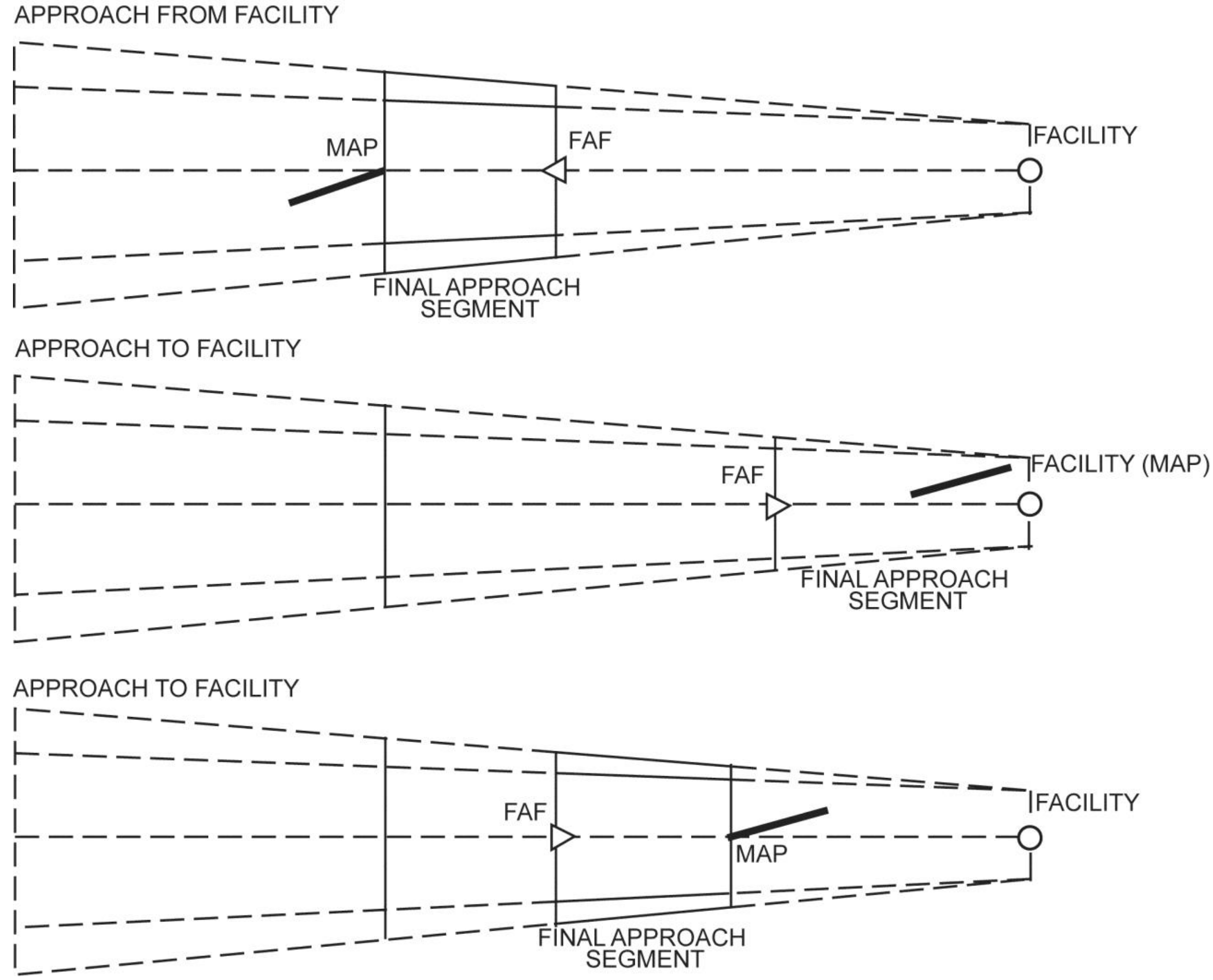
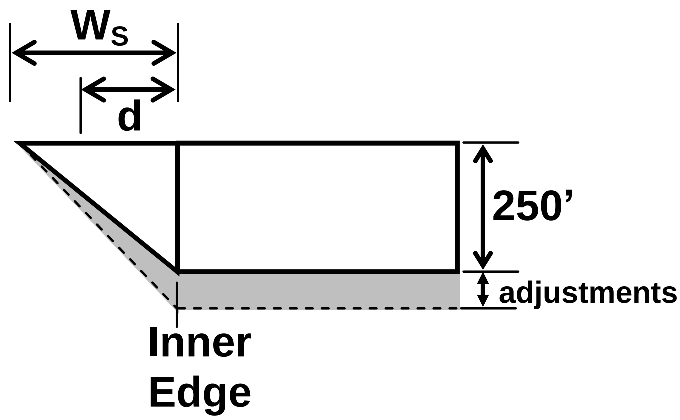


Figure 5-51: Typical Straight -In Final Approach. VOR with FAF. Para 513.b.



Secondary ROC = $(250 + adj) \times \frac{(W_S - d)}{W_S}$

Where: d = distance from inner edge to obstacle (ft)

W_S = Width of secondary area (ft)

adj = adjustments (ft) as per para 323.

Figure 5- 51a: Minimum Obstacle Clearance. Para 513.c(1).

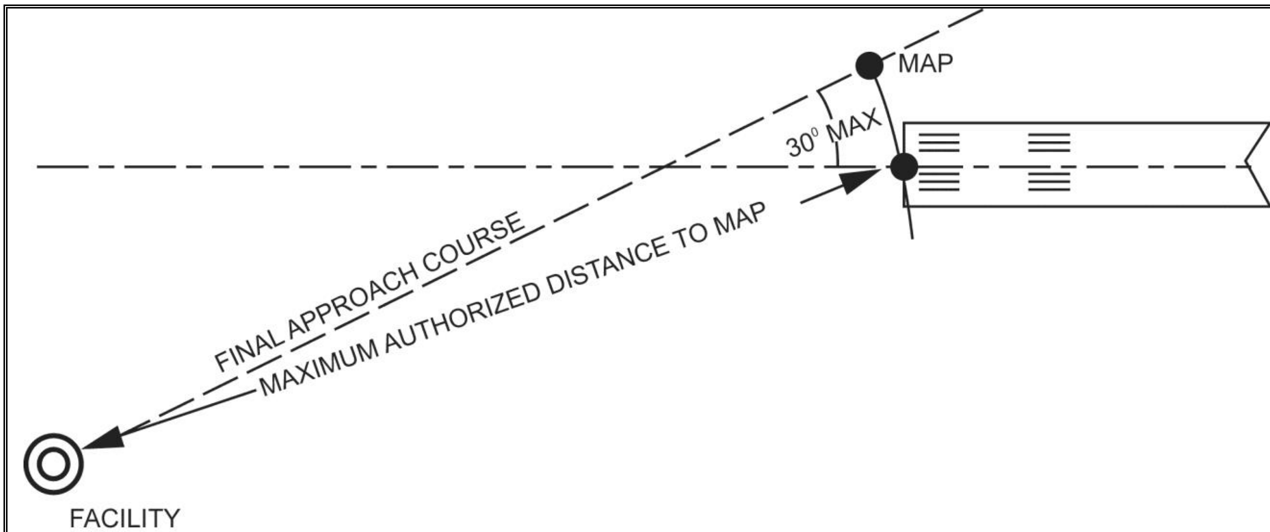


Figure 5-52: Missed Approach Point. Off-Airport VOR with FAF. Para 514.a.(1).

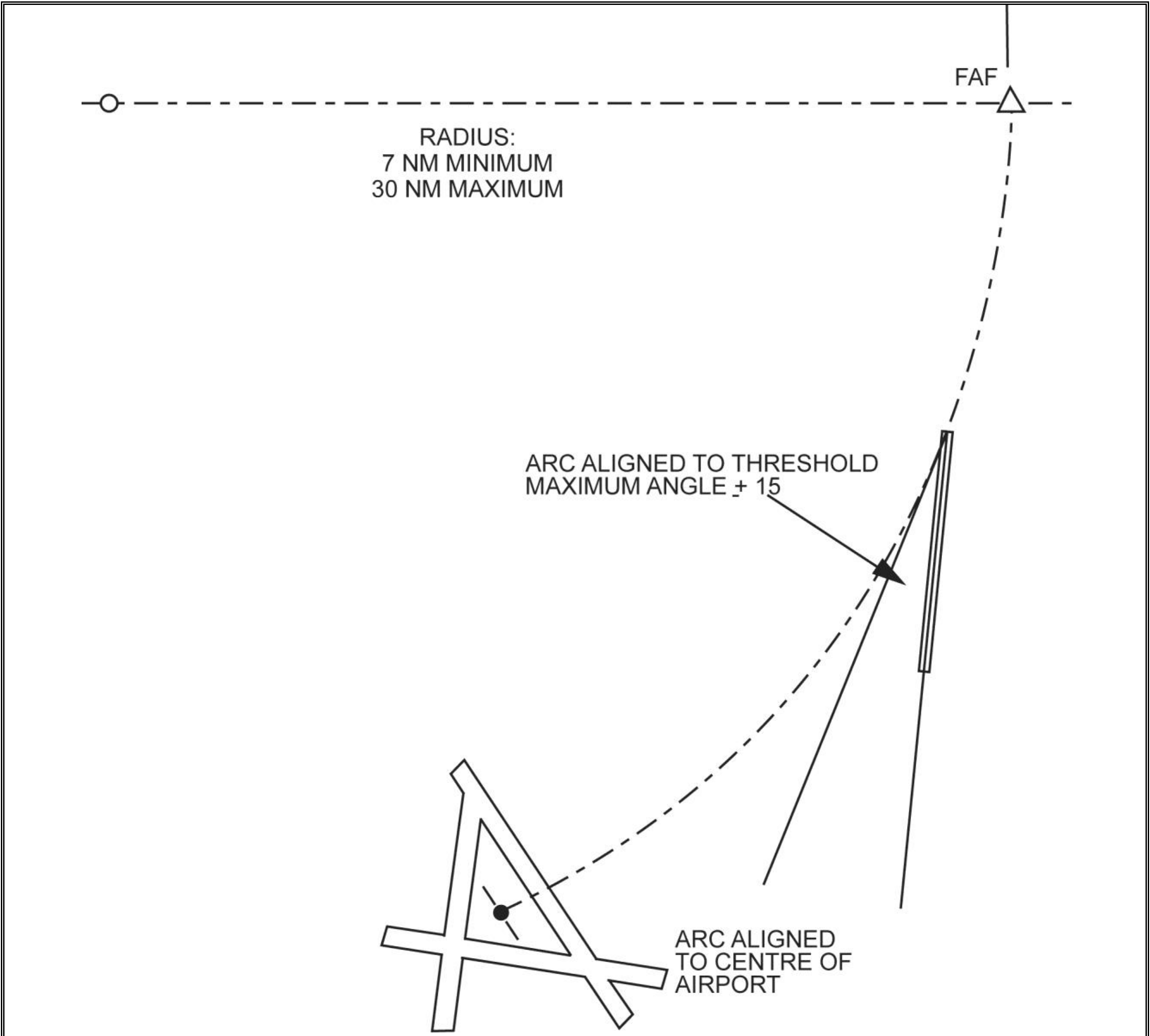


Figure 5-53: Arc Final Approach Alignment. Arc Aligned To Threshold. TACAN or VOR/DME. Para 523.b.(1).

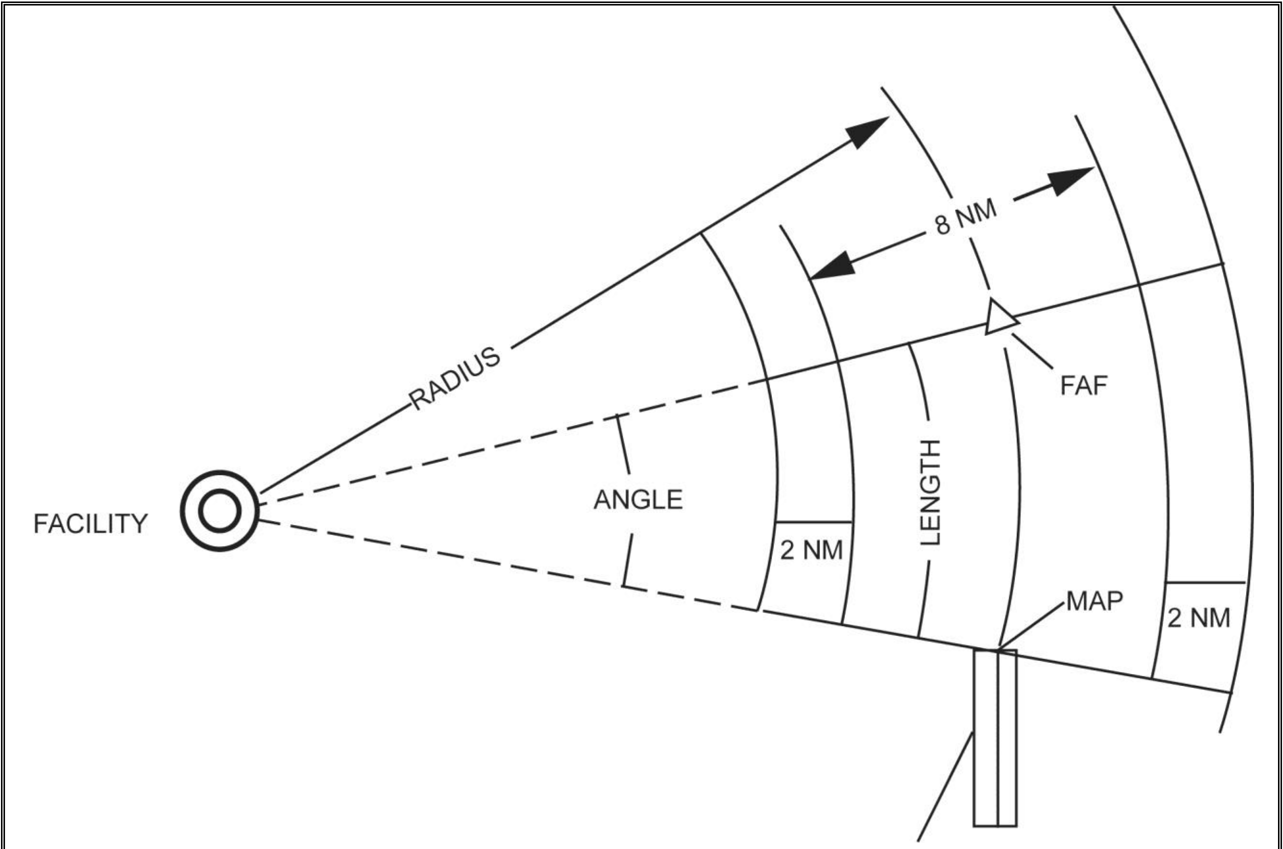
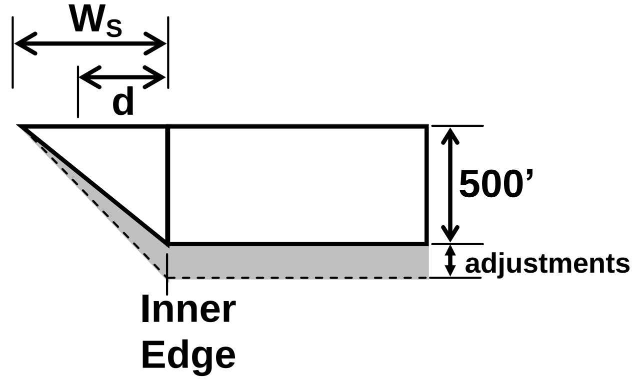


Figure 5-54: Arc Final Approach Area. TACAN or VOR/DME. Para 523.b.(2).



Secondary ROC = $(500 + adj) \times \frac{(W_S - d)}{W_S}$

Where:	d =	distance from inner edge to obstacle (ft)
	W_S =	Width of secondary area (ft)
	adj =	adjustments (ft) as per para 323.

Figure 5- 54a: Minimum Obstacle Clearance. Para 523.b(3).

CHAPTER 6. NDB PROCEDURES ON-AIRPORT FACILITY, NO FAF

600. General

This chapter is divided into two sections: one for low altitude procedures and one for high altitude teardrop penetration procedures. These criteria apply to NDB procedures based on a facility located on the airport in which no final approach fix is established. These procedures must incorporate a procedure turn or a penetration turn. An on-airport facility is one that is located:

a. For Straight-in Approach. Within 1 mile of any portion of the landing runway.

b. For Circling Approach. Within 1 mile of any portion of the usable landing surface on the airport.

601—609. Reserved

SECTION 1. LOW ALTITUDE PROCEDURES

610. Feeder Routes

Criteria for feeder routes are contained in Para 220.

611. Initial Approach Segment

The initial approach fix is received by overheading the navigation facility. The initial approach is a procedure turn. Criteria for the procedure turn areas are contained in Para 234.

612. Intermediate Approach Segment

This type of procedure has no intermediate segment. Upon completion of the procedure turn the aircraft is on final approach.

613. Final Approach Segment

The final approach begins where the procedure turn intersects the final approach course.

a. Alignment. The alignment of the final approach course with the runway centreline determines whether a straight-in or circling-only approach may be established.

(1) Straight-in. The angle of convergence of the final approach course and the extended runway centreline shall not exceed 30 degrees. The final approach course should be aligned to intersect the extended runway centreline 3,000 feet outward from the runway threshold. When an operational advantage can be achieved, this point of intersection may be established at any point between the runway threshold and a point 5,200 feet outward from the runway threshold. Also, where an operational advantage can be achieved a final approach course which does not intersect the runway centreline, or intersects it at a distance greater than 5,200 feet from the threshold, may be established provided that such course lies within 500 feet laterally of the extended runway centreline at a point 3,000 feet outward from the runway threshold. Straight-in category C, D, and E minimums are not authorized when the final approach course intersects the extended runway centerline at an angle greater than 15° and a distance less than 3,000 feet. (See Figure 6-55.)

(2) Circling Approach. When the final approach course alignment does not meet the criteria for straight-in landing, only a circling approach shall be authorized, and the course alignment should be made to the centre of the landing area. When an operational advantage can be achieved, the final approach course may be aligned to pass through any portion of the usable landing surface. (See Figure 6-56.)

b. Area. Figure 6-57 illustrates the final approach primary and secondary areas. The primary area is longitudinally centred on the final approach course, and is 10 miles long. The primary area is 2.5 miles wide at the facility, and expands uniformly to 6 miles wide at 10 miles from the facility. A secondary area is on each side of the primary area. It is zero miles wide at the facility, and expands uniformly to 1.34 miles on each side of the primary area at 10 miles from the facility. When the 5-mile procedure turn is used, only the inner 5 miles of the final approach area need be considered.

c. Obstacle Clearance.

(1) Straight-in. The minimum obstacle clearance in the primary area is 350 feet. In the secondary area, 350 feet of obstacle clearance shall be provided at the inner edge, tapering uniformly to zero feet at the outer edge. To determine ROC in the secondary area, see Figure 6-57a.

(2) Circling Approach. In addition to the minimum requirements specified in Para 613.c.(1), obstacle clearance in the circling area shall be as prescribed in Chapter 2, Section 6.

d. Procedure Turn Altitude (Descent Gradient). The procedure turn completion altitude shall be within 1,500 feet of the MDA (1,000 feet with a 5-mile procedure turn), provided the distance from the facility to the point where the final approach course intersects the runway centreline (or the first usable portion of the landing area for "circling only" procedures) does not exceed 2 miles. When this distance exceeds 2 miles, the maximum difference between the procedure turn completion altitude and the MDA shall be reduced at the rate of 25 feet for each one-tenth of a mile in excess of 2 miles. (see Figure 6-58.)

Note: For those procedures in which the final approach course does not intersect the extended runway centreline within 5,200 feet of the runway threshold (Para 613.a.(1)), the assumed point of intersection for computing distance from the facility shall be 3,000 feet from the runway threshold. (See Figure 6-55.)

e. Use of Step-down Fix. Use of the step-down fix (Para 288.c) is permitted provided the distance from the facility to the step-down fix does not exceed 4 miles. The descent gradient between PT completion altitude and stepdown fix altitude shall not exceed 150 ft/NM. The descent gradient will be computed based upon the difference in PT completion altitude minus stepdown fix altitude, divided by the specified PT distance, minus the facility to stepdown fix distance. Obstacle clearance may be reduced to 300 feet from the stepdown fix to the MAP/FEP (see Figure 6-59, and Paras 251, 252, and 253).

f. Minimum Descent Altitude. Criteria for determining the MDA are contained in Chapter 3, Section 2.

614. Missed Approach Segment

Criteria for the missed approach segment are contained in Chapter 2, Section 7. The missed approach point is the facility. (see Figure 6-59. The missed approach surface shall commence over the facility at the required height. (See Para 274.)

615—619. Reserved

SECTION 2. HIGH ALTITUDE TEARDROP PENETRATIONS

620. Feeder Routes

Criteria for feeder routes are contained in Para 220.

621. Initial Approach Segment

The initial approach fix is received by overheading the navigation facility. The initial approach is a teardrop penetration turn. The criteria for the penetration turn are contained in Para 235.

622. Intermediate Approach Segment

The procedure has no intermediate segment. Upon completion of the penetration turn, the aircraft is on final approach.

623. Final Approach Segment

An aircraft is considered to be on final approach upon completion of the penetration turn. However, the final approach segment begins on the final approach course 10 miles from the facility. That portion of the penetration procedure prior to the 10-mile point is treated as the initial approach segment. (see Figure 6-60.)

a. **Alignment**. Same as low altitude criteria. (See Para 613.a.)

b. **Area**. Figure 6-60 illustrates the final approach primary and secondary areas. The primary area is longitudinally centred on the final approach course, and is 10 miles long. The primary area is 2.5 miles wide at the facility, and expands uniformly to 8 miles at 10 miles from the facility. A secondary area is on each side of the primary area. It is zero miles wide at the facility and expands uniformly to 2 miles each side of the primary area at 10 miles from the facility.

c. **Obstacle Clearance**.

(1) Straight-in. The minimum obstacle clearance in the primary area is 500 feet. In the secondary area, 500 feet of obstacle clearance shall be provided at the inner edge, tapering to zero feet at the outer edge. The minimum required obstacle clearance at any given point in the secondary area is shown in Annex C, Figure C–3.

(2) Circling Approach. In addition to the minimum requirements specified in Para 623.c.(1), obstacle clearance in the circling area shall be as prescribed in Chapter 2, Section 6.

d. **Penetration Turn Altitude** (Descent Gradient). The penetration turn completion altitude shall be at least 1,000 feet, but not more than 4,000 feet above the MDA on final approach.

e. **Use of a Step-down Fix**. Use of a step-down fix (see Para 288.c) is permitted, provided the distance from the facility to the step-down fix does not exceed 10 miles.

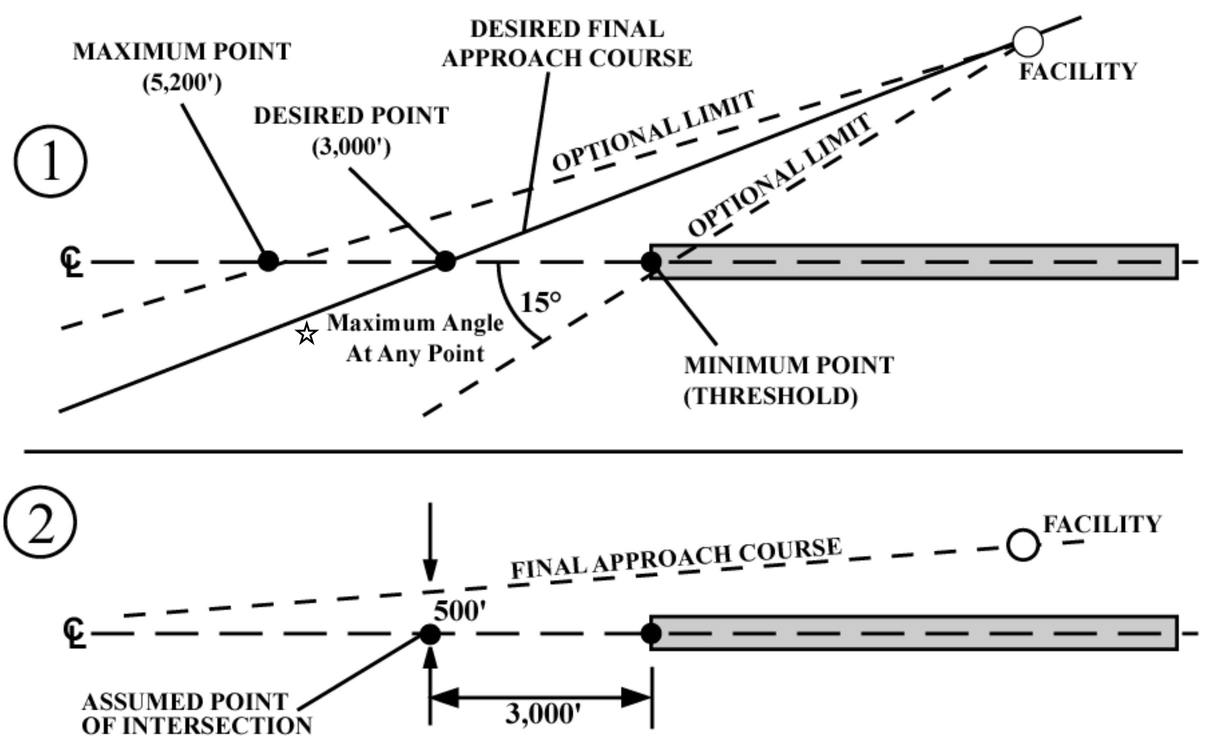
f. **Minimum Descent Altitude**. In addition to the normal obstacle clearance requirements of the final approach segment (see Para 623.c), the MDA specified shall provide at least 1000 feet of clearance over obstacles in that portion of the initial approach segment between the final approach segment and the point where the assumed penetration turn track intercepts the inbound course. (See Figure 6-60.)

624. Missed Approach Segment

Criteria for the missed approach segment are contained in Chapter 2, Section 7. The missed approach point is the facility. (See Figure 6-60.) The missed approach surface shall commence over the facility at the required height. (See Para 274.)

625—699. Reserved

Figure 6-1 TO 6-54: Reserved



☆**Supplementary Note:** In diagram (1), the "Maximum Angle At Any Point" for CAT A & B is 30 degrees, and for CAT C, D & E is 15 degrees (Para 613.a.)

Figure 6-55: Alignment Options For Final Approach Course. On-Airport NDB, No FAF, Straight-In Procedure. Para 613.a.(1).

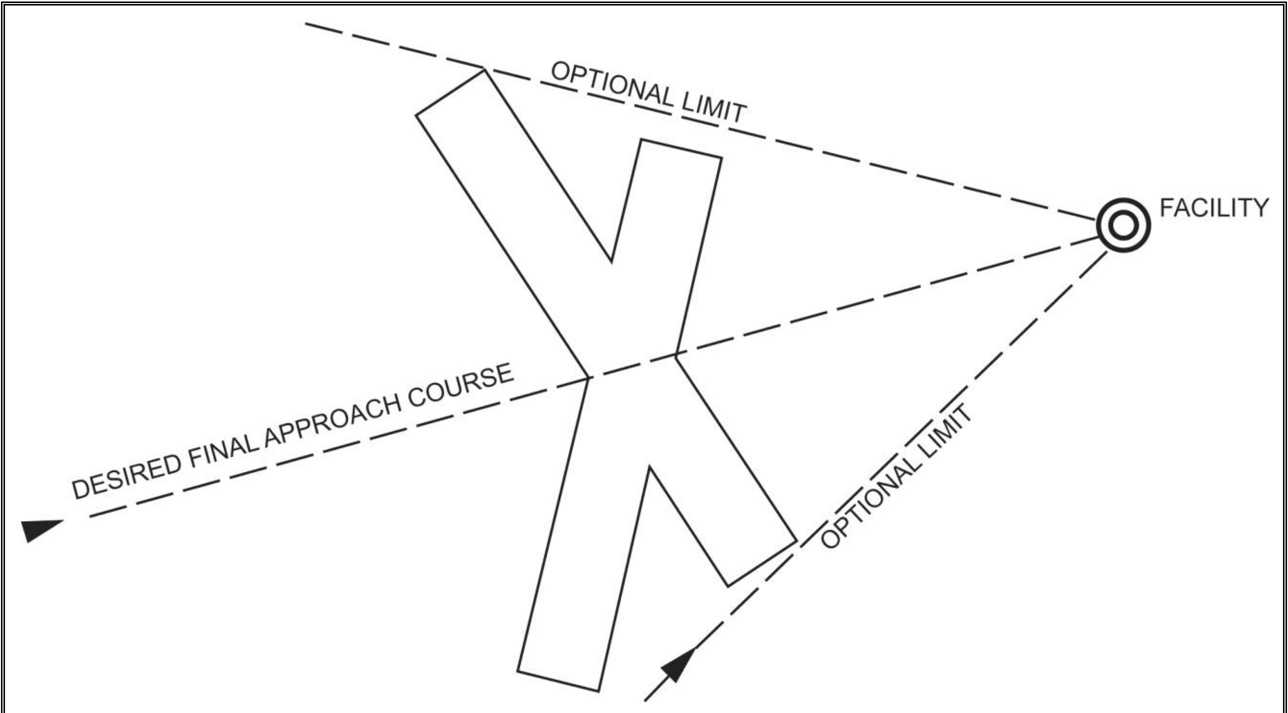


Figure 6-56: Alignment Options For Final Approach Course. On Airport NDB, No FAF, Circling Approach. Para 613.a.(2)

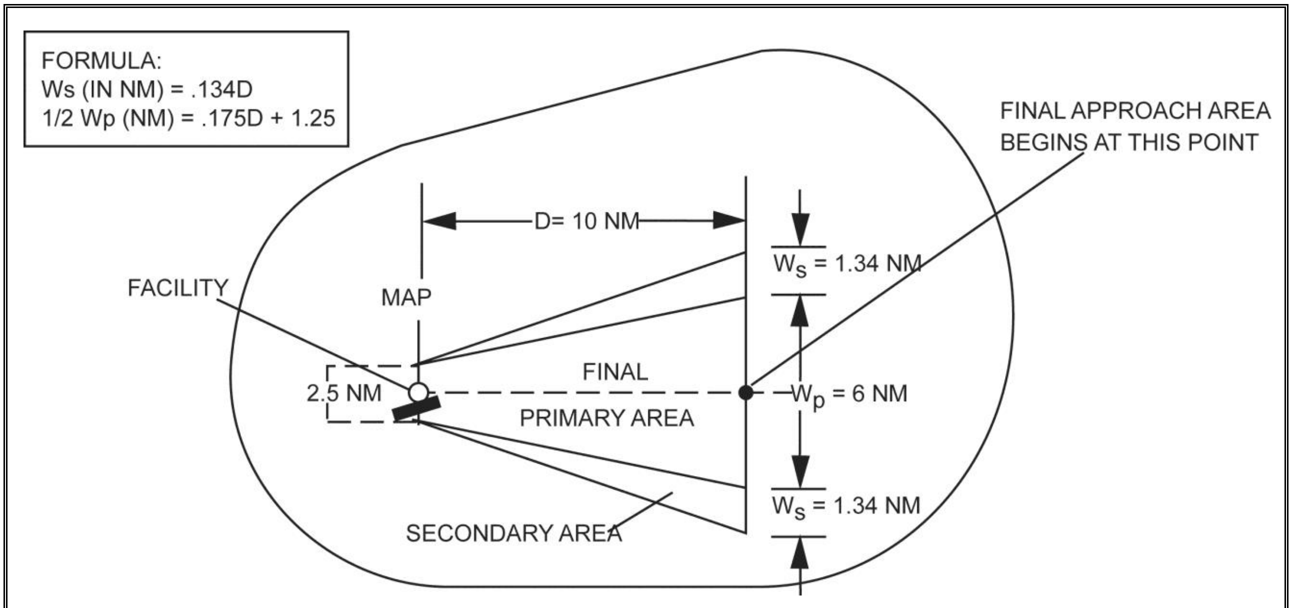
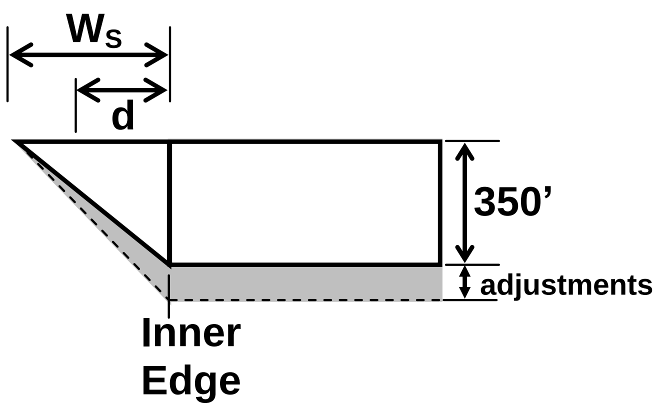


Figure 6-57: Final Approach Primary And Secondary Areas. On-Airport NDB, No FAF. Para 613.b.



Secondary ROC $= (350 + adj) \times \frac{(W_S - d)}{W_S}$

Where: d = distance from inner edge to obstacle (ft)

W_S = Width of secondary area (ft)

adj = adjustments (ft) as per para 323.

Figure 6-57a: Secondary ROC. Para 6-13.c.

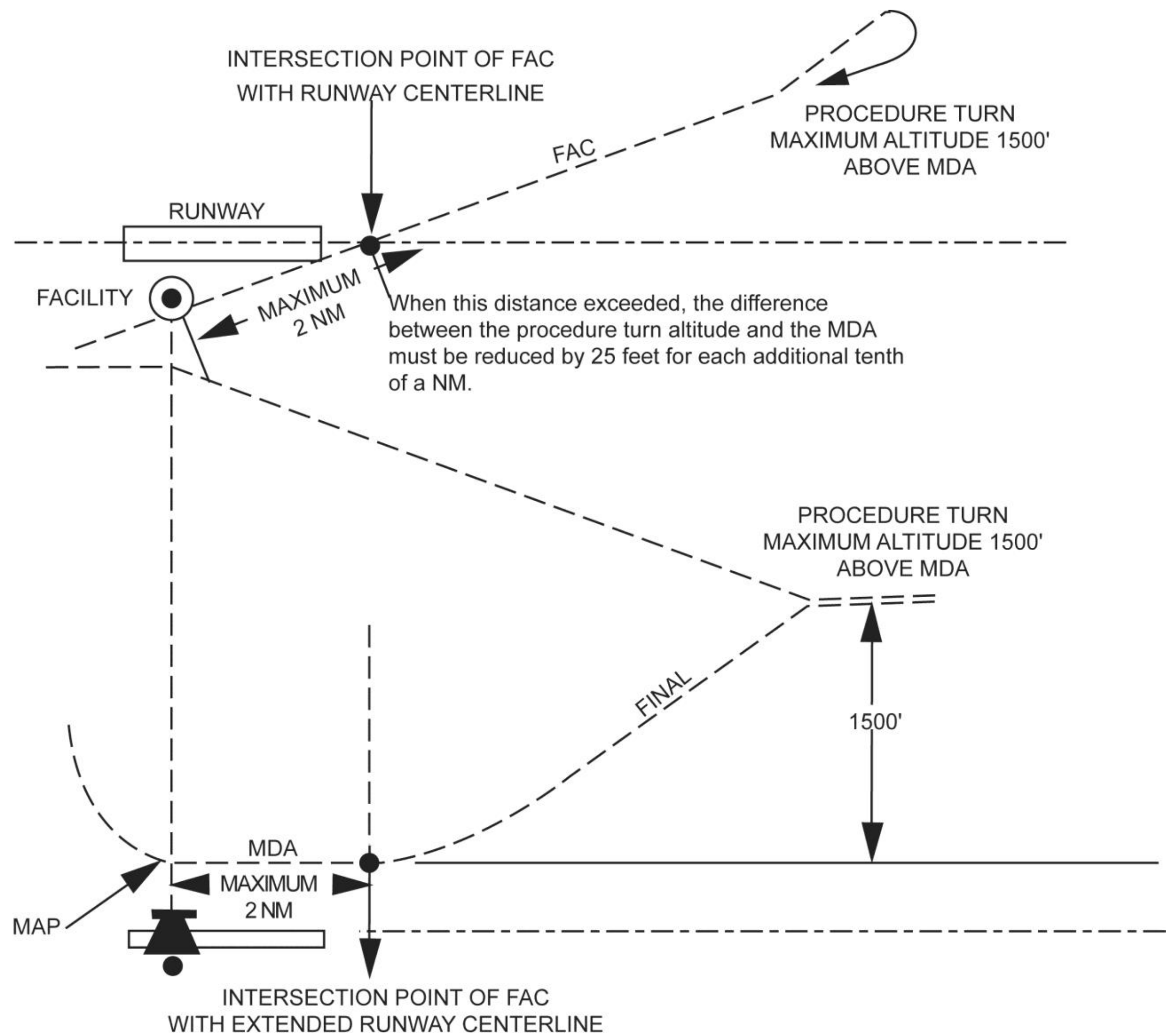


Figure 6-58: Procedure Turn Altitude. On-Airport NDB, No FAF. Para 613.d.

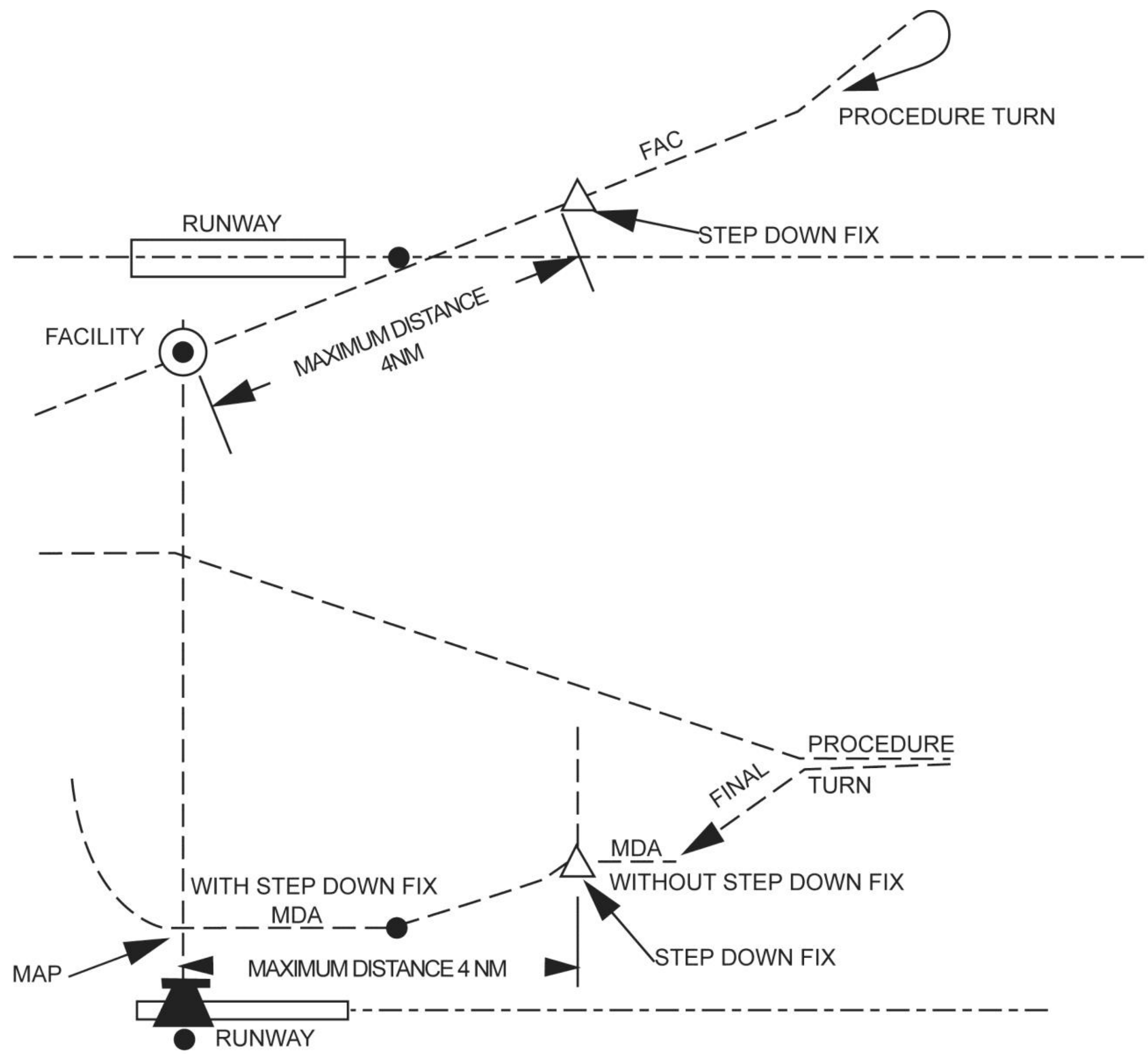


Figure 6-59: Use Of Step-Down Fix. On-Airport NDB, No FAF. Para 613.e.

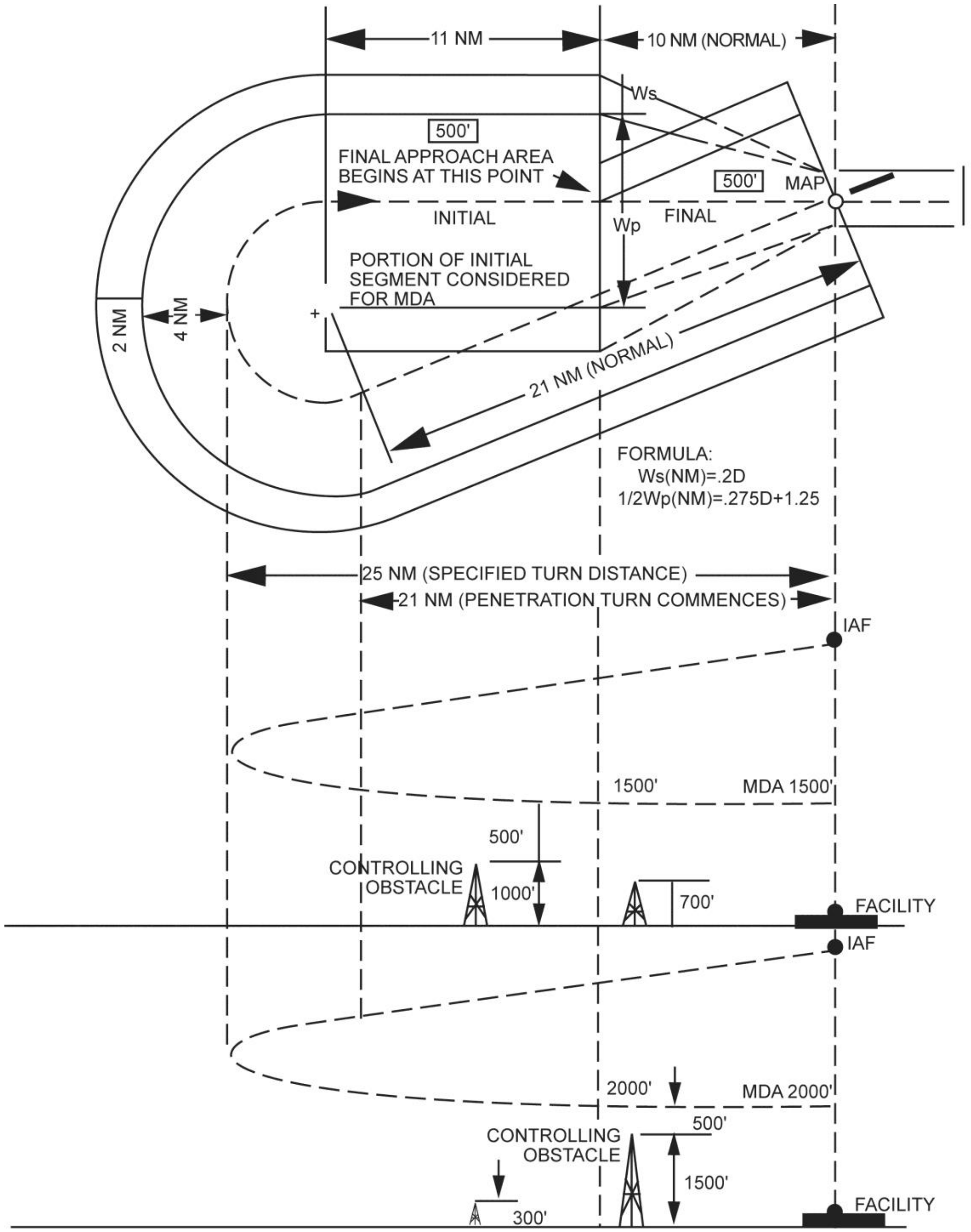


Figure 6-60: Penetration Turn. On Airport VOR, No FAF. Para 623.

CHAPTER 7. NDB WITH FAF

700. General

This chapter prescribes criteria for NDB procedures that incorporate a final approach fix. NDB procedures shall be based only on facilities that transmit a continuous carrier.

701—709. Reserved

SECTION 1. NDB WITH FAF

710. Feeder Routes

Criteria for feeder routes are contained in Para 220.

711. Initial Approach Segment

Criteria for the initial approach are contained in Chapter 2, Section 3.

712. Intermediate Approach Segment

Criteria for the intermediate approach segment are contained in Chapter 2, Section 4.

713. Final Approach Segment

The final approach may be made either FROM or TOWARD the facility. The final approach segment begins at the final approach fix and ends at the runway or missed approach point, whichever is encountered last.

Note: Criteria for the establishment of arc final approaches are specified in Para 523.b.

a. The alignment of the final approach course with the runway centreline determines whether a straight-in or circling-only approach may be established. The alignment criteria differ depending on whether the facility is OFF or ON the airport. See definition in Para 400.

(1) Off-airport Facility.

(a) **Straight-in**. The angle of convergence of the final approach course and the extended runway centreline shall not exceed 30 degrees. The final approach course should be aligned to intersect the runway centreline at the runway threshold. However, when an operational advantage can be achieved, the point of intersection may be established anywhere from the runway threshold to as much as 3,000 feet outward from the runway threshold. (See Figure 7-61.)

(b) **Circling Approach**. When the final approach course alignment does not meet the criteria for straight-in landing, only a circling approach shall be authorized, and the alignment should be made to the centre of the landing area. When an operational advantage can be achieved, the final approach course may be aligned to any portion of the usable landing surface. (See Figure 7-62.)

(2) On-airport Facility.

(a) **Straight-in**. The angle of convergence between the final approach course and the extended runway centreline shall not exceed 30 degrees. The final approach course should be aligned to intersect the extended runway centreline 3,000 feet outward from the runway threshold. When an operational advantage can be achieved, this point of intersection may be established at any point between the runway threshold and a point 5,200 feet outward from the runway threshold. Also, where an operational advantage can be achieved, a final approach course which does not intersect the runway centreline, or which intersects it at a distance greater than 5,200 feet from the threshold, may be established provided such a course lies within 500 feet laterally of the extended runway centreline at a point 3,000 feet outward from the runway threshold (See Figure 7-63).

(b) **Circling Approach**. When the final approach course alignment does not meet the criteria for a straight-in landing, only a circling approach shall be authorized, and the course alignment should be made to the centre of the landing area. When an operational advantage can be achieved, the final approach course may be aligned to any portion of the usable landing surface. (See Figure 7-64).

b. Area. The area considered for obstacle clearance in the final approach segment starts at the final approach fix and ends at the runway or missed approach point, whichever is encountered last. It is a portion of a 15 nautical mile long trapezoid (see Figure 7-65), which is made up of primary and secondary areas. The primary area is centred longitudinally on the final approach course. It is 2.5 nautical miles wide at the facility and expands uniformly to 5 nautical miles at 15 nautical miles from the facility. A secondary area is on each side of the primary area. It is zero miles wide at the facility, and expands uniformly to 1 nautical mile each side of the primary area at 15 nautical miles from the facility. Final approaches may be made to airports which are a maximum of 15 nautical miles from the facility. The **OPTIMUM** length of the final approach segment is 5 nautical miles. The **MAXIMUM** length is 10 nautical miles. The **MINIMUM** length of the final approach segment shall provide adequate distance for an aircraft to make the required descent, and to regain course alignment when a turn is required over the facility. Table 7-15 shall be used to determine the minimum length needed to regain the course.

c. Obstacle Clearance.

(1) **Straight-in**. The minimum obstacle clearance in the primary area is 300 feet. In the secondary area, 300 feet of obstacle clearance shall be provided at the inner edge, tapering uniformly to zero feet at the outer edge (see Figure 6-66a). Allowance for adjustments should be considered as specified in Para 323.

(2) **Circling Approach**. In addition to the minimum requirements specified in Para 713.c.(1), obstacle clearance in the circling area shall be as prescribed in Chapter 2, Section 6.

d. Descent Gradient. Para 252 applies

e. Use of Fixes. Criteria for the use of radio fixes are contained in Chapter 2, Section 8. Where a procedure is based on a procedure turn and an on-airport facility is the procedure turn fix, the distance from the facility to the FAF shall not exceed 4 nautical miles.

f. Minimum Descent Altitude. Criteria for determining the MDA are contained in Chapter 3, Section 2.

714. Missed Approach Segment

Criteria for the missed approach segment are contained in Chapter 2, Section 7. The missed approach point and surface shall be established as follows:

a. Off-airport Facilities.

(1) **Straight-in**. The missed approach point is a point on the final approach course which is not farther from the FAF than the runway threshold. The missed approach surface shall commence over the missed approach point at the required height. (See Para 274 and Figure 7-67.)

(2) **Circling Approach**. The missed approach point is a point on the final approach course which is not farther from the final approach fix than the first usable portion of the landing area. The missed approach surface shall commence over the missed approach point at the required height. (See Para 274.)

b. On-airport Facilities. The missed approach point is a point on the final approach course which is not farther from the final approach fix than the facility. The missed approach surface shall commence over the missed approach point at the required height. (See Para 274.)

715—799. Reserved

Table 7-1 TO 7-14 : Reserved

Approach Category	Magnitude of Turn over Facility		
	10°	20°	30°
A	1.0	1.5	2.0
B	1.5	2.0	2.5
C	2.0	2.5	3.0
D	2.5	3.0	3.5
E	3.0	3.5	4.0

Note: This table may be interpolated. If turns of more than 30° are required, or if the minimum lengths specified in the table are not available, straight-in minima are not authorized. See Figure 7-66 for typical final approach areas.

Table 7-15: Minimum Length Of Final Approach Segment — NDB (NM). Para 713.b.

Figure 7-1 TO 7-60: Reserved

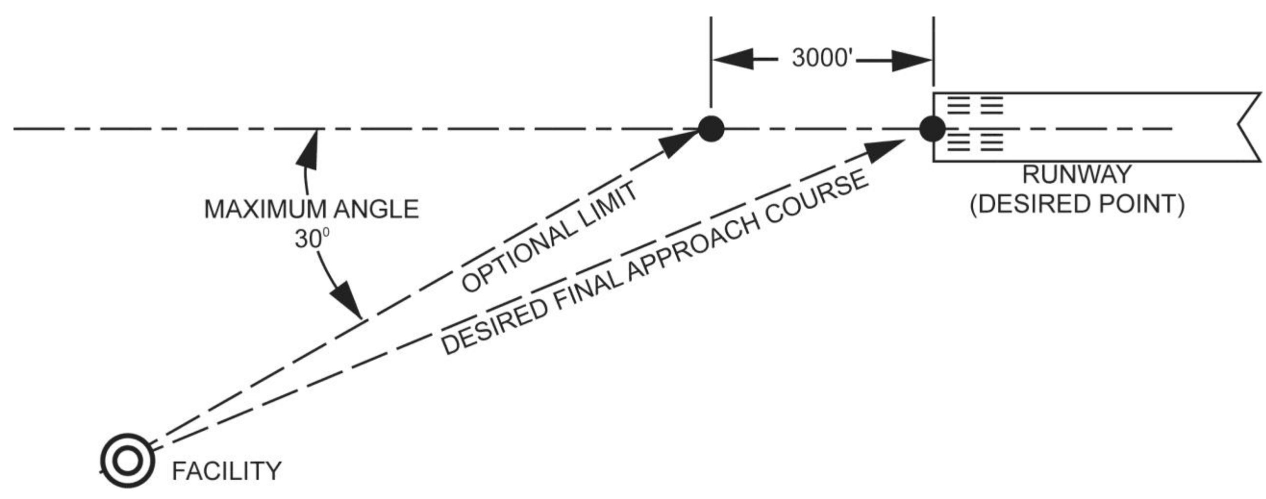


Figure 7-61: Alignment Options For Final Approach Course. Off-Airport NDB with FAF. Straight-In Approach. Para 713.a.(1)(a).

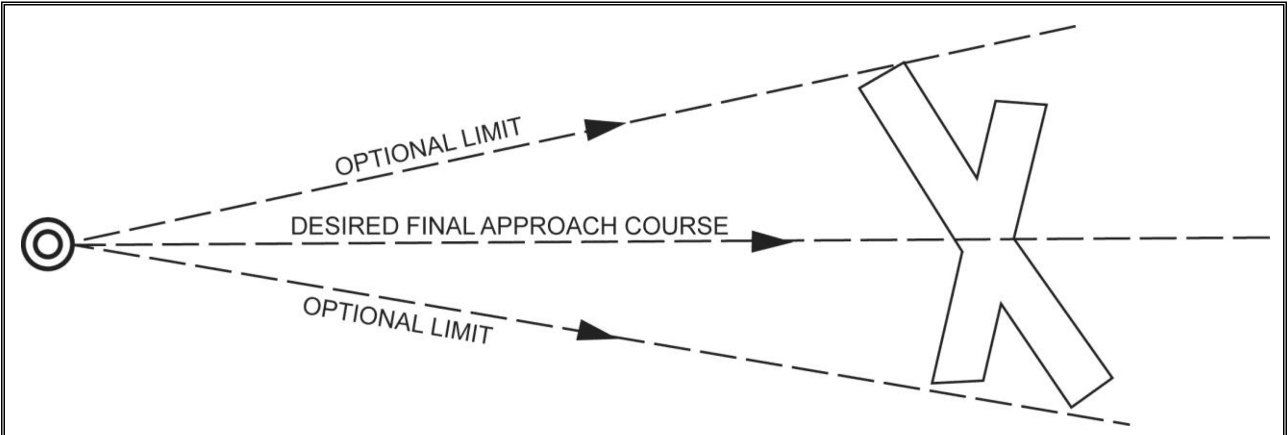


Figure 7-62: Alignment Options For Final Approach Course. Off-Airport NDB with FAF. Circling Approach. Para 713.a.(1)(b).

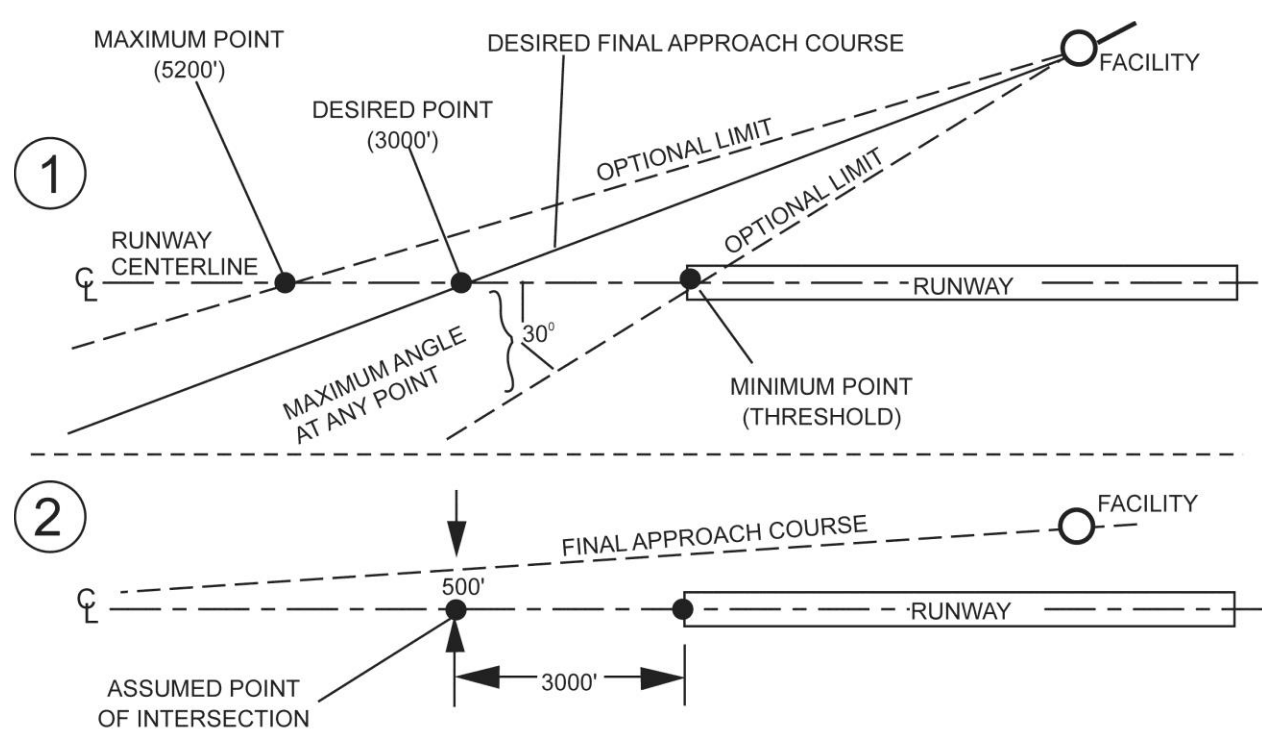


Figure 7-63: Alignment Options For Final Approach Course. On-Airport NDB. Para 713.a.(2)(a).

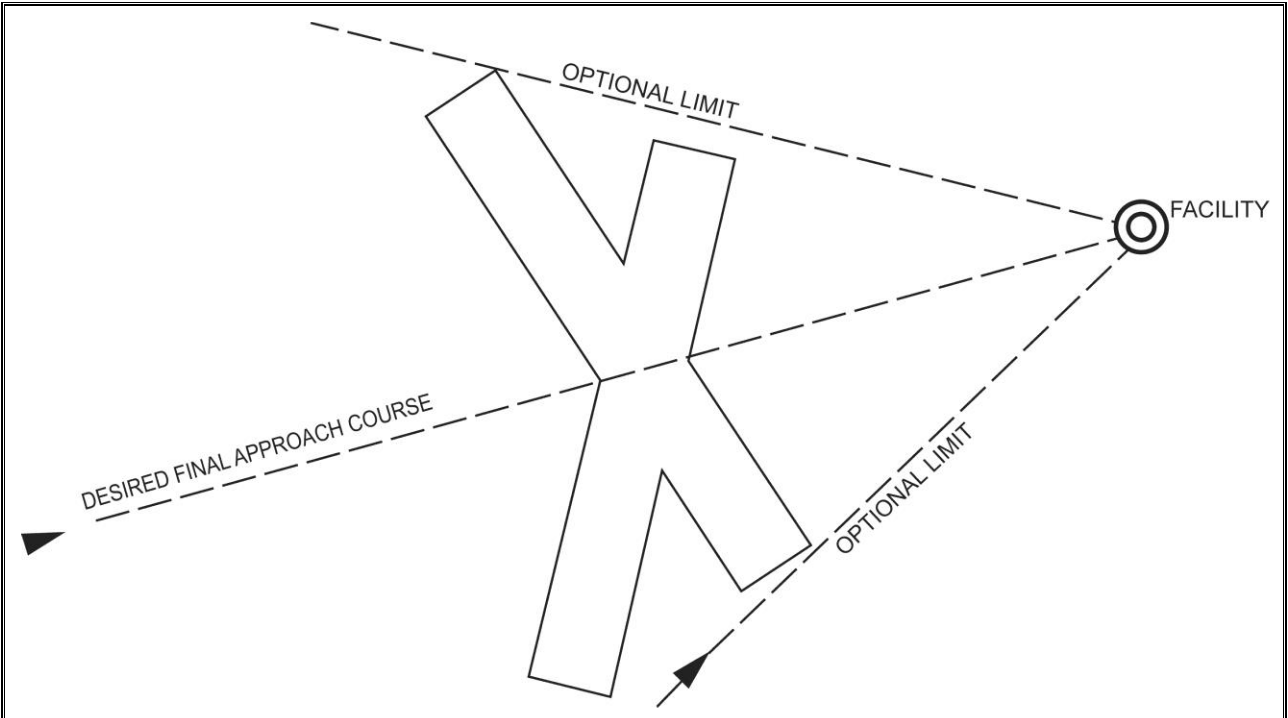


Figure 7-64: Alignment Options For Final Approach Course. On Airport NDB with FAF, Circling Approach. Para 713.a.(2)(b).

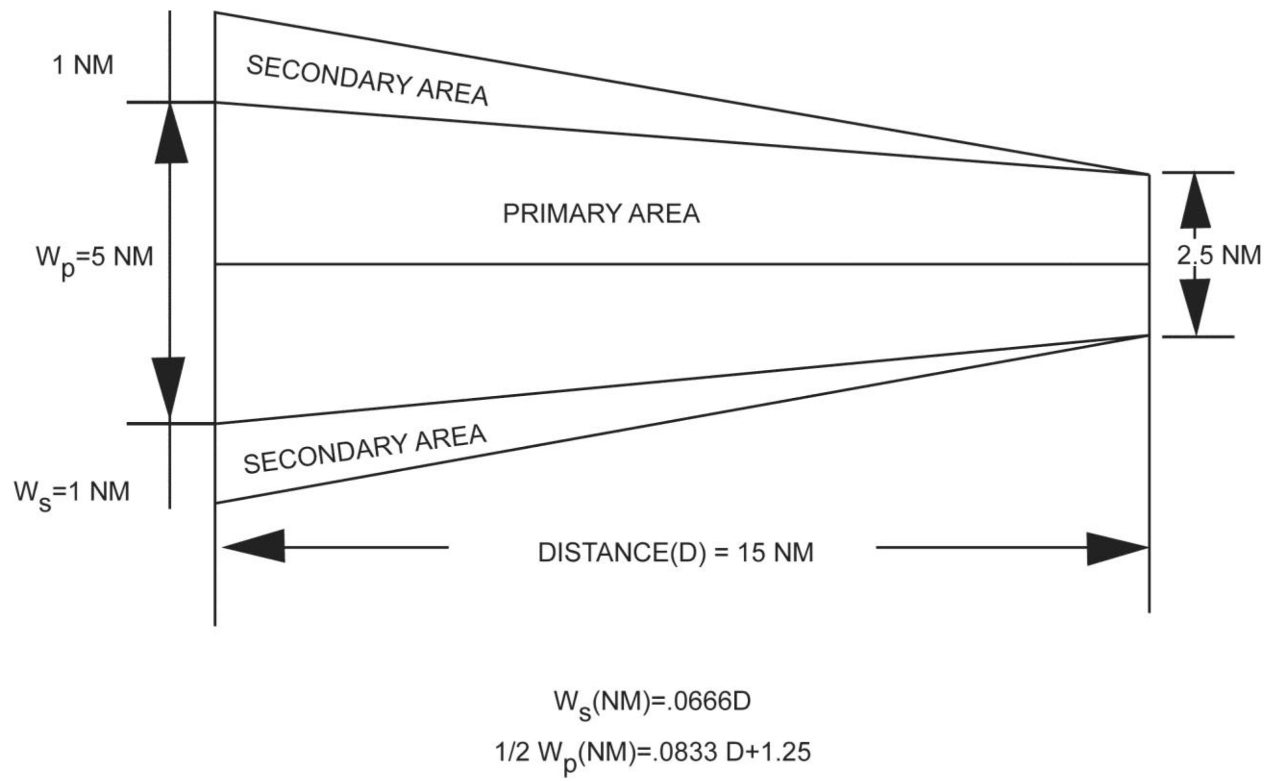
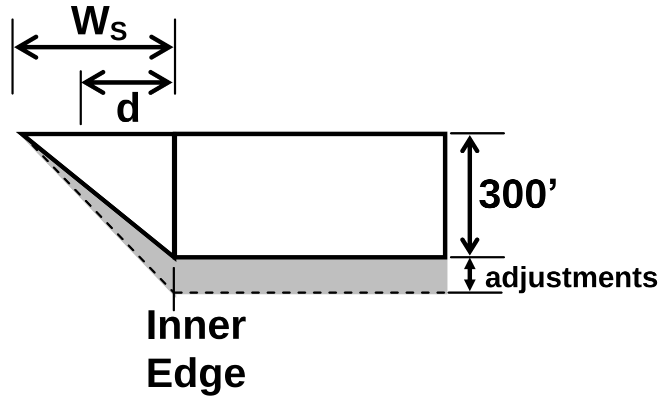


Figure 7-65: Final Approach Trapezoid. NDB with FAF. Para 713.b.



Secondary ROC $=(300 + adj) \times \frac{(W_S - d)}{W_S}$

Where:	d =	distance from inner edge to obstacle (ft)
	W_S =	Width of secondary area (ft)
	adj =	adjustments (ft) as per para 323.

Figure 7-66a: Minimum Obstacle Clearance. Para 713.c.

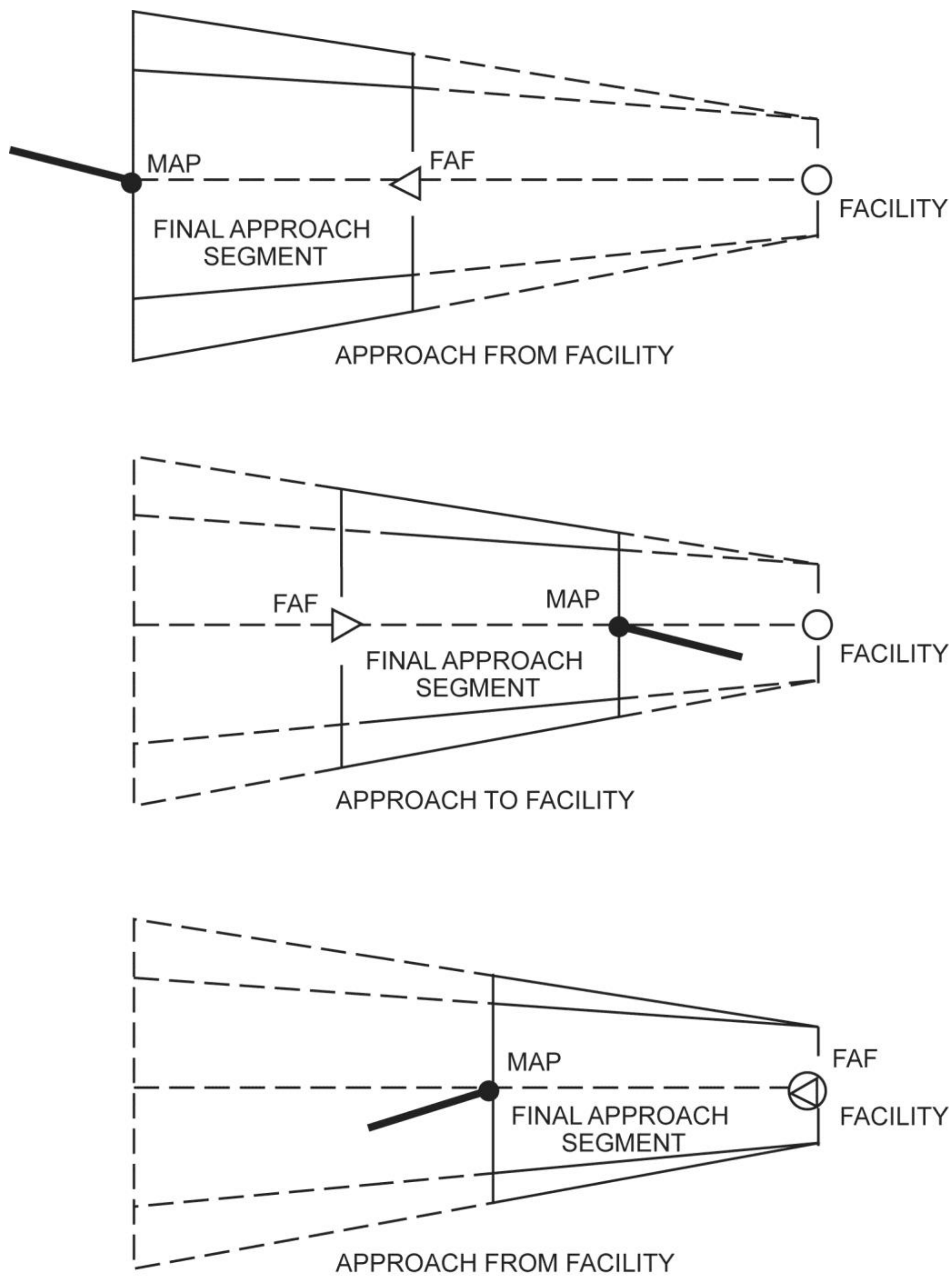


Figure 7-66: Typical Final Approach Areas. NDB with FAF. Para 713.b.

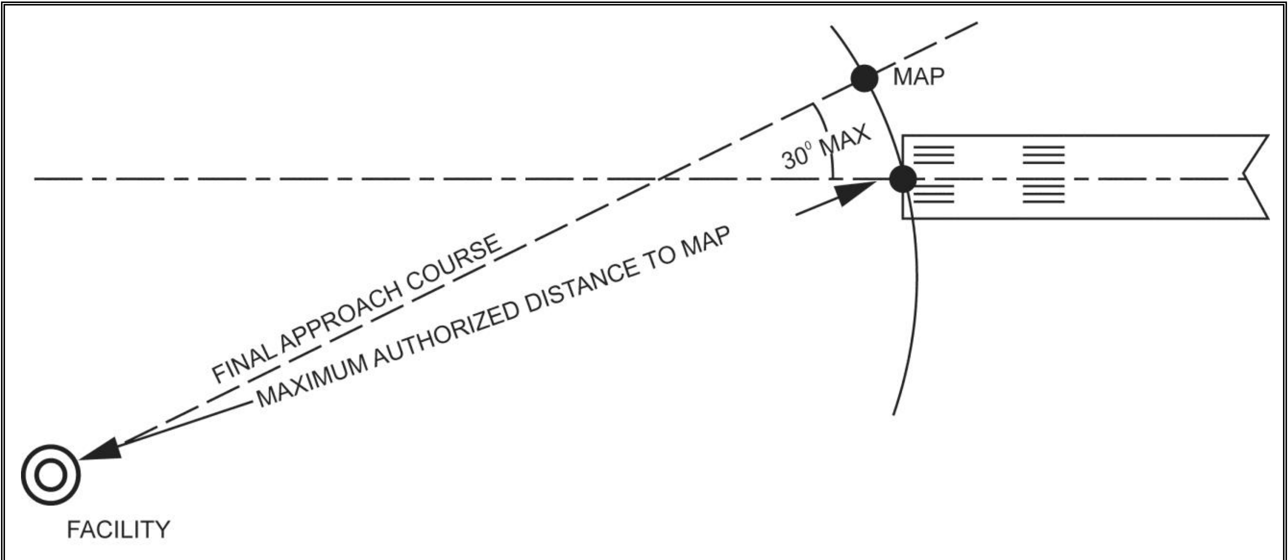


Figure 7-67: Missed Approach Point. Off-Airport NDB with FAF. Para 714.a.(1).

CHAPTER 8. EMERGENCY VHF/UHF DF PROCEDURES

800. General

These criteria apply to Direction Finding (DF) procedures for both high and low altitude aircraft. DF criteria shall be the same as criteria provided for automatic direction finder (ADF) procedures, except as specified herein. As used in this chapter, the word “facility” means the DF antenna site. DF approach procedures are established for use in emergency situations. Detailed operational instructions for Emergency VHF/UHF DF Procedures are contained in Flight Service Station MANOPS 5-10 and 6-70.

801—809. Reserved

SECTION 1. VHF/UHF DF CRITERIA

810. En Route Operations

En route aircraft under DF control follow a course to the DF station as determined by the DF controller. A minimum safe altitude shall be established which provides at least 1,000 feet (1,500 or 2,000 feet in mountainous areas) of clearance over all obstacles within the operational radius of the DF facility. When this altitude proves unduly restrictive, sector altitudes may be established to provide relief from obstacles that are clear of the area where flight is conducted. Where sector altitudes are established, they shall be limited to sectors of not less than 45 degrees in areas BEYOND a 10-mile radius around the facility. For areas WITHIN 10 miles of the facility, sectors of NOT LESS THAN 90 degrees shall be used. Because the flight course may coincide with the sector division line, the sector altitude shall provide at least 1,000 feet (2,000 feet in mountainous terrain) of clearance over obstacles in the adjacent sectors within 6 miles or 20 degrees of the sector division line, whichever is the greater. No sector altitude shall be specified which is lower than the procedure turn altitude or lower than the altitude for area sectors which are closer to the navigation facility.

811. Initial Approach Segment

The initial approach fix is overhead the facility.

a. **Area**. The initial approach is a low altitude triangular procedure illustrated in Figure 8-1. When the triangular procedure is used, final descent is based on a single heading at 500 feet per minute rate of descent. (See Table 8-1 and Figure 8-2.)

Rate of Descent – 500 Feet per Minute									
Aircraft Ground Speed (Knots)	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**Time (Mins)**	**Descent in feet**
Descent (feet per NM)	**500**	**429**	**375**	**330**	**300**	**272**	**250**		
Distance (NM) covered for time flown at estimated compared to descent in feet (Last two columns) **Note: Distances are to nearest tenth of a nautical mile (NM)**	1.0	1.2	1.3	1.5	1.7	1.8	2.0	1	500
	2.0	2.3	2.7	3.0	3.3	3.6	4.0	2	1000
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	3	1500
	4.0	4.6	5.3	6.0	6.6	7.3	8.0	4	2000
	5.0	5.8	6.6	7.5	8.3	9.2	10.0	5	2500
	6.0	7.0	8.0	9.0	10.0	11.0	12.0	6	3000
	7.0	8.1	9.3	10.5	11.7	12.8	14.0	7	3500
	8.0	9.3	10.6	12.0	13.3	14.6	16.0	8	4000
	9.0	10.4	12.0	13.5	15.0	16.5	18.0	9	4500
	10.0	11.6	13.3	15.0	16.7	18.3	20.0	10	5000

Table 8-1: DF Emergency Descent Gradients. Para 811.a.

b. **Obstacle Clearance**. Obstacle clearance in the initial approach primary area shall be a MINIMUM of 1,000 feet. Obstacle clearance at the inner edge of the secondary area shall be 500 feet, tapering to zero feet at the outer edge. The altitudes selected by application of the obstacle clearance specified in this paragraph may be rounded to the nearest 100 feet provided the ROC is not violated. (See Para 231.)

812. Intermediate Approach Segment

Except as outlined in this paragraph, criteria for the intermediate segment are contained in chapter 2, section 4. An intermediate segment is used only when the DF facility is located off the airport, and the final approach is made from overhead the facility to the airport or visual contact area.

a. **Area**. The width of the primary intermediate area is 3.4 nautical miles at the facility expanding uniformly on each side of the course to 8 nautical miles wide 10 nautical miles from the facility. A secondary area is on each side of the primary area. It is zero miles wide at the facility expanding along the primary area to 2 nautical miles each side at 10 nautical miles from the facility. (See Figure 8-3.)

b. Obstacle Clearance. A MINIMUM of 500 feet of obstacle clearance shall be provided in the primary area of the intermediate approach segment. In the secondary area, 500 feet of obstacle clearance shall be provided at the inner edge, tapering to zero feet at the outer edge. The minimum obstacle clearance required at any given point in the secondary area may be determined by using formula specified in Para 523.b. The altitudes selected by application of the obstacle clearance specified in this paragraph shall be rounded to the nearest 100 feet, provided the ROC is not violated. (See Para 241.)

The obstacle clearance is applied to provide clearance until the inbound aircraft is over the facility. Descent through cloud is commenced at a point as determined by the DF controller, using the DF Emergency Descent Gradients (see Table 8-1). The objective is to have the aircraft descend at a constant rate so as to pass over the facility with at least 500 feet obstacle clearance.

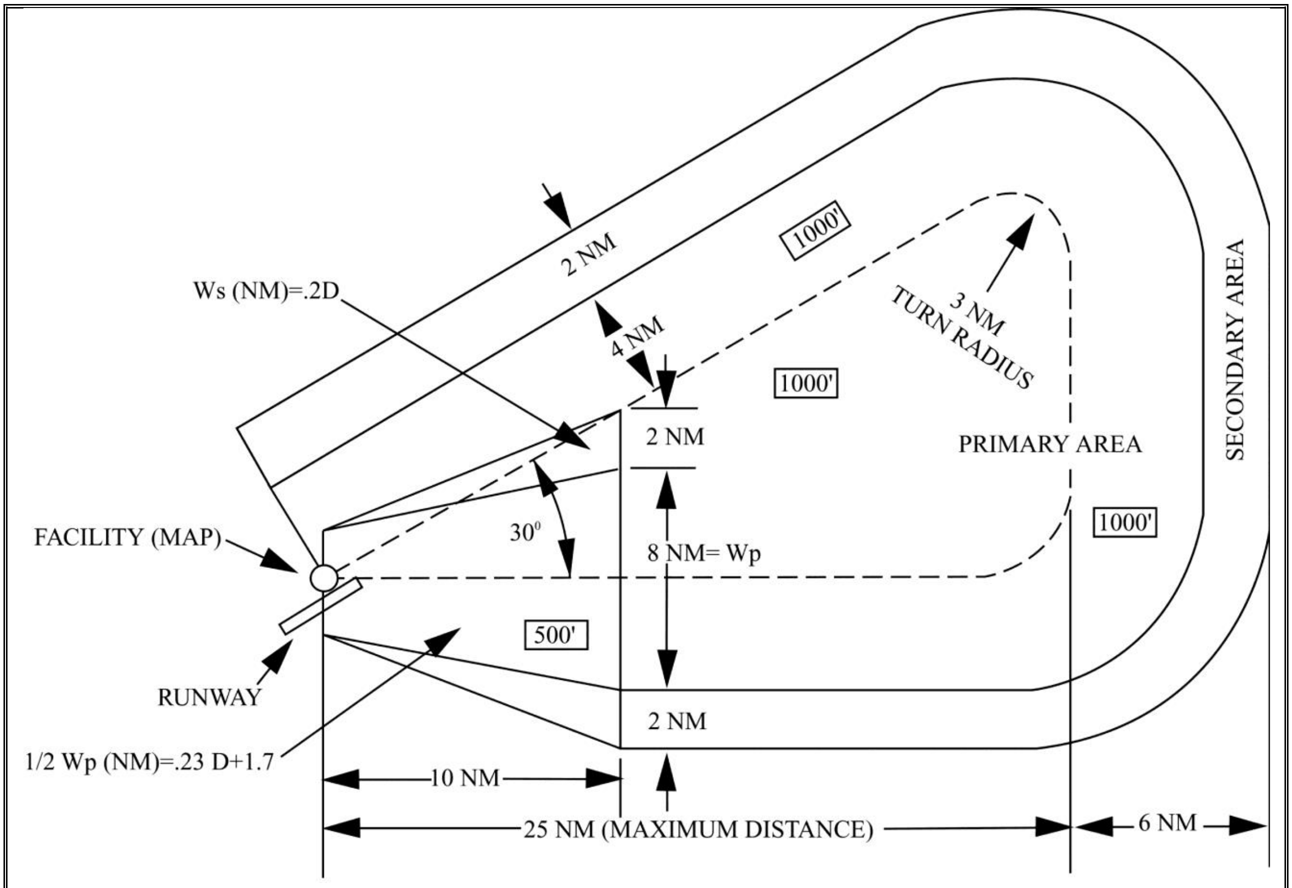


Figure 8-1: Triangular Turn Area. Para 811.a.

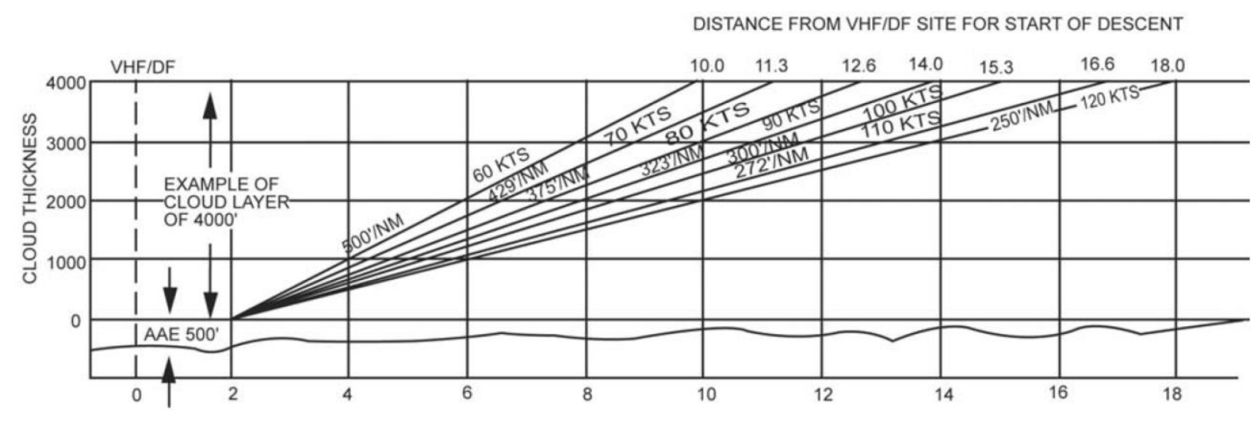


Figure 8-2: DF Descent Distance/ Airspeed Profiles. Para 811.a.

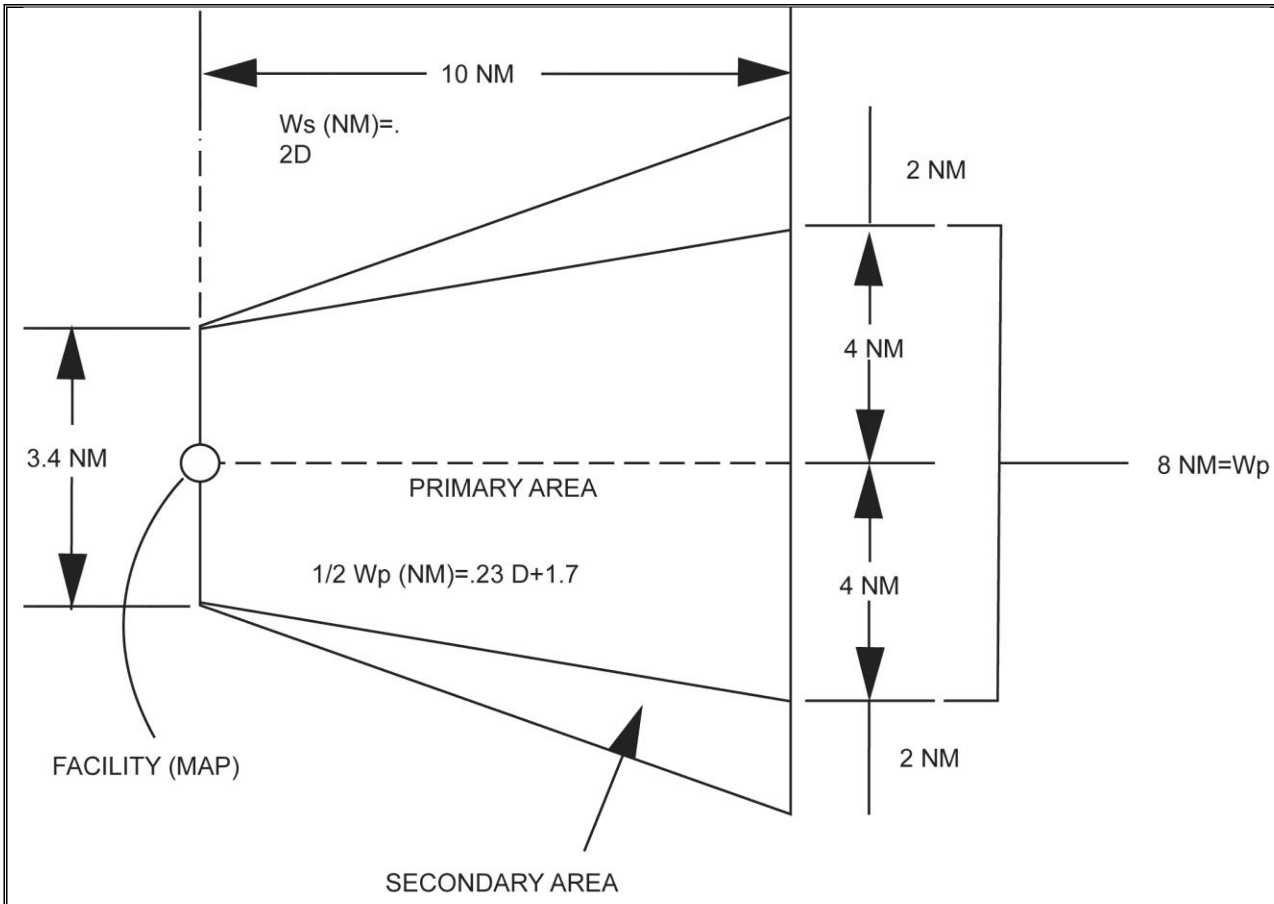


Figure 8-3: Off-Airport DF Intermediate Approach Area On-Airport DF Final Approach Area. Para 812 and 813.

813. Final Approach Segment

The final approach begins at the facility for off-airport facilities or where the procedure turn intersects the final approach course for on-airport facilities (see Para 400 for the definition of on-airport facilities). DF procedures shall not be developed for airports that are more than 10 nautical miles from the DF facility. When a facility is located in excess of 6 nautical miles from an airport, the instrument approach shall end at the facility and flight to the airport shall be conducted in accordance with Visual Flight Rules (VFR).

a. Alignment. Final approach course alignment with the runway is not a consideration in Emergency VHF/UHF DF Procedures.

b. Area.

(1) On-airport Facilities. Figure 8-3 illustrates the final approach primary and secondary areas. The primary area is longitudinally centred on the final approach course and is 10 nautical miles long. The primary area is 3.4 nautical miles wide at the facility and expands uniformly to 8 nautical miles wide at 10 nautical miles from the facility. A secondary area is on each side of the primary area. It is zero miles wide at the facility and expands uniformly to 2 nautical miles on each side of the primary area at 10 nautical miles from the facility.

(2) Off-airport Facilities. The area considered is identical to that described in Para 713a(1)(a) and (b) and Figure 7-65 except that the primary area is 3.4 nautical miles wide at the facility.

(3) Final Approach to Visual Contact Area. (DF site located on or off-aerodrome). Figure 8-4 illustrates the final approach area. The segment starts at the VHF/DF site and ends at the visual contact area that is a portion of a 15 nautical mile long trapezoid located in the best area for emergency descent. The area is centred longitudinally on the final descent course. It is 3.4 nautical miles wide at the facility and expands uniformly to 8 nautical miles at 15 nautical miles from the facility. Final approach should be made within a maximum of 15 nautical miles from the facility. The MINIMUM length of the final approach segment shall provide adequate distance for an aircraft to make a descent at 500 feet per nautical mile from the minimum altitude (1,000 feet obstacle clearance) over the VHF/ DF facility down to 500 feet above the highest centreline elevation of obstacles in the visual contact area. For the MAXIMUM length, descent at 250 feet per mile shall be used. These calculations form the beginning and end of the visual contact area and the width is formed by the boundaries of the trapezoid. (See Table 8-1). The profile in Figure 8-4 illustrates a descent of 3,500 feet, ceiling of 500 feet, rate of descent 500 feet per minute and the visual contact area for ground speeds from 60 to 120 knots.

c. Obstacle Clearance.

(1) Straight-in. The minimum obstacle clearance in the primary area is 500 feet. In the secondary areas, 500 feet of obstacle clearance shall be provided at the inner edge, tapering to zero feet at the outer edge. The minimum required obstacle clearance at any given point in the secondary area can be computed by using the formula specified in para 523.b.

(2) Final Approach to Visual Contact Area. The minimum obstacle clearance in the final approach segment to the visual contact area is 500 feet. An inclined plane is used within the final approach area, originating at the facility with at least 1,000 feet of obstacle clearance and descending at 500 feet per nautical mile to 500 feet above

the highest obstacle in the centreline zone of the visual contact area. The centreline zone boundaries shall be 3,000 feet either side of centreline. The minimum obstacle clearance of 500 feet is maintained between the inclined plane and obstacles in the descending portion of the final approach area. If 500 feet of obstacle clearance from the inclined plane cannot be maintained, the point of origin over the facility is raised accordingly. Example: if the inclined plane originating at the facility with 1,000 feet of obstacle clearance clears the governing obstacle by only 400 feet then the point of origin is raised by 100 feet. (See Figure 8-4.)

814. Missed Approach Segment

Criteria for missed approach is not required for Emergency VHF/UHF/DF Cloud Breaking procedures.

815—819. Reserved

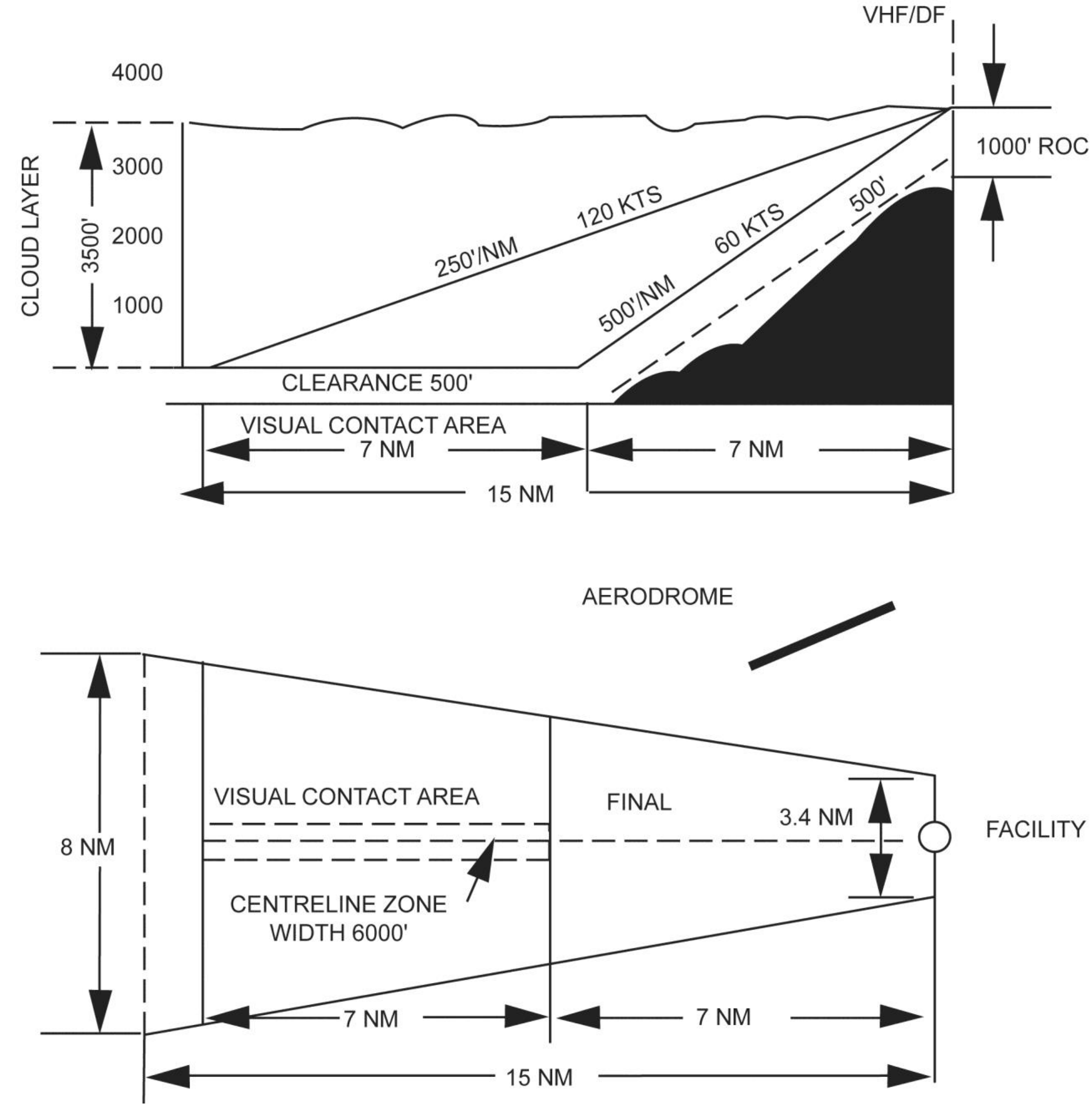


Figure 8-4: Final Approach Segment To Visual Contact Area. Para 813.b.(3) and Para c.(2).

SECTION 2. COMMUNICATIONS

820. Transmission Interval

DF navigation is based on voice transmission of heading and altitude instructions by a ground station to the aircraft. The MAXIMUM interval between transmissions is:

- **a. En route Operations**. 60 seconds.
- **b. From the Initial Approach Fix** to Within an Estimated 30 Seconds of commencement of descent through cloud. 15 seconds.

821—829. Reserved

SECTION 3. MINIMA

830. Approach Minima

No minimum descent altitude (MDA) is given. Prior to final descent the pilot will be informed of the aerodrome elevation. When the outbound type Emergency Cloud-Breaking procedure is used, the pilot will also be informed of the highest elevation of obstacles in the centreline zone of the visual contact area. (See Para 813.c.(2).) The objective is to have the aircraft descend at a constant rate, so as to pass over obstacles in the final approach segment with the required obstacle clearance, until 500 feet above aerodrome elevation is reached. The descent is continued until the aircraft is below cloud.

Note: See the Flight Service Station MANOPS 5-10 and 6-70 for procedure guidelines.

831—899. Reserved

CHAPTER 9. LOCALIZER

900. Feeder Routes, Initial Approach, and Intermediate Segments.

These criteria are contained in chapter 2, Sections 2, 3 and 4. When associated with a precision approach procedure, Volume 3, Para 2.3 applies.

901. Use of Localizer Only.

Where no usable glide slope is available, a localizer-only (front or back course) approach may be approved, provided the approach is made on a localizer from a final approach fix located within 10 nautical miles of the runway threshold. Back course procedures shall not be based on courses that exceed 6 degrees in width and shall not be approved for offset localizers. Back course procedures must be aligned within 3 degrees of the runway alignment.

902. Alignment.

Localizers are normally aligned within 3 degrees of the runway alignment. If the alignment exceeds 3 degrees the alignment shall meet the final approach alignment criteria for VOR on-airport facilities. See Chapter 5, Para 513, and Figure 5–48. Procedures developed utilizing localizers that are offset from the runway centreline up to and including 3° shall have an operational note published identifying the number of degrees of offset. Procedures developed utilizing localizers that are offset more than 3° shall have an operational note published indicating that the procedure is not aligned with the runway.

903. Area.

The final approach dimensions are specified in figure 9-75. However, only that portion of the final approach area that is between the FAF and the runway need be considered as the final approach segment for obstacle clearance purposes. The optimum length of the final approach segment is 5 nautical miles. The MINIMUM length of the final approach segment shall be sufficient to provide adequate distance for an aircraft to make the required descent. The area shall be centered on the FAC and shall commence at the runway threshold. For offset procedures, the final approach area shall commence at the facility and extend to the FAF. The MAP shall not be farther from the FAF than a point adjacent to the landing threshold perpendicular to the FAC. Calculate the width of the area using Vol 3, Chap 3 criteria.

904. Obstacle Clearance.

The minimum ROC in the final approach area is 250 feet in the W and X OCS. In addition, the MDA established for the final approach area shall assure that no obstacles penetrate the 7:1 transitional surfaces (Y OCS).

905. Descent Gradient.

The OPTIMUM gradient in the final approach segment is 318 feet per mile. Where a higher descent gradient is necessary, the MAXIMUM permissible gradient for a straight-in is 400 feet per mile. When maximum straight-in descent gradient is exceeded, then a "circling only" procedure is authorized. When a stepdown fix is incorporated, descent gradient criteria must be met from FAF to SDF and SDF to FEP. See Para 251, 252, and 288a.

906. MDA.

The lowest altitude on final approach is specified as an MDA. The MDA adjustments specified in para 323 shall be considered.

907. Missed Approach Segment.

The criteria for the missed approach segment are contained in chapter 2, section 7. The MAP is on the FAC not farther from the FAF than the runway threshold (first usable portion of the landing area for circling approach). The missed approach surface shall commence over the MAP at the required height (see para 274).

908—999. Reserved

Figure 9-1 TO 9-74: Reserved

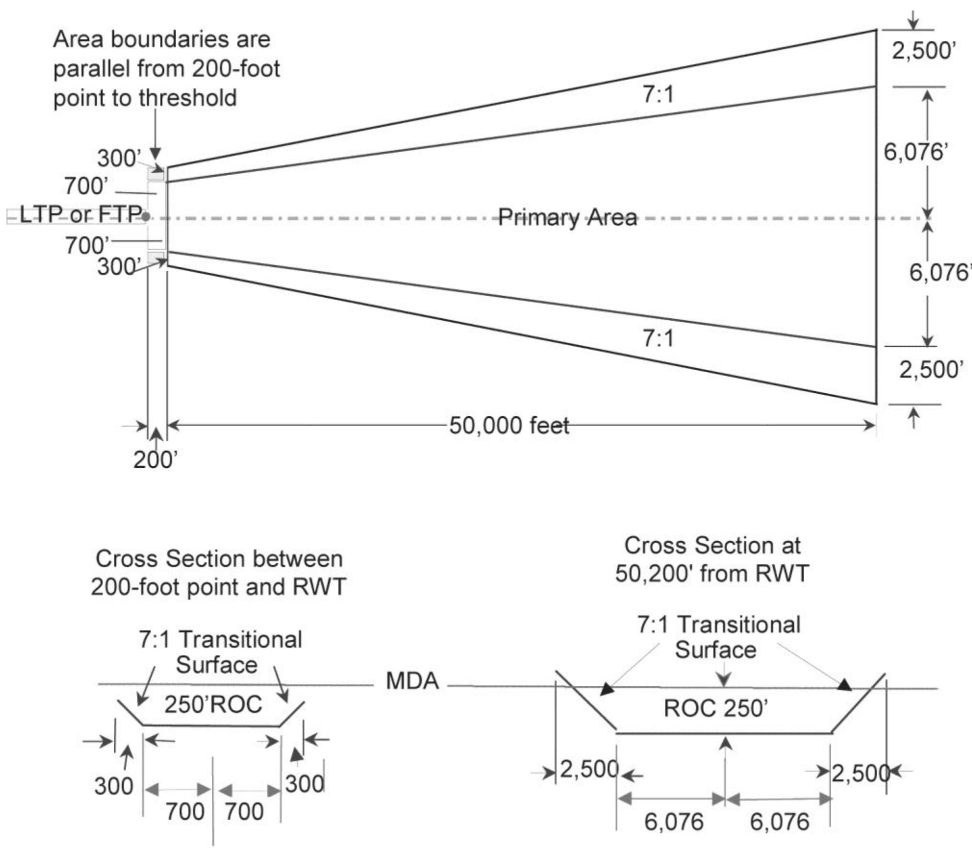


Figure 9-75: Localizer Final Trapezoid. Para 903.

CHAPTER 10. RADAR APPROACH PROCEDURES AND VECTORING CHARTS

SECTION 1. GENERAL INFORMATION

10.0. GENERAL

This chapter applies to radar approach procedures utilizing ground-based radar.

10.0.1 Precision Approach Radar (PAR)

Precision Approach Radar is a system that graphically displays lateral course, glidepath, and distance from touchdown information of sufficient accuracy, continuity, and integrity to provide precision approach capability to a runway/landing area.

10.0.2 Surveillance Radar

Surveillance Radar is a system that displays direction and distance information with suitable accuracy, continuity, and integrity to safely provide radar vectoring capability for departures, arrivals, and en route operations.

10.0.3 Inoperative Components

Failure of azimuth and range information renders the entire PAR inoperative. When the glide slope feature becomes inoperative, the PAR reverts to a non-precision approach system. In such a case, obstacle clearance shall be as specified in Vol. 1, Chapter 9 for localizer approaches.

10.0.4 Lost Communications Procedures

The PAR procedure shall include instructions for the pilot to follow in the event of a loss of communications with the radar controller.

10.0.5 Minimum Vectoring Altitude Charts

See Annex B. Whenever it is necessary to deviate from established radar patterns, obstacle clearance prescribed in paragraph 10.1.1.a for diverse vectors shall be provided by approved minimum vectoring altitude charts (MVAC's) which depict all controlling obstacle(s) within the maximum range capability of the primary radar system. The chart is based upon the minimum clearance criteria and the maximum radar system range capability. Minimum vectoring altitude charts do not require flight inspection certification.

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SECTION 2. RADAR APPROACHES

10.1 RADAR APPROACHES

PAR procedures may be established where coverage and alignment tolerances are met.

10.1.1 Feeder Routes and Initial Approach Segments

Feeder and initial segments do not need to be established when navigation guidance and obstacle clearance are provided by Air Traffic Control radar vectors, during the transition from the enroute to the terminal phase of flight.

a. **Feeder/Initial Segments based on Routes.** When operationally required, establish feeder routes and/or initial segments based on conventional navigation, Area Navigation (RNAV), or radar routes.

(1) **Conventional/RNAV Feeder/Initial**. Develop in accordance with TP308/GPH209 Volume 1, chapter 2, section 2 and 3 or Volume 6 DOC 7 when Area Navigation (RNAV) is used.

(2) **Radar Feeder/Initial**. The route/segment begins at an established fix that permits positive radar identification and ends at the appropriate termination fix for the segment. Display the course centerline on a radar video map display.

(a) **Alignment**. Design feeder/initial and initial/initial segment intersections with the smallest amount of course change necessary for the procedure. The maximum allowable course change between segments is 90 degrees.

(b) **Area**. The Obstacle Evaluation Area (OEA) begins at the applicable radar fix displacement prior to the route/segment start fix and extends to the segment termination fix. Primary area half-width is equal to the minimum lateral clearance applicable to the radar adaptation (e.g. 3 NM if the aircraft is less than 40 NM from the antenna). There is no secondary area. The primary area has no specified maximum or minimum length; however, the segment must be long enough to permit the required altitude loss without exceeding the maximum authorized descent gradient.

Note: When the minimum lateral clearance changes within a segment (e.g. 5 NM to 3 NM), the OEA half-width also changes without the need to “splay” or “taper”.

(c) **Obstacle Clearance**. Apply the Volume 1, chapter 2 standard applicable to the segment. Volume 1, chapter 3 precipitous terrain adjustments apply.

(d) **Descent Angle**. Apply Volume 1, chapter 2 standard applicable to the segment.

(e) **Altitude Selection**. Apply Volume 1, chapter 2 standard applicable to the segment. Do not publish fix altitudes higher than the minimum required for obstacle clearance or airspace to achieve an "optimum" descent gradient.

10.1.2 Intermediate Approach Segment.

Establish an intermediate segment when necessary (e.g., ATC radar vectors not available or MVA too high to support desired FAF/PFAF altitude). The intermediate segment begins at the intermediate fix and extends to the PFAF. When there is a preceding conventional / RNAV route segment, the applicable conventional/RNAV intermediate segment standards apply, except as specified in paragraph 10.1.2b(2).

a. Alignment. The intermediate course is an extension of the final approach course (no course change permitted at the PFAF).

b. Area.

(1) **Radar Intermediate**. When radar is used for course guidance (route or vector), the OEA begins at the applicable radar fix displacement prior to the Intermediate Fix (IF) and extends to the PFAF. Primary area half-width is equal to the minimum lateral clearance applicable to the radar adaptation (e.g. 3 NM if the A/C is less than 40 NM from the antenna and 5 NM if the A/C is 40 NM or more from the antenna) until reaching a point 2 NM prior to the PFAF, then tapers to the width of the PAR Final Approach segment (FAS) primary OEA when abeam the PFAF. There are no intermediate secondary areas. See figure 10-1.

Note: When the minimum lateral clearance changes within a segment (e.g. 5 NM to 3 NM), the OEA half-width also changes without the need to "splay" or "taper".

(2) **Non-Radar Intermediate**. When conventional/RNAV navigation is used for course guidance, apply the intermediate OEA criteria from the applicable TP308/GPH209 volume with the following exceptions:

(a) **Connection to PAR Final**. Connect the outer edges of the intermediate primary area abeam the IF to the outer edges precision "X" Obstacle Clearance Surface (OCS) and the intermediate secondary area to the precision "Y" OCS abeam the PFAF.

(3) **Length**. The intermediate segment length is normally 6 NM. The MINIMUM length varies based on course guidance but must always accommodate the required altitude loss. The maximum length is 15 NM.

(a) For conventional/RNAV and radar route course guidance, apply Volume 1, chapter 2 for ASR approaches and Volume 3, chapter 2 for PAR approaches. Radar intermediate segments may not be less than 2 NM.

c. Obstacle Clearance. Apply 500 ft ROC over the highest obstacle in the area. Volume 1, chapter 3 precipitous terrain and RASS adjustments apply. For conventional/RNAV course guidance, apply secondary area ROC criteria from the applicable TP308/GPH209 Volume.

d. Descent gradient. Apply Volume 1, Chapter 2.

10.1.3 PAR Final Approach Segment (FAS).

a. Inoperative/unused Components. Failure of the azimuth component renders the entire PAR system inoperative. When the glide slope feature becomes inoperative, the PAR reverts to a non-precision approach system. In this case, obstacle clearance shall be as specified in Vol. 1, Chapter 9 for localizer approaches.

The missed approach instructions are the same, and the radar missed approach point is identifiable on the PAR scope. NPA minimums are established according to TP308/GPH209, Volume 1, Chapter 3, section 3 and are documented as applicable.

b. General. Apply the current basic vertically guided final segment general criteria applicable to Instrument Landing System (ILS) for Glidepath Angle (GPA), Threshold Crossing Height (TCH), Precise Final Approach Fix (PFAF), Glidepath Qualification Surface (GQS), and Precision Obstacle Free Zone (POFZ).

(1) Use the highest applicable MVA to determine the PFAF distance to LTP/coordinates when there is no preceding segment.

(2) ILS Height Above Touchdown/Threshold (HAT/HATh) and Decision Altitude (DA) standards apply (to include Volume 1, chapter 3 adjustments), except the minimum HAT/HATh may be 100 ft for helicopter approaches when the OCS is clear.

Note: Adjusting TCH to reduce/eliminate OCS penetrations is not applicable to PAR FAS evaluations.

c. Obstacle Evaluation Area (OEA)/Obstacle Clearance Surface (OCS). Apply current ILS FAS criteria for alignment, OCS slope, width, height, and OEA/OCS evaluation except the OEA extends to the PFAF (no radar fix tolerance applied). Also, where the PFAF must be located more than 50200 ft from the RWT coordinates, the OEA continues to splay to the PFAF or until reaching the minimum lateral clearance applicable to the radar adaptation.

10.1.4 Missed Approach Segment (MAS).

a. PAR. Apply the Volume 3 Category (CAT) I ILS missed approach criteria to approaches with HAT/HATh values greater than or equal to 200 ft. Apply CAT II missed approach criteria for approaches with HAT/HATh values lower than 200 ft.

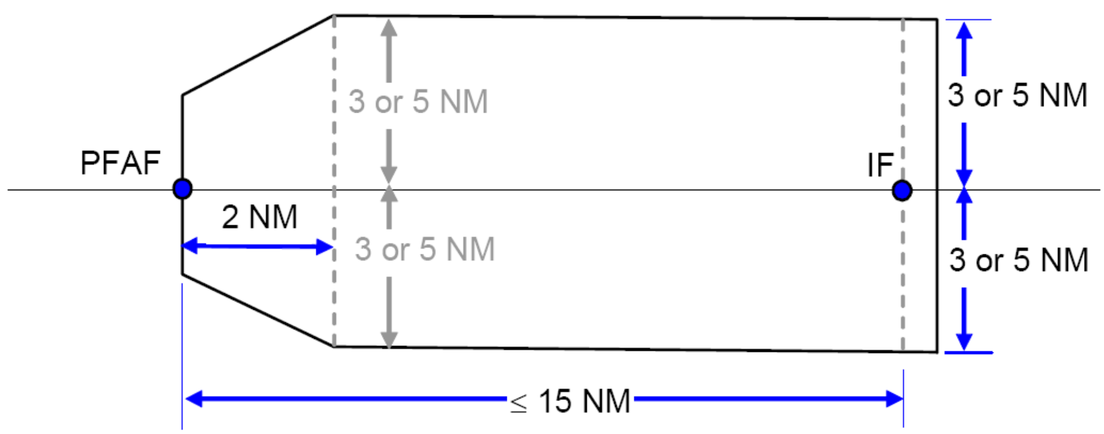

Figure 10-1: Intermediate Segment Area

CHAPTER 11. RESERVED

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CHAPTER 12. DEPARTURE PROCEDURES

1200. General

These criteria specify the obstacle clearance requirements to be applied to diverse departures and departure routes. Obstacle identification surfaces (OIS) of 40:1 are used. A climb gradient of 200 feet per NM will provide at least 48 feet per NM of clearance above objects, which do not penetrate the OIS. Objects which penetrate the OIS are obstacles and shall be considered in the departure procedure by specifying a flight path which will safely avoid the obstacle(s) or by specifying a climb gradient greater than 200 feet per NM that will provide 48 feet (24%) of required obstacle clearance (ROC) for each NM of the flight path. Take-off visibility minima (SPEC VIS) and a visual climb to altitude shall be established for those departures specifying a climb gradient (unless authorized by Transport Canada Standards).

1201. Application

Diverse departure criteria (Para 1202) shall be applied to all runways authorized by the approving authority for instrument departures. Application of diverse departure criteria may result in the need to develop specific departure routes to avoid obstacles (Para 1203).

1202. Diverse Departures

At many airports, a prescribed departure route is not required for ATC purposes nor as the only suitable route to avoid obstacles. In spite of this, there may be obstacles in the vicinity of the airport that should be considered in determining that restrictions to departures are to be prescribed in a given section(s). The areas and surfaces described herein are to be used to identify such obstacles. Sectors shall be described by bearings and distance from the airport reference point which diverge at least 15° either side of the controlling obstacle. Departure restrictions shall be published as described in Para 1207.a.

a. Zone 1.

(1) **Area**. The area begins at the departure end of the runway (DER) and has a beginning width of 1,000 feet (+/- 500 feet from centreline). The area splays 15° on each side of the extended runway centreline for a distance of 2 NM from the DER (see Figure 12–116A).

(2) **Obstacle Identification Surface**. A 40:1 OIS overlies Zone 1. It begins at the DER, at the DER altitude and rises in the direction of departure. Obstacle distance measurements shall be made by projecting a line from the obstacle to intersect the extended runway centreline at 90°. The distance from this intersect point to the DER shall be considered the obstacle distance.

b. Zone 2.

(1) **Area**. Zone 2 extends radially from a point on the runway centreline located 2,000 feet from the start end of the runway. It is centred on the extended take-off surface centreline and excludes Zone 1. It extends the distance necessary for the 40:1 OIS to reach the minimum altitude authorized for en-route operations (see Figure 12–116B).

(2) **Obstacle Identification Surface**. A 40:1 OIS overlies Zone 2 and has a beginning height equal to the height of the OIS at the end of Zone 1. Distance measurements to an obstacle shall be made from the runway edge or edge of Zone 1, whichever in the shorter distance.

c. Zone 3.

(1) **Area**. Zone 3 covers the area in the direction opposite to the take-off beginning 2,000 feet from the start end of the runway. It provides clearance for 180° turn departures and extends the distance necessary for the 40:1 OIS to reach the minimum altitude authorized for en-route operations (see Figure 12–116C).

(2) **Obstacle Identification Surface**. A 40:1 OIS overlies Zone 3 and begins 400 feet above airport elevation along the runway edge and rises there from.

1203. Departure Routes

There are three basic types of departure routes: straight, turning, and combination straight and turning. Departure routes shall be based on positive course guidance acquired within 10 NM from the DER on straight departures and within 5 NM after completion of turns on departures requiring turns. Surveillance radar, when available, may be used to provide positive course guidance.

a. Straight Departures. A straight departure is one in which the initial departure course is within 15° of the alignment of the take-off surface. Additionally, the departure course must intersect the runway centreline extended within 2 NM from the DER or the departure course must lie within 500 feet laterally of the runway centreline at the DER (see Figures 12–116D to 12–116H). When the initial departure course is to a facility, a manoeuvring segment is provided under the provisions of Para 1203.a.(1)(b).

(1) Area. The area begins at the departure end of the runway. It is based on the departure course and has a minimum beginning width of 1,000 feet (+500 feet from centreline). The edge of the area shall be no less than 500 feet from the centreline of the runway and the departure course. For example, if the departure course lies 500 feet from the centreline, the beginning width of the area shall be no less than 1,500 feet (see Figure 12–116G). The area splays 15° on each side of the departure course and/or runway centreline extended (whichever protects the greater area) to the point where the boundaries intercept the area associated with the navaid providing course guidance.

(a) When course guidance is provided by a localizer, the area specified in Para 1202.a.(1) shall be used for the first 2 NM of the departure. This area shall be joined to the localizer final approach area stated in Para 903 by lines drawn from the extremities of the area at 2 NM from the departure threshold to the width of the localizer area at 10 NM (see Figure 12–116H). (At certain airports, localizers, although installed, may not be available for use as a departure navaid.)

(b) The area associated with the navaid (other than a localizer) providing course guidance shall have the following dimensions. It shall be 3 NM (±1.5 NM) wide at the facility, it shall have a minimum length of 10 NM and shall splay to a width of 5 NM (±2.5 NM), 6 NM (±3.0 NM) for NDB, at 10 NM from the facility. If additional distance is required, the area may be joined from its extremities to the primary en-route area using 4.5°, 5° for NDB, or splay until primary en-route width is reached.

(i) If a turn of 15° or less is required over the facility, the inbound and outbound areas outer boundaries shall be joined by an arc of 1.5 NM radius.

(ii) If a turn of more than 15° but less than 30° is required over the facility, the turning departure area outer boundary radius (Table 12–31) shall be applied to join the two areas. The outbound area outer boundary shall be applied to join the two areas. The outbound area outer boundary shall be constructed by a line tangent to the arc and drawn to the edge of the outbound area at 10 NM from the facility (see Figure 12–116I).

(iii) If a turn of 30° or more is required over the facility, the area shall be extended a distance of 1 NM beyond the facility aligned with the inbound track at a width of 3 NM (+1.5 NM) and the turning departure area outer boundary radius (Table 12–31) shall be applied to join the extension to the area associated with the outbound track. The outbound area outer boundary shall be constructed by a line tangent to the arc and drawn to the edge of the outbound area at 10 NM from the facility (see Figure 12–116J).

(2) Obstacle Identification Surface. A 40:1 OIS overlies the straight departure area and rises in the direction of departure. The OIS begins at the DER, at the DER elevation.

b. Turning Departures. If the initial departure course does not meet the criteria specified in Para 1203.a, a turning departure shall be constructed. A turning departure is one in which the aircraft climbs straight ahead on the heading of the take-off surface until reaching 400 feet above the airport elevation (within 2 NM) and then immediately begins a turn to intercept a departure course. Positive course guidance is required within 5 NM after completion of the turn (see Figure 12–116K).

(1) Area. The turning departure area is divided into Sections 1 and 2.

(a) Section 1 is identical to the 15° splay area specified in Para 1203.a.(1). It terminates 2 NM from the beginning of the 15° splay area.

(b) Section 2 starts at the end of Section 1. The flight track and outer boundary radii shall be determined from Table 12–31. The outer boundary line shall splay 15° from the departure course beginning at the point abeam the point where the turn is completed. The inner boundary line shall begin at the runway edge 2,000 feet from the start end of the take-off surface on the side in the direction of the turn (Point D). It terminates at the same distance abeam the departure course as the outer boundary does at the end of the departure. The splay of Section 2 terminates when the width reaches that of the primary en-route structure. Thereafter, en-route criteria apply.

(2) Obstacle Identification Surface

(a) Section 1. A 40:1 OIS overlies Section 1 and is identical to the 40:1 specified in Para 1203.a.(2).

(b) Section 2. The dividing line between Sections 1 and 2 are identified as "AB, BC, CD". A 40:1 OIS overlies Section 2 and has an initial height equal to the terminating height of Section 1 at any point along the dividing line and rises in the direction of the departure course. The height of the OIS at any point in Section 2 is determined by measuring the straight line distance from this point to the nearest point on the "AB, BC, CD" dividing line.

c. Combination Straight and Turning Departure. If a straight climb to a height, which is more than 400 feet above the elevation of the DER is necessary prior to beginning the departure turn, a combination straight and turning departure area must be applied. Whenever possible, the point at which the turn commences shall be identified by a fix or by the intersection of the initial dead reckoning departure course with a radial or bearing which provides positive course guidance. When a fix, radial or bearing is not available, the turn may be specified to commence at an altitude based on a climb gradient of 200 feet per NM. For example, a turn 1,000 feet above DER elevation shall be assumed to commence 5 NM from the end of the runway. Positive course guidance is required within 5 NM after completion of the turn.

(1) Area. The combination straight and turning departure is divided into Sections 1 and 2 (see Figure 12–116L).

(a) Section 1 is identical to the straight departure area except that it extends to the point at which the turn begins.

(b) Section 2 starts at the end of Section 1. The flight track and outer boundary radii shall be determined from Table 12–31. The outer boundary radius shall be drawn beginning a distance past the plotted position of the turning point equal to the fix error, along track accuracy, or abeam plotted position; whichever is further from the end of the departure runway. The inner boundary line shall begin at the edge of the 15° splay area at a distance prior to the plotted position of the turning point equal to the fix error or along track accuracy plot plus 1 NM. Where the turn is specified to commence at an altitude, the outer boundary radius begins at the end of Section 1, and the inner boundary line begins at the edge of the 15° splay area abeam the DER. The outer boundary line shall splay 15° from the departure course beginning at the point abeam the point where the turn is completed. The inner boundary line is drawn from the point of beginning to a point which is the same distance abeam the departure course as the outer boundary is at the end of the departure.

(c) Where a turn is required to intercept a radial/bearing to proceed to or from a facility, alternate area construction is necessary (see Figure 12–116M). The appropriate flight track radius will join the radial/bearing and the runway centreline extended. The arc will be drawn from a point on the bisector of the angle between the runway centreline extended and the plotted position of the radial/bearing. Section 1 ends at the point of tangency of the extended centreline and the arc. The inner boundary begins at the near edge of Section 1 at a point 1 NM prior to the end of that section. The outer boundary begins at the intersection of the extended 15° splay line of Section 1 and the plotted position of the radial/bearing. The splay of Section 2 terminates when the width reaches that of the primary en-route structure. Thereafter, en-route width criteria apply.

(2) Obstacle Identification Surface.

(a) Section 1. A 40:1 OIS overlies the straight departure area. It begins at the DER, at the DER elevation, and rises in the direction of departure.

(b) Section 2. The dividing lines between Sections 1 and 2 are identified as "AB, BC". A 40:1 OIS overlies Section 2. It has the same height as the Section 1 OIS at the dividing line AB and rises in the direction of the departure course.

1204. Reserved

1205. Climb Gradients

Climb gradients shall include 48 feet per NM (24%) required obstacle clearance. When precipitous terrain is a factor, consideration shall be given to increasing the obstacle clearance (see Para 323). Gradients shall be specified to an altitude or fix at which a gradient of more than 200 feet per NM is no longer required. **Climb Gradients in excess of 500/NM require approval of Flight Standards (or the appropriate military authority).**

- **a. Diverse Departures**. In cases where departure routes are not required to avoid obstacles, but obstacles exist in a sector(s) such as a mountain range, the required gradient shall be computed from the origin of the Zone 2 or 3 OIS (as applicable) direct to the obstacle. The altitude to which the climb gradient must be maintained is based on the obstacle plus ROC requiring the highest altitude in that sector.
- **b. Departure Routes**. Climb gradients shall be computed from the elevation of the OIS at the DER along the shortest possible flight path within the obstacle clearance area to the obstacle.
- **c. Climb gradients.** Where low, close-in obstacles result in climb gradient to an altitude 200 feet or less above DER elevation. Publish a note identifying obstacle(s) type, location relative to DER and ASL elevation.

1206. End of Departure

The departure area terminates at a point where the 40:1 OIS, measured along the flight track, reaches the minimum altitude authorized for en-route operations or radar vectoring, whichever is applicable. Where a climb in hold is required to achieve enroute operations, is shall be assessed in accordance with Chapter 18, Holding Criteria. The departure instructions shall specify a climb in hold altitude that is equivalent to an enroute altitude; or the instructions shall specify a climb in hold altitude that will ensure that after leaving the hold and proceeding on course, the 40:1 OIS will be clear until achieving the enroute ROC.

1207. Published Information

The minimum information to be published for departure procedures is specified as follows:

- **a. Diverse Departures**. Departure restrictions shall be expressed as sectors to be avoided or sectors in which climb gradients and/or minimum altitudes are specified to enable an aircraft to safely overfly an obstacle. When more than one sector is involved, the climb gradient selected shall be the highest in any sector that may be expected to be overflown. The altitude to which the gradient is specified must permit the aircraft to continue at 200 feet per NM minimum through that sector, a succeeding sector, or to an en-route altitude. A fix may also be designated to mark the point at which a climb gradient in excess of 200 feet per NM is no longer required.
- **b. Departure Routes**. A departure route must specify all courses, points, fixes, and altitudes required in the procedure. When obstacles must be overflown, minimum crossing altitudes and climb gradient information shall be provided for all departures requiring a climb gradient greater than 200 feet per NM. The altitude or fix at which a climb gradient in excess of 200 feet per NM is no longer required shall also be specified.
- **c. Minima** imposed shall be in accordance with Para 1208 and Chapter 3.
- **d.** When departures are limited to a specific category of aircraft, i.e. Cat A and B, Cat A, B & C, the procedure shall be clearly annotated.

1208. Required Minima

IFR departure procedures requiring a climb gradient in excess of 200 feet per NM to meet obstacle clearance requirements shall have published "SPEC VIS" (SPECIFIED TAKE-OFF MINIMM VISIBILITY) and a visual climb to altitude (i.e. Visual Climb Over Airport (VCOA) maneuver) to accommodate aircraft that cannot meet the required climb gradient.

Supplementary Note: It is possible that VCOA operations may be deemed impractical or even a detriment to the overall performance of certain high traffic density aerodromes. Should this be the case and the aerodrome has 24 hr control tower service in Class B, C or D controlled airspace, then the aerodrome may be exempt from the requirement to build a VCOA. A note stating the above shall be required in the design documentation.

1209. Visual Climb Over Airport (VCOA)

Option to allow an aircraft to climb over the airport with visual reference to obstacles to attain a suitable altitude from which to proceed with an IFR departure.

1210. Visual Climb Area (VCA)

Construct this area in the same manner as the circling approach area described in Para 260.a, using the radii in Table 12–32. Elimination of sectors as per para 261 does not apply.

Supplementary Note: From an operational point of view the title Visual Climb Area is misleading as the aircraft is not required to climb solely within this “cylinder”. The pilot is only required to depart from within this area at or above the climb-to altitude, after visually maneuvering his aircraft into position.

1211. Establishment Of Altitude For Visual Climb Area

To determine the preliminary climb-to altitude for the VCA, add 264 feet, plus any Para 323. b adjustments, to the highest obstacle in the VCA. Round the resultant altitude to the next higher

100-foot increment. If this altitude does not support en-route flight, evaluate a straight departure area using a 40:1 obstacle identification surface.

1212. Straight Departure Area

a. This area begins over the airport reference point (or on-airport navaid). Area width is appropriate to the navaid used, as defined in Para 1203.a.(1)(b).

b. When DR is used, the area has the same width as the VCA abeam the point of beginning. The DR area begins over the airport reference point. The splay begins where a line constructed perpendicular the DR course and through the Aerodrome Geometric Centre (AGC) intercepts the VCA boundary. It splays 15° each side of and in the direction of the DR course until positive course (track) guidance is acquired (see Figure 12–117).

c. For straight-out segment evaluations, determine the 40:1 surface beginning height by subtracting 264 feet, plus any Para 323.b adjustments, from the computed climb-to altitude. The 40:1 surface begins at the VCA boundary, and rises in the shortest distance to the obstacle being evaluated. Where penetrations exist, increase the climb-to altitude by the greatest amount of penetration rounded to the next higher 100-foot increment.

1213. Published Annotations

The procedure must include instructions to climb in visual conditions to cross a location/fix at or above the climb to altitude determined during the evaluation of the procedure.

a. For a VCOA diverse departure, include the term, “before proceeding on course” (BPOC) following the climb to altitude.

Example:

(1) “Climb in visual conditions to cross the airport at or above 2200 BPOC.”

b. For a VCOA route departure, specify the visual climb to altitude, then the initial heading or track followed by the routing.

Examples:

(1) “Climb in visual conditions to cross the airport at or above 4200, then climb on track of 125° to ABC VOR BPOC”

-or-

(2) “Climb in visual conditions to cross the airport eastbound at or above 5000, then via LEX R-281 to LEX”

1214—1299. Reserved

Turn Altitude (feet MSL)	Flight Track Radius (R_1) (NM)		Outer Boundary Radius (R) (NM)	
	CAT A & B	Others	CAT A & B	Others
S.L. to 1,000	1.0	2.5	2.0	5.5
1,001 to 3,500	1.2	2.7	2.4	5.9
3,501 to 6,000	1.3	2.9	2.6	6.3
6,001 to 8,500	1.4	3.1	2.8	6.7
Above 8,501	1.6	3.4	3.2	7.3

Note: These turn radii will accommodate speeds up to 350 KIAS with 30° angle of bank. Outer boundary radius may be reduced ½ **NM** operational advantage. Procedure must be annotated with airspeed restriction 250 KIAS.

Table 12-1: Departure Turn Radii. Para 1203.a.(1) (b), 1203.b.(1)(b), and 1203.c.(1)(b).

Category	Radius (NM)
A	2.3
B	2.5
C	2.7
D	3.3
E	5.5

Table 12-2: Visual Climb Area Radii. Para1210.

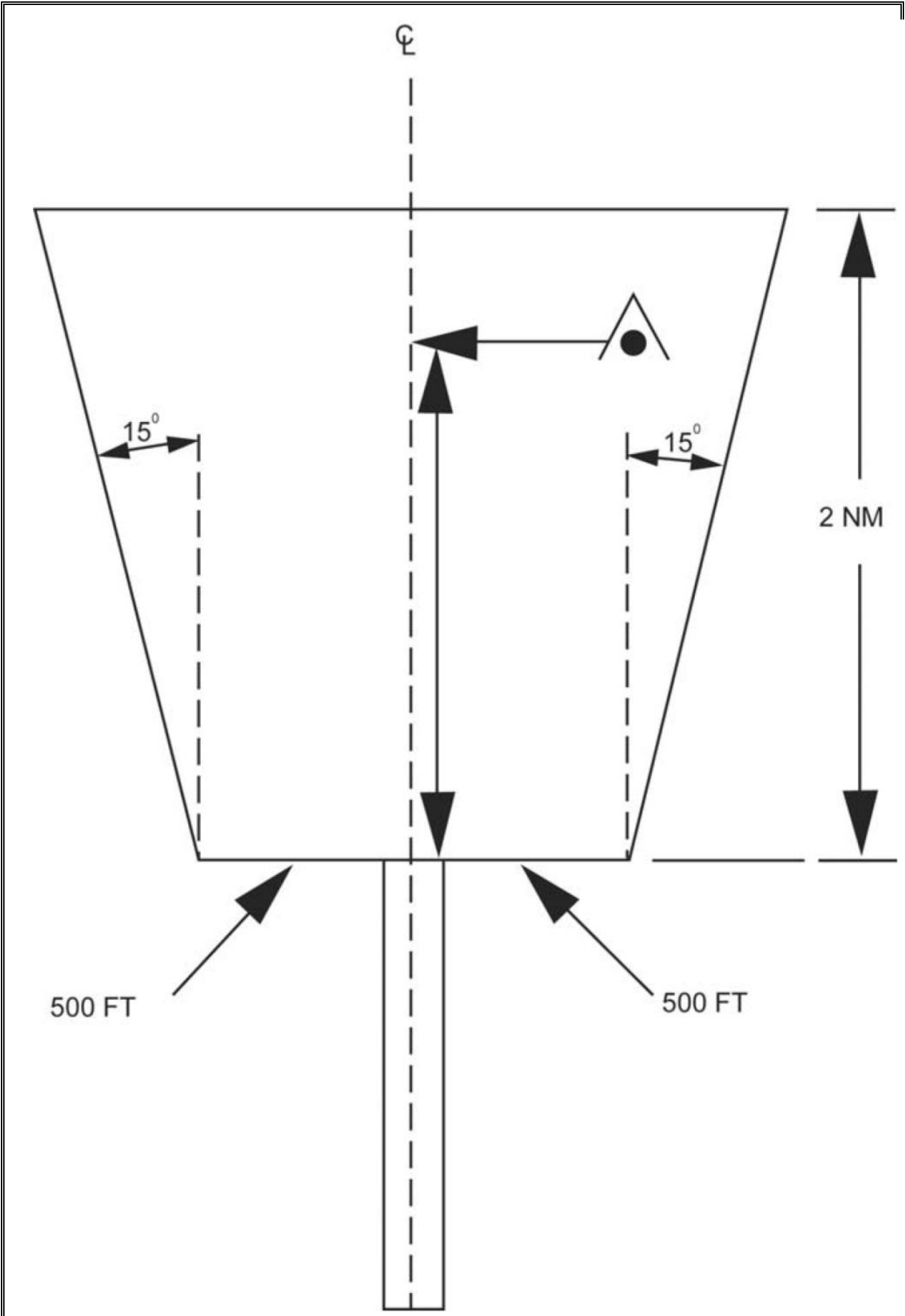

Figure 12-116A: Zone 1 Diverse Departure. Para 1202.a.

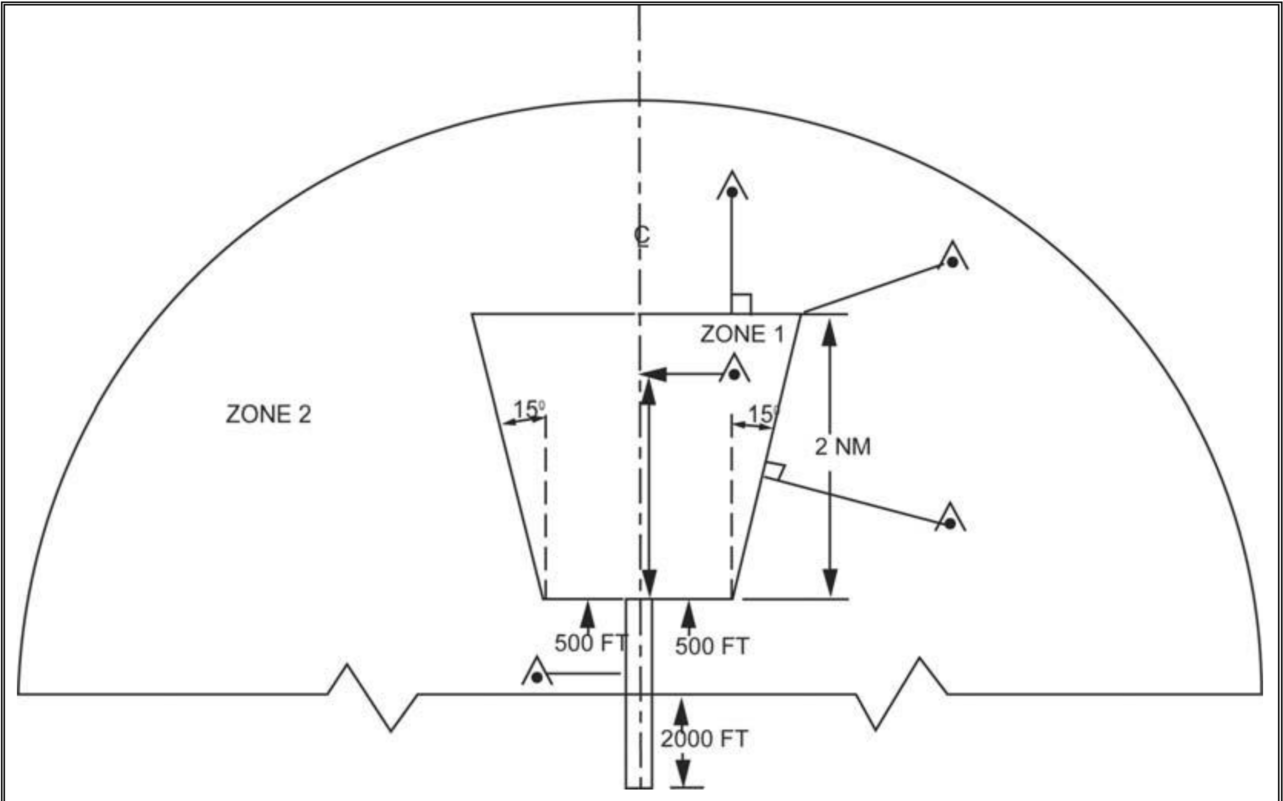

Figure 12-116B: Zone 2 Diverse Departure. Para 1202.b.

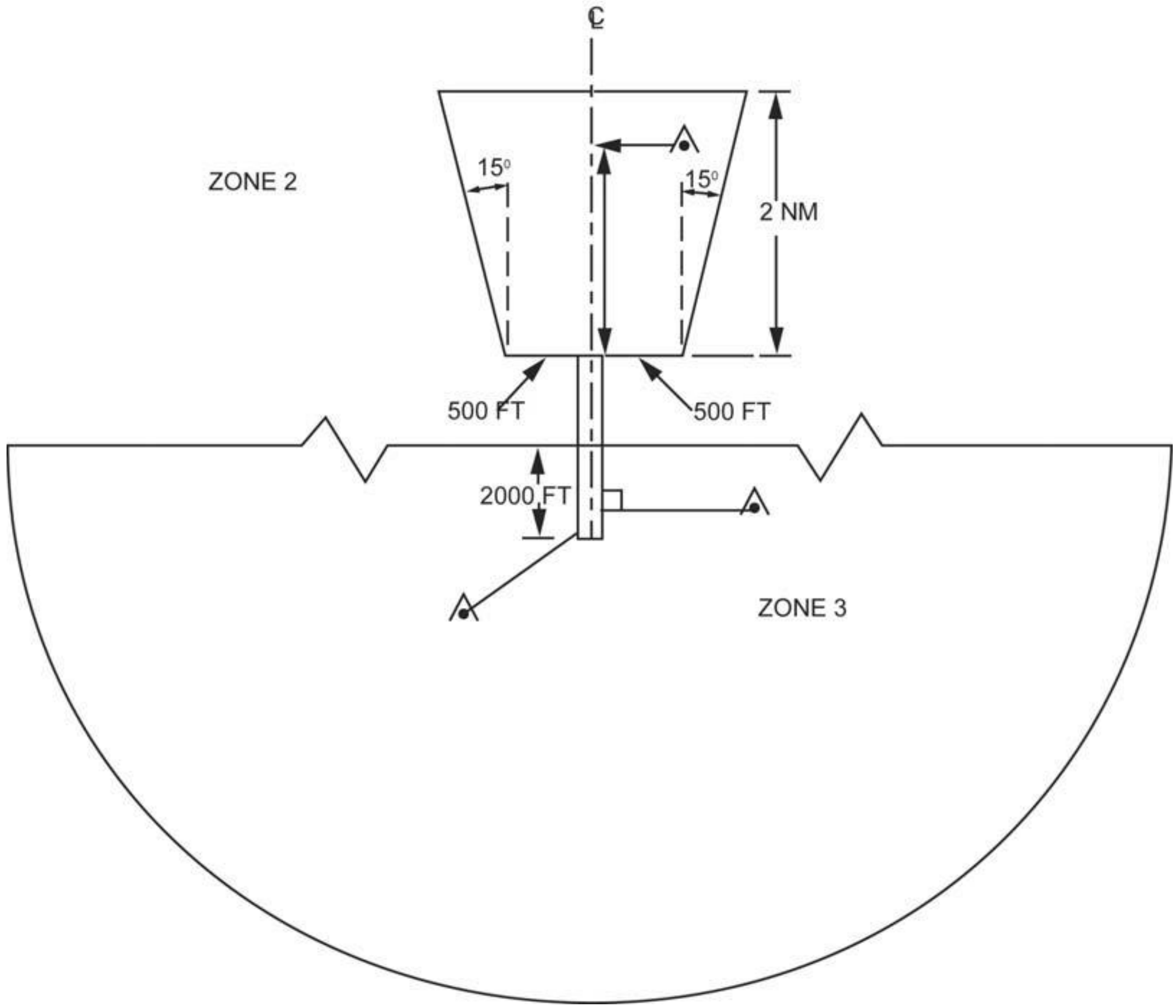

Figure 12-116C: Zone 3 Diverse Departure. Para 1202.c.

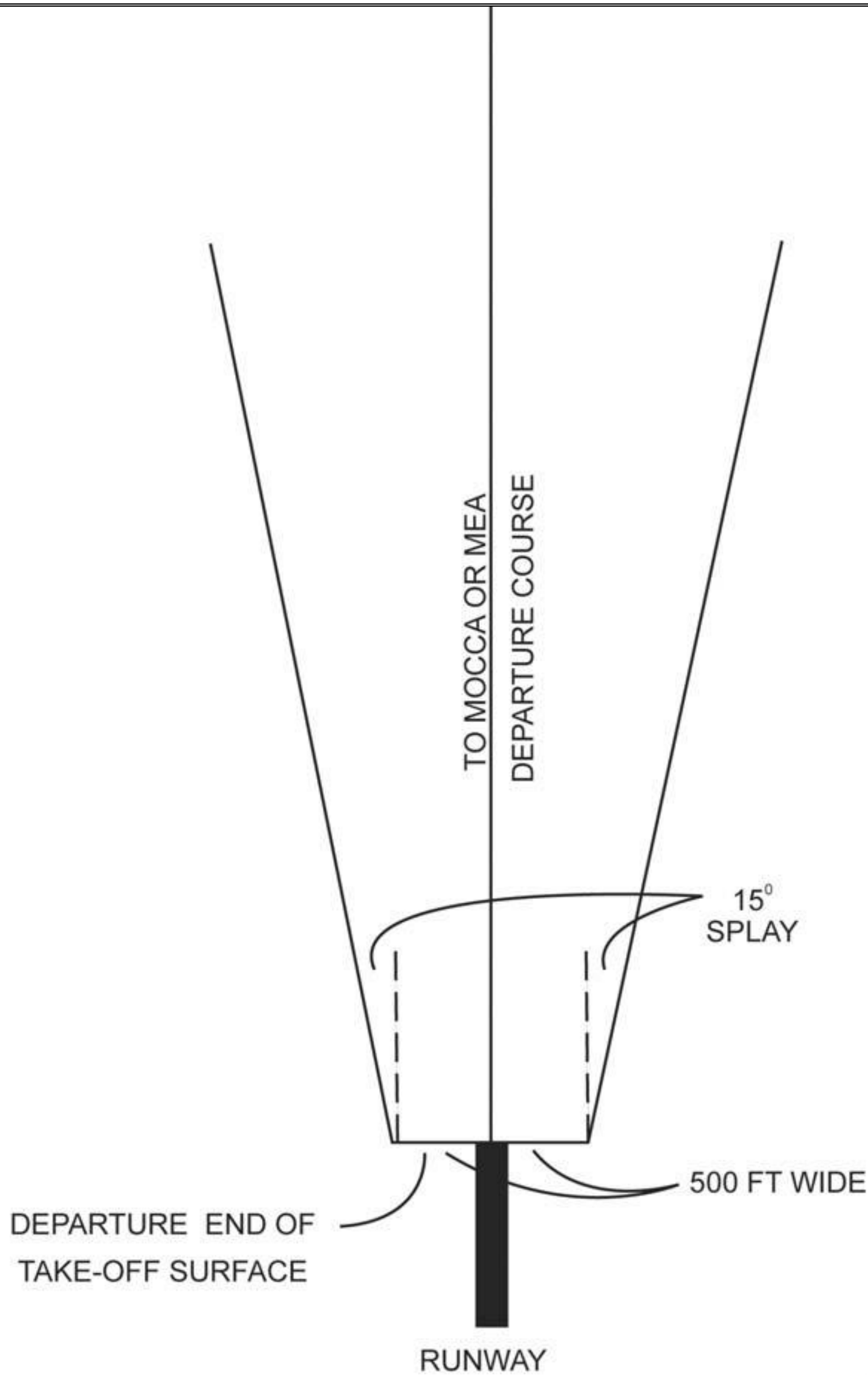

Figure 12-116D: Straight Departure Area Without Course Guidance. Para 1203.

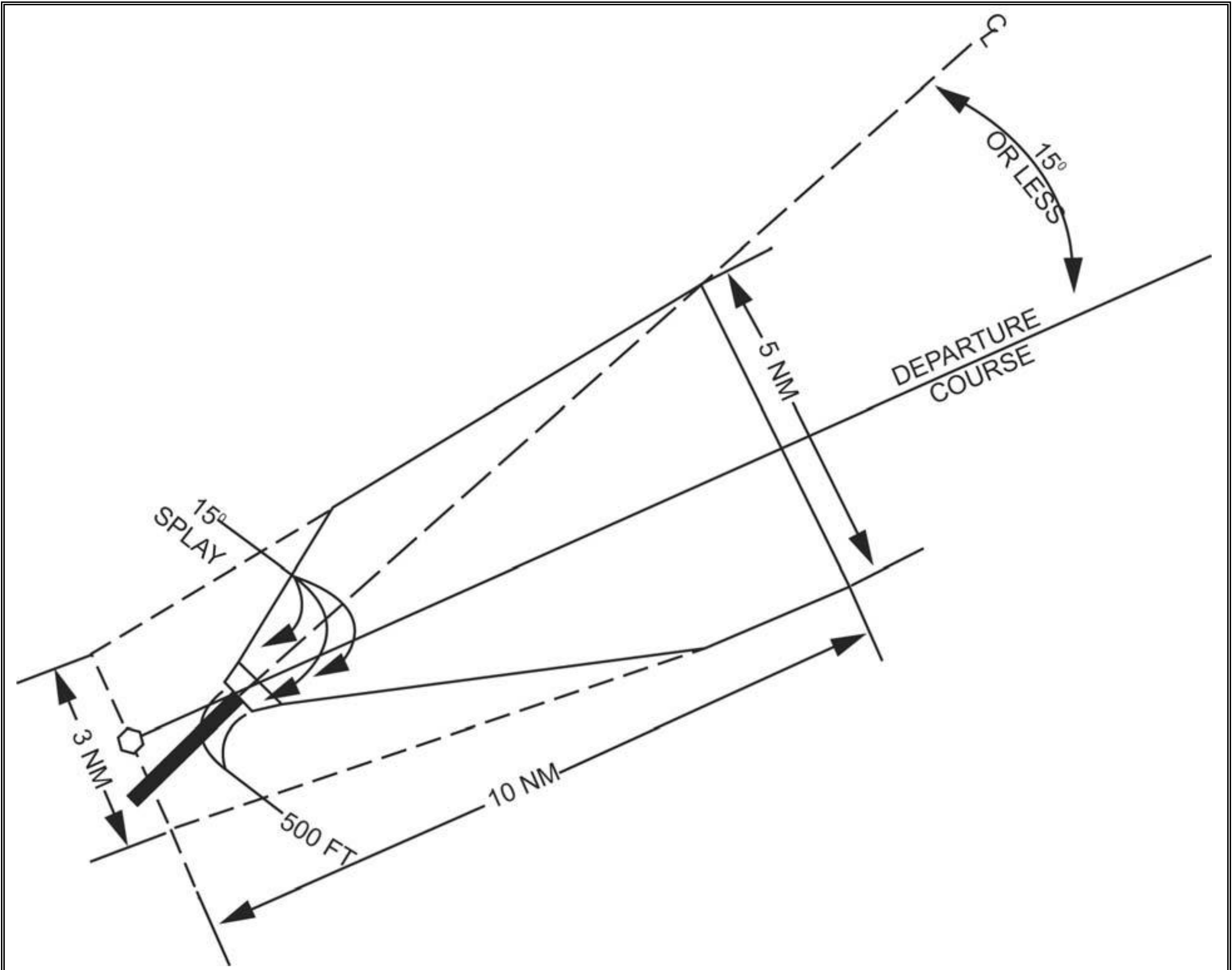

Figure 12-116E: Straight Departure With Course Guidance From On Aerodrome Facility. Para 1203.

Supplementary Note: The Splay is 6 NM for NDB at 10 NM from the facility.

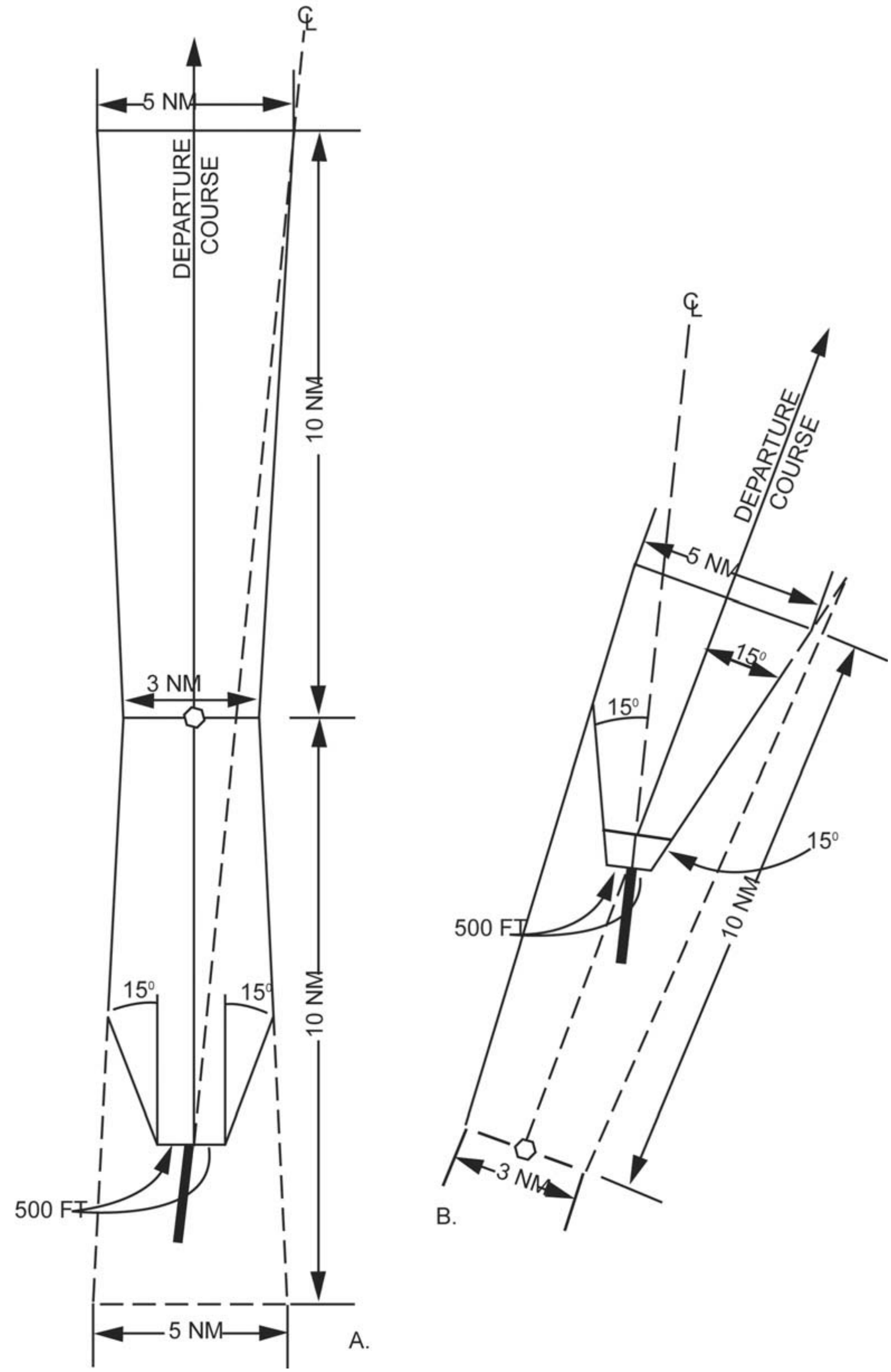

Figure 12-116F: Straight Departure With Course Guidance From Off Aerodrome Facility. Para 1203.

Supplementary Note: The Splay is 6 NM for NDB at 10 NM from the facility.

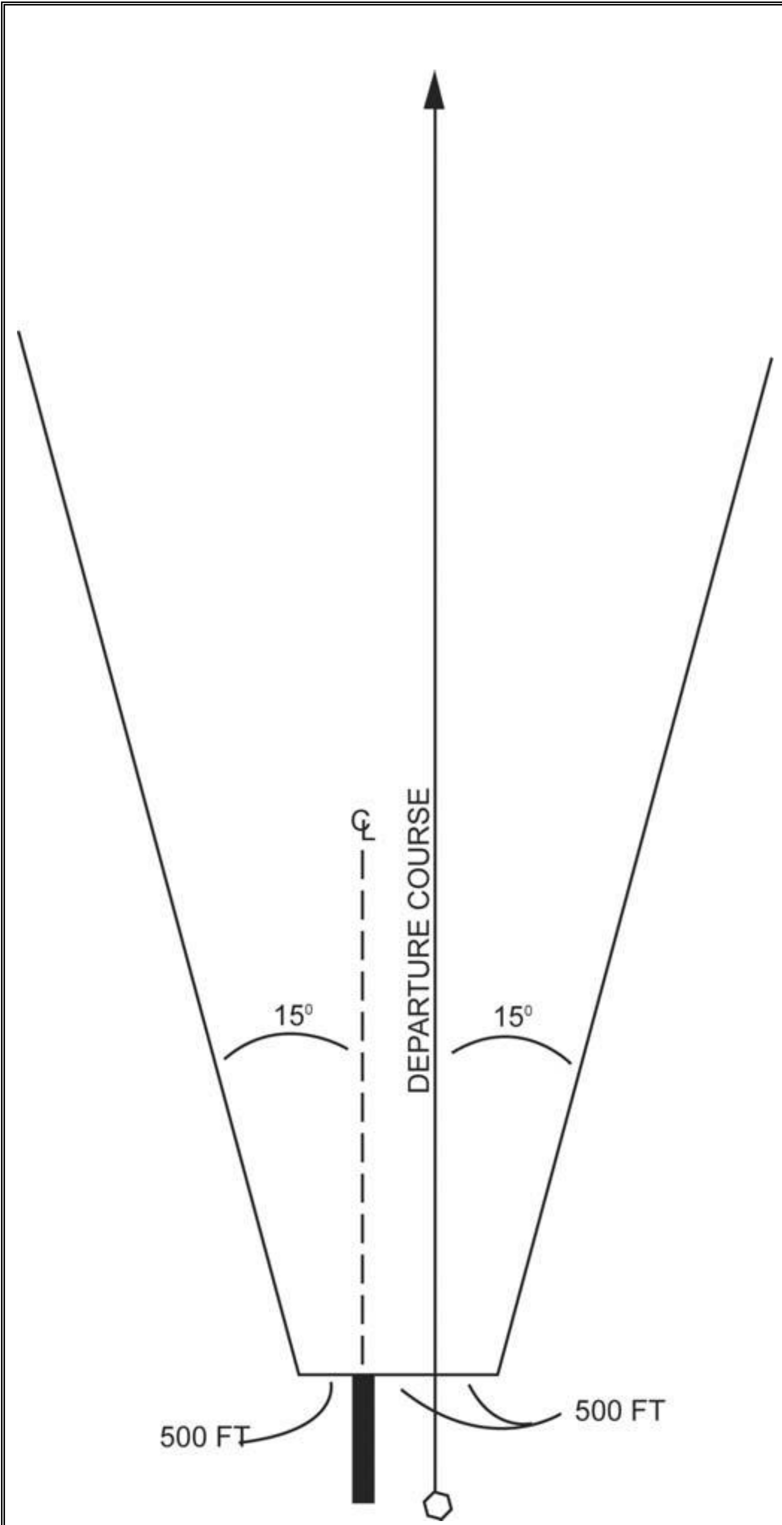

Figure 12-116G: Straight Departure With Offset Departure Course. Para 1203.

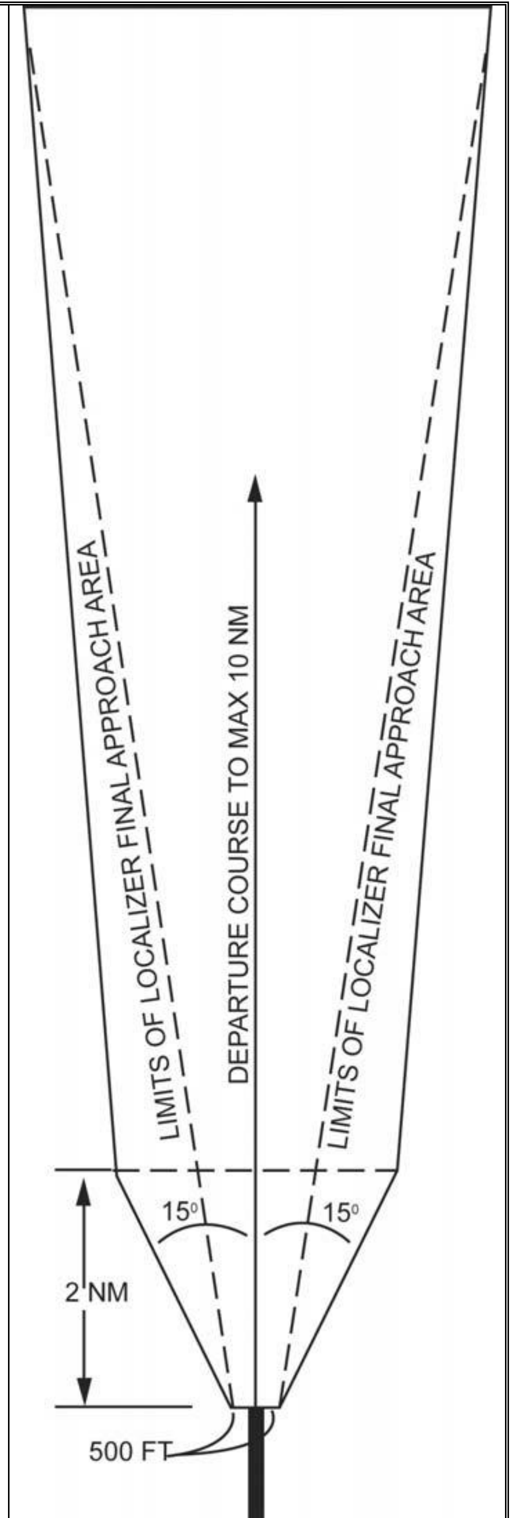

Figure 12-116H: Departure Area When Localizer Is Used For Course Guidance. Para 1203.

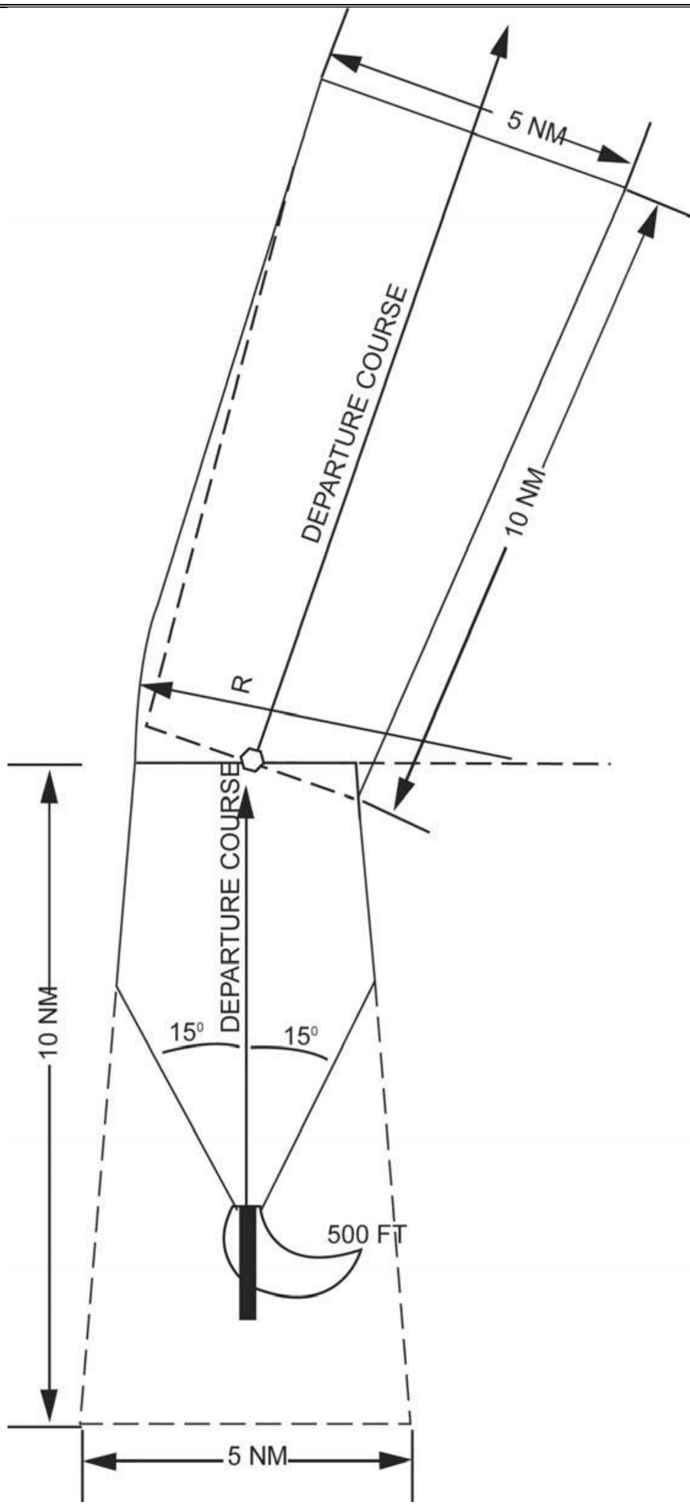

Figure 12-116I: Turn of More Than 15° But Less Than 30° Over Facility. Para 1203.a.

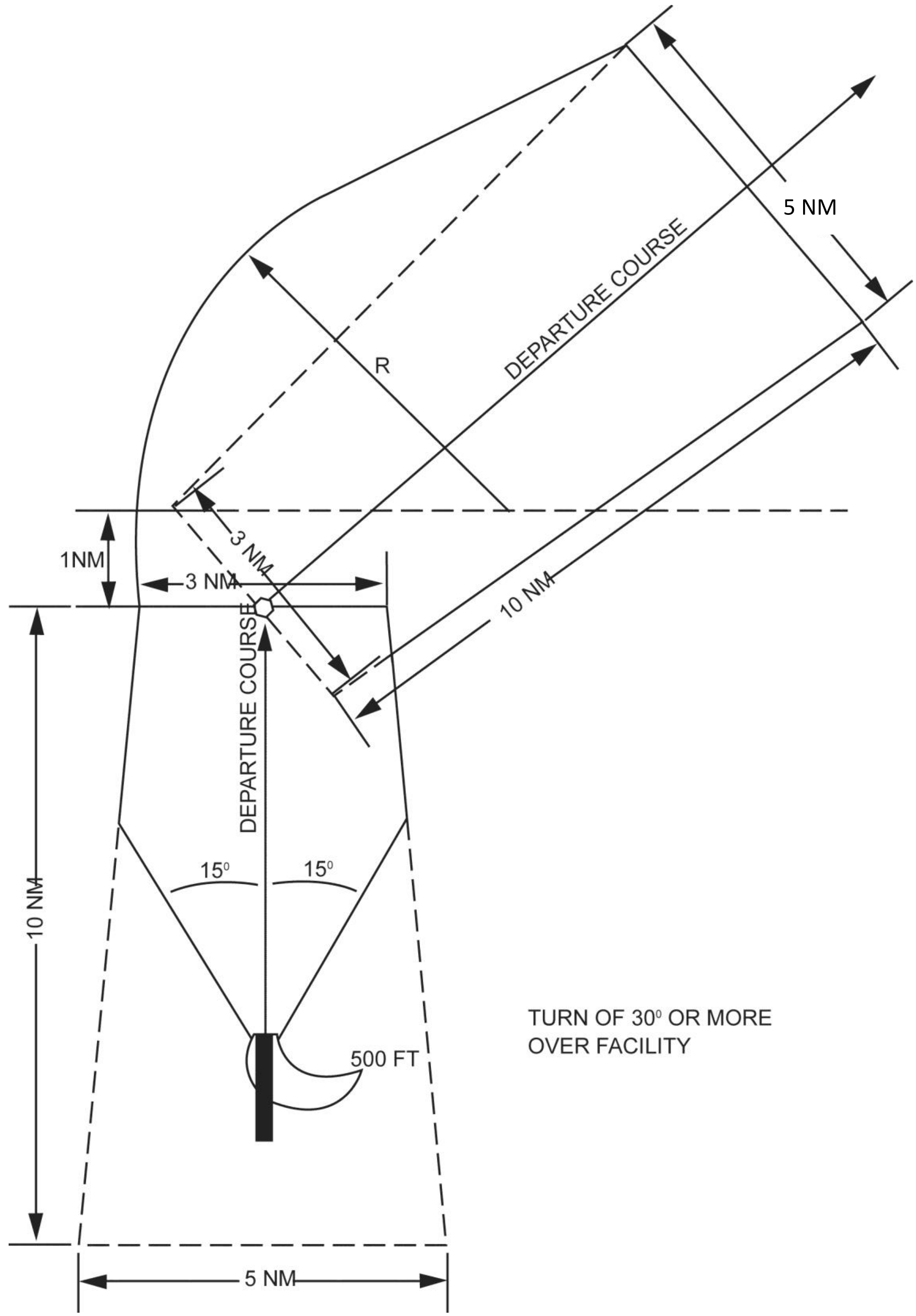

Figure 12-116J: Turn Of 30° Or More Over Facility. Para 1203.a. (1).

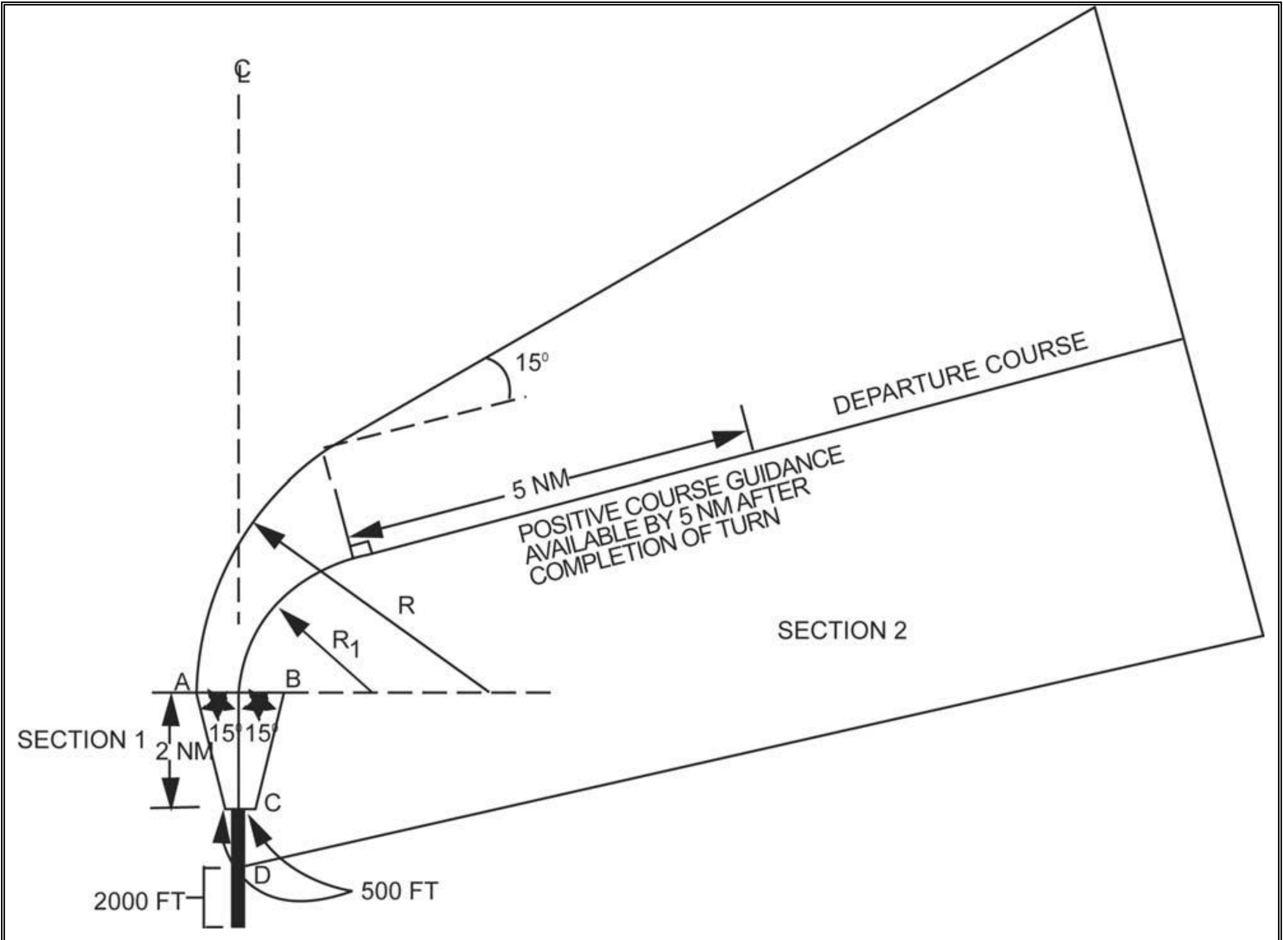

Figure 12-116K: Turning Departure. Para 1203.b.

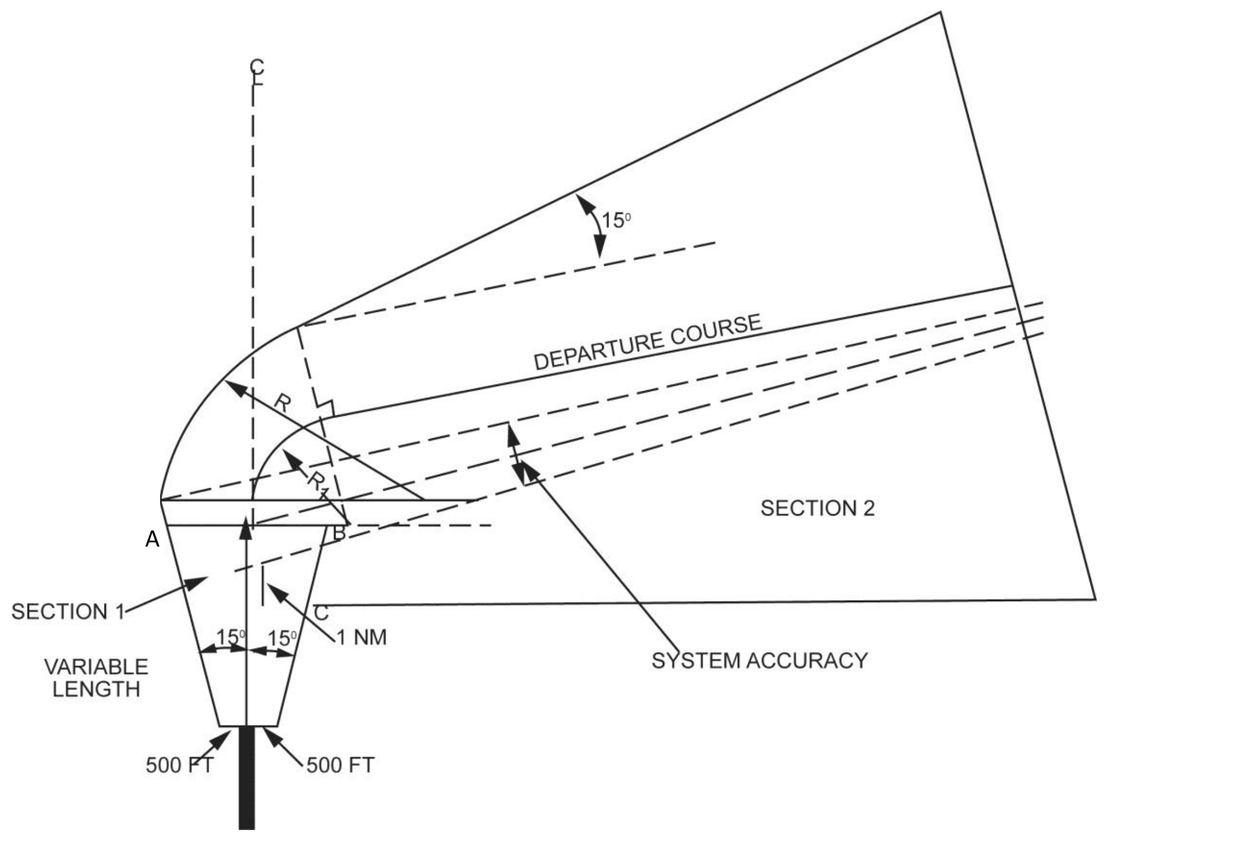

Figure 12-116L: Combination Straight And Turning Departure. Para 1203.c.

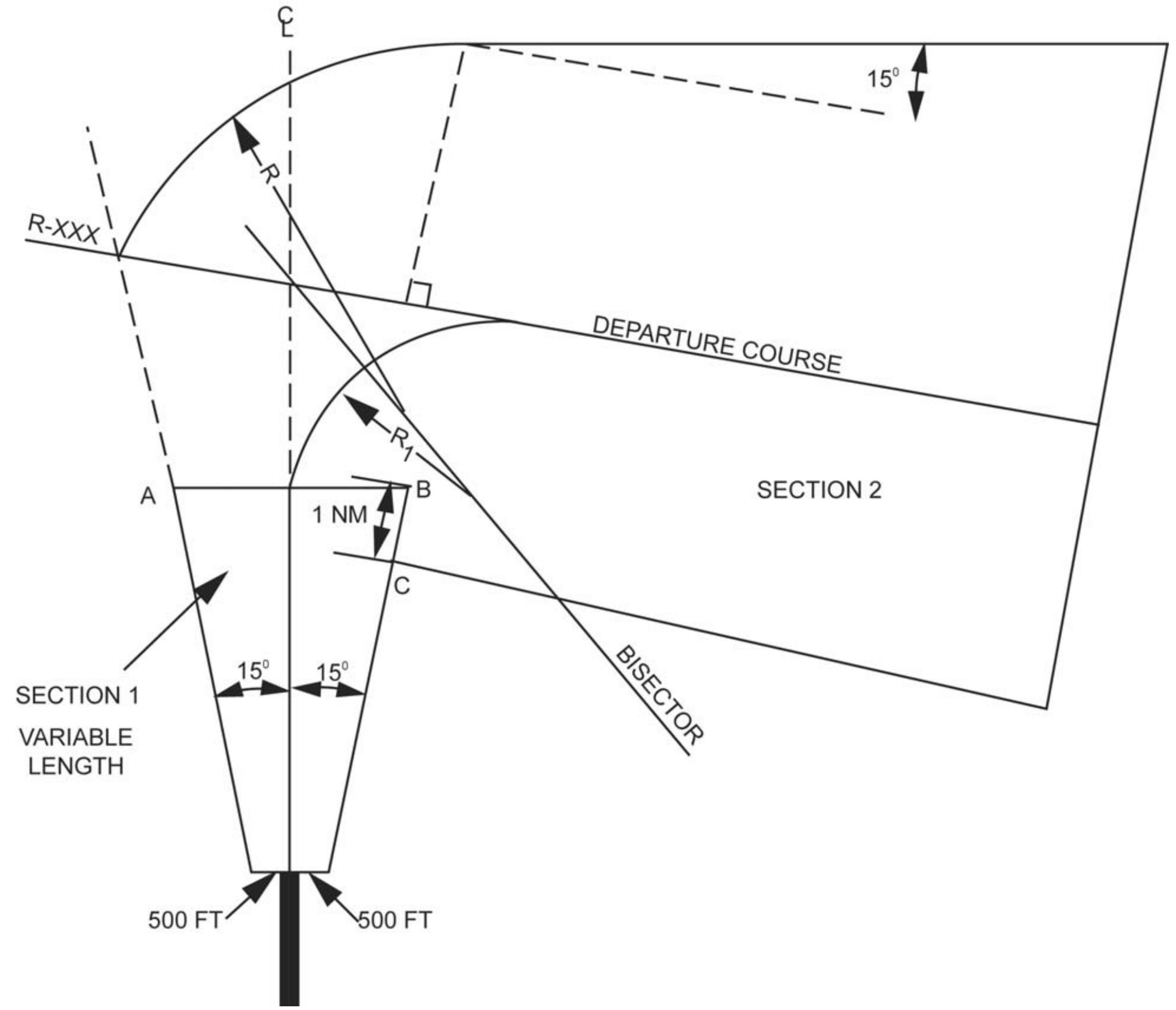

Figure 12-116M: Combination Straight And Turning Departure (To Intercept Radial Or Bearing). Para 1203.c.

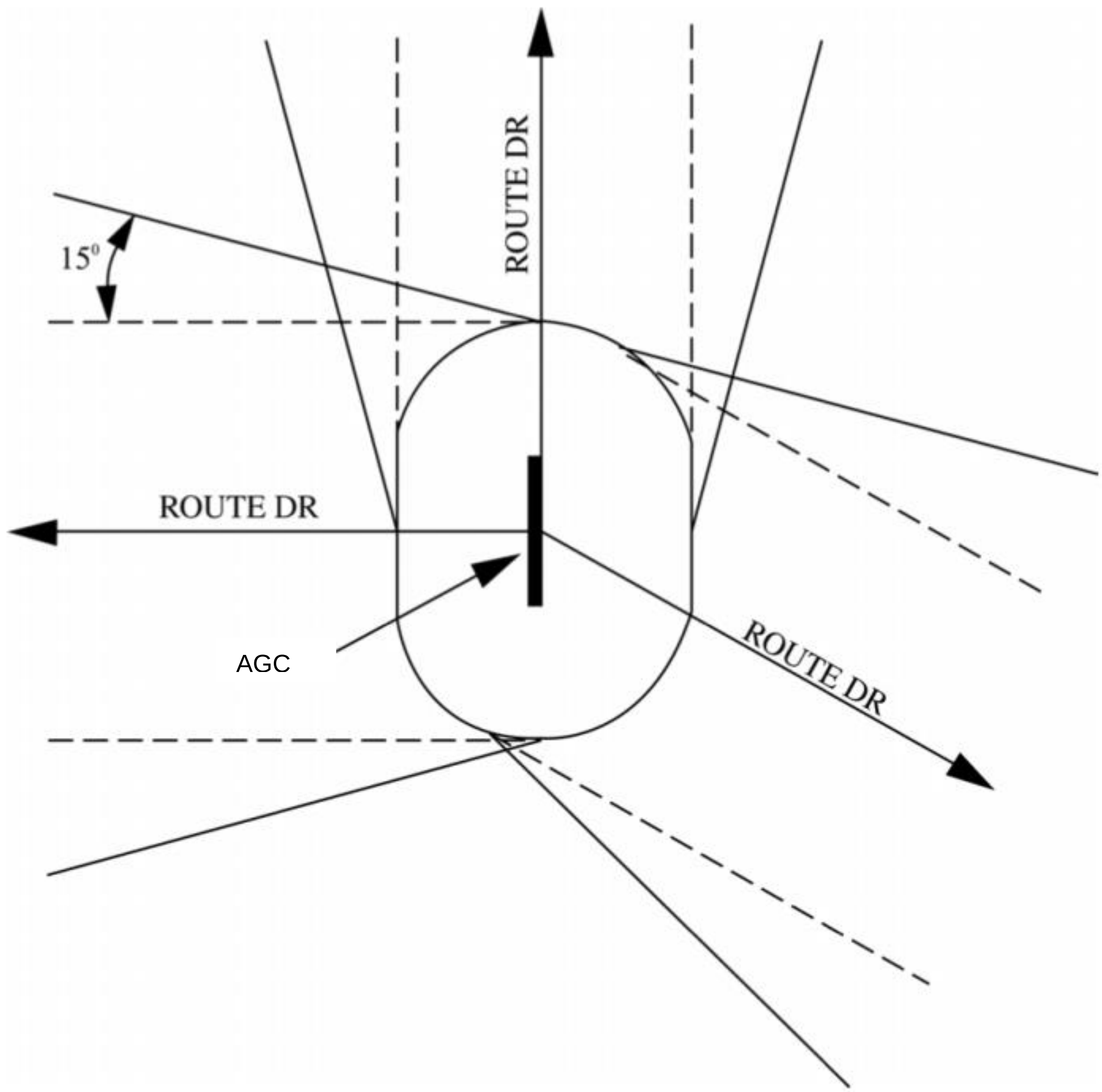

Figure 12-117: Variations Of DR Straight Departure Areas. Para 1212.b.

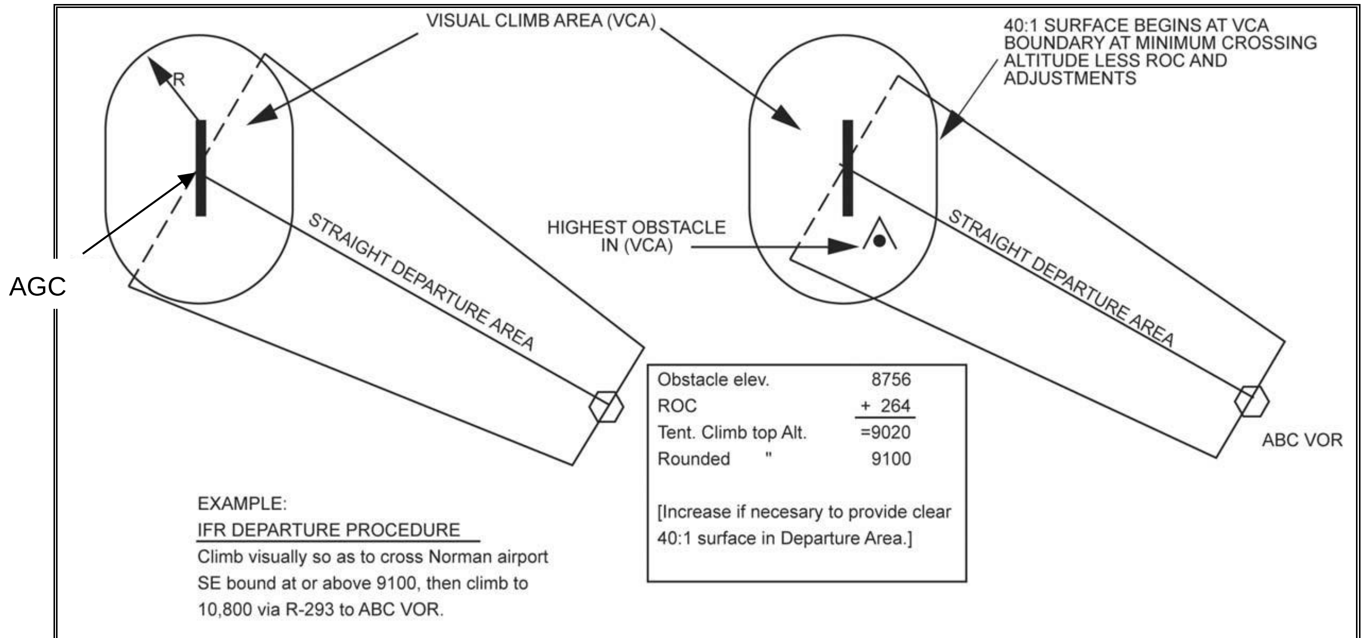

Figure 12-118: Variations Of A Straight Departure Area To A NAVAID. Para 1212 and 1213.

Supplementary Note: Add Para 323b to ROC.

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CHAPTER 17. EN ROUTE CRITERIA

1700—1709. Reserved

SECTION 1. VHF OBSTACLE CLEARANCE AREAS

1710. En Route Obstacle Clearance Areas

Obstacle clearance areas for en route planning are identified as "primary", "secondary", and turning areas.

1711. Primary Areas

a. Basic Area. The primary en route obstacle clearance area extends from each radio facility on an airway or route to the next facility. It has a width of 8 NM; 4 NM on each side of the centreline of the airway or route (see Figure 17-1).

b. System Accuracy. System accuracy lines are drawn at a 4.5° angle on each side of the course or route (see Figure 17-1). The apexes of the 4.5° angles are at the facility. These system accuracy lines will intersect the boundaries of the primary area at a point 50.8 NM from the facility. (Normally 51 NM is used.) If the distance from the facility to the change over point (COP) is more than 51 NM, the outer boundary of the primary area extends beyond the 4 NM width along the 4.5° lines (see Figure 17-2). These examples apply when the COP is at mid point. Para 1716 covers the effect of offset COP or dogleg segments.

c. Termination Point. When the airway or route terminates at a navigational facility or other radio fix, the primary area extends beyond that termination point. The boundary of the area may be defined by an arc which connects the two boundary lines. The centre of the arc is, in the case of a facility termination point, located at the geographic location of the facility. In the case of a termination at a radial or DME fix, the boundary is formed by an arc with its centre located at the most distant point of the fix displacement area on course line. Figure 17-8 and its inset show the construction of the area at the termination point.

1712. Secondary Areas

a. Basic Area. The secondary obstacle clearance area extends along a line drawn 2 NM on each side of the primary area (see Figure 17-3).

b. System Accuracy. Secondary area system accuracy lines are drawn at a 6.7° angle on each side of the course or route (see Figure 17-3). The apexes are at the facility. These system accuracy lines will intersect the outer boundaries of the secondary areas at the same point as primary lines, 51 NM from the facility. If the distance from the facility to the COP is more than 51 NM the secondary area extends along the 6.7° line (see Figure 17-4 and Para 1716.c. and d. for offset COP or dogleg airway).

c. Termination Point. Where the airway or route terminates at a facility or radio fix the boundaries are connected by an arc in the same way as those in the primary area. Figure 17-8 and its inset show termination point secondary areas.

1713. Turning Segments

a. Definition. The en route turning area may be defined as an area, which may extend the primary and secondary obstacle clearance areas when a change of course is necessary. The dimensions of the primary and secondary areas will provide adequate protection where the aircraft is tracking along a specific radial, but when the pilot executes a turn, the aircraft may go beyond the boundaries of the protected airspace. The turning area criteria supplements the airway and route segment criteria to protect the aircraft in the turn.

b. Requirement for Turning Segment Criteria. Because of the limitation on aircraft indicated air speeds below 10,000 feet MSL some conditions do not require the application of turning area airspace criteria.

(1) The graph in Figure 17-5 may be used to determine if the turning segment should be plotted for airways/routes below 10,000 feet MSL. If the point of intersection on the graph of the "amount of turn at intersection" versus "VOR facility to intersection distance" falls outside the hatched area of the graph, the turning segment criteria need not be applied.

(2) If the "amount of turn" versus "facility distance" values fall within the hatched area or outside the periphery of the graph, then the turning segment criteria must be applied as described in Para 1714.

c. Track. The flight track resulting from a combination of turn delay, inertia, turning rate, and wind effect is represented by a parabolic curve. For ease of application, a radius arc has been developed which can be applied to any scale chart.

d. Curve Radii. A 250-knot IAS, which is maximum allowed below 10,000 feet MSL, results in radii of 2 NM for the primary area and 4 NM for the secondary area up to that altitude. For altitudes at or above 10,000 feet MSL up to but not including 18,000 feet MSL the primary area radius is 6 NM and the secondary area radius is 8 NM. At and above 18,000 feet MSL the radii are 11 NM for primary and 13 NM for secondary.

e. System Accuracy. In drawing turning segments it will be necessary to consider system accuracy factors by applying them to the most adverse displacement of the radio fix or airway/route boundaries at which the turn is made. The 4.5 and 6.7° factors apply to the VOR radial being flown but since no pilot or aircraft factors exist in the measurement of an intersecting radial, a navigation facility factor of plus-or-minus 3.6° is used (see Figure 17-6).

Note: If a radio fix is formed by intersecting signals from two LF, or one LF and VOR facility, the obstacle clearance areas are based upon accuracy factors of 5.0° (primary) and 7.5° (secondary) each side of the course or route centreline of the LF facilities. If the VOR radial is the intersecting signal, the 3.6° value stated in Para 1713.e applies.

1714. Application Of Turning Segment Criteria

a. Techniques. Figures 17-8, 17-9, and 17-10 illustrate the application of the criteria. They also show areas which may be deleted from considerations when obstacle clearance is the deciding factors for establishing minimum en route altitudes (MEAs) on airways or route segments.

b. Computations. Computations due to obstacles actually located in the turning segments will probably be indicated only in a minority of cases. These methods do, however, add to the flexibility of procedures designers in resolving specific obstacle clearance problems without resorting to the use of deviations to procedures.

c. Minimum Turning Altitude (MTA). Where the application of the turn criteria obviates the use of an MEA with a cardinal altitude, the use of an MTA for a special direction of flight may be authorized.

1715. Turn Area Template

A turn area template has been designed for use on charts scaled at 1:500,000 (see Figure 17-7). It is identified as a “TA-1.”

a. Use of Template Intersection Fix.

(1) **Primary Area**. At an intersection fix the primary obstacle clearance area arc indexes are placed at the most adverse points of the fix displacement area as determined by the outer intersections of the en route radial 4.5° lines (VOR) and the cross-radial 3.6° lines (VOR) (see Figures 17-8 and 17-9). If LF signals are used the 5.0° system accuracy lines apply. The parallel dashed lines on the turn area template are aligned with the appropriate system accuracy lines and the curves are drawn.

(2) **Secondary Area "Outside" Curve**. The outside curve of the secondary area is the curve farthest from the navigation facility that provides the intersecting radial. This curve is indexed to the distance from the fix to the en route facility as follows:

(a) Where the fix is less than 51 NM from the en route facility, the secondary arc is started at a point 2 NM outside the primary index with the parallel dashed lines of the template aligned on the 4.5° lines (see Figure 17-8).

(b) Where the fix is farther than 51 NM from the en route station, the arc is started at the point of intersection of the 3.6 and 6.7° lines with the parallel dashed lines of the template aligned on the 6.7° lines (see Figure 17-9).

(3) **Secondary Area "Inside" Curve**. The inside curve is the turning segment arc which is nearest the navigation facility which provides the intersecting radial. This arc is begun 2 NM beyond the primary index and on the 3.6° line. The parallel dashed lines on the turning segment template are aligned with the 4.5° lines from the en route station.

(a) Where the fix is less than 51 NM from the en route facility and the magnitude of the turn is less than 30°, the "inside" curves do not affect the size of the secondary area.

(b) Where the distance from the en route facility to the fix is more than 51 NM but the magnitude of the turn is less than 45°, the "inside" curves do not increase the size of the secondary area.

(c) Where the magnitude of the turn is greater than those stipulated in (a) and (b) the "inside" curves will affect the size of the secondary area.

(d) Whether the secondary area curves affect the size of the secondary obstacle clearance area or not, they must be drawn to provide reference points for the tangential lines described in (4) below.

(4) **Connecting Lines**. Tangential straight lines are now drawn connecting the two primary arcs and the two secondary arcs. The outer limits of both curves are symmetrically connected to the respective primary and secondary area boundaries in the direction of flight by lines drawn at a 30° angle to the airway or route centreline (see Figures 17-9 and 17-10).

b. Use of Template When Fix Overheads A Facility (see Figure 17-10). The geographical position of the fix is considered to be displaced laterally and longitudinally by 2 NM at all altitudes.

(1) **Primary Arcs**. The primary arcs are indexed at points 2 NM beyond the station and 2 NM on each side of the station. The parallel dotted lines on the template are aligned with the airway or route boundaries and the curves drawn.

(2) **Secondary Arcs**. The secondary arcs are indexed 2 NM outside the primary points, and on a line with them. The parallels dotted lines on the template are aligned with the airway or route boundaries and the curves drawn.

(3) **Connection Lines**. Tangential straight lines are now drawn connecting the two primary and the two secondary arcs. The outer limits of both curves are connected to the primary and secondary area boundaries by intercept lines, which are drawn 30° to the airway or route centreline. The 30° lines on the template may be used to draw these intercept lines.

c. Deletion Areas. Irregular areas remain on the outer corners of the turn areas (see Figures 17-8, 17-9, and 17-10). These are the areas identified in Para 1714 which may be deleted from consideration when obstacle clearance is the deciding factor for determination of MEA on an airway or route segment.

(1) Where the "outside" secondary area curve is started within the airway or route secondary area boundary (see Figure 17-8), the area is blended by drawing a line from the point where the 3.6° (5.0° with LF facility) line meets the line which forms the en route secondary boundary tangent to the "outside" secondary arc. Another line is drawn from the point where the same 3.6° (or 5.0°) line meets the line, which forms the primary boundary, tangent to the matching primary arc. These two lines now enclose the secondary area at the turn. The corner, which was formerly part of the secondary area, may be disregarded; the part, which was formerly part of the primary area, may now be considered secondary area. These areas are shaded in Figure 17-8.

(2) Where the secondary curve is indexed on the secondary area boundary formed by the 6.7° lines, the arc itself cuts the corner and prescribes the deleted area (see Figure 17-9). This condition occurs when the radio fix is over 51 NM from the en route navigation facility.

(3) When overheading the facility, the secondary area corner deletion area is established by drawing a line from a point opposite the station index at the secondary area boundary, tangent to the secondary "outside" curve (see Figure 17-10). A similar line is drawn from a point opposite the station index at the primary area boundary, tangent to the primary turning arc. The corner formerly part of the primary area now becomes secondary area. Shading in Figure 17-10 shows the deletion areas.

1716. Change Over Points (COP)

Points have been defined between navigation facilities along airway/route segments, which are called "change over points (COP)". These points indicate that the pilot using the airway/route should "change over" the navigation equipment to receive course guidance from the facility ahead of the aircraft instead of the one behind. These COP divide a segment and assure continuous reception of navigation signals at the prescribed minimum enroute IFR altitude (MEA). They also assure that aircraft operating within the same portion of an airway or route segment will not be using azimuth signals from two different navigation facilities. Where signal coverage from two facilities overlaps at the MEA, the COP will normally be designated at the mid point, and is not shown on the chart. Where radio frequency interference or other navigation signal problems exist, the COP will be at the optimum location, taking into consideration the signal strength, alignment error, or any other known condition, which affects reception. The effect, of COP on the primary and secondary obstacle clearance areas is as follows:

- **a. Short Segments**. If the airway or route segment is less than 102 NM long and the COP is placed at the mid point, the obstacle clearance areas are not affected (see Figure 17-11).
- **b. Long Segments**. If the distance between two facilities is over 102 NM and the COP is placed at the mid point, the system accuracy lines extend beyond the minimum widths of 8 and 12 NM, and a flare results at the COP (see Figure 17-12).
- **c. Offset Cop**. If the change over point is offset due to facility performance problems, the system accuracy lines must be carried from the farthest facility to a position abeam the change over point, and these lines on each side of the airway or route segment at the COP are joined by lines drawn from the nearer facility. In this case the angles of the lines drawn from the nearer facility have no specific angle (see Figure 17-13).
- **d. Dogleg Segment**. A dogleg airway or route segment may be treated in a manner similar to that given offset COPs. The system accuracy lines will be drawn to meet at a line drawn as the bisector of the dogleg "bend" angle and the boundaries of the primary and secondary areas extended as required (see Figure 17-14).

1717. Course Change Effect

The complexity of defining the obstacle clearance areas is increased when the airway or route becomes more complex. Figure 17-15 shows the method of defining the primary area when a radio fix and a COP are involved. Note that the system accuracy lines are drawn from the farthest facility first, and govern the width of the airway or route at the COP. The application of secondary area criteria results in a segment similar to that depicted in Figure 17-16.

1718. Reserved

1719. Protected En Route Areas/Segments

As previously established, the en route areas, which must be considered for obstacle clearance protection, are identified as primary and secondary turn areas. The overall consideration of these areas is necessary when determining obstacle clearances.

SECTION 2. VHF OBSTACLE CLEARANCE

1720. Obstacle Clearance, Primary Area

a. Non-Mountainous Regions. The minimum obstacle clearance over areas not designated as, mountainous will be 1,000 feet over the highest obstacle.

b. Mountainous Areas. Owing to the action of Bernoulli Effect and of atmospheric eddies, vortices, waves, and other phenomena, which occur in conjunction with the disturbed airflow attending the passage of strong winds over mountains, pressure deficiencies manifested as very steep horizontal pressure gradients develop over such regions. Since down drafts and turbulence are prevalent under these conditions, the hazards to air navigation are multiplied. Except as set forth in (1) below, the minimum obstacle clearance over terrain and manmade obstacles, within designated mountainous regions will be 2,000 feet.

(1) Obstacle clearance may be reduced to not less than 1,500 feet above terrain and manmade obstacles within the designated mountainous regions located in eastern Canada which includes part of Quebec, New Brunswick and Newfoundland as described in TP 1820 DAH/GPH 204.

Note: Altitudes of 1,000 feet of obstacle clearance within designated mountainous regions may be provided on airways/routes located within terminal areas. That segment is to be identified by a fix or facility.

1721. Obstacle Clearance, Secondary Areas

In all areas, mountainous and non-mountainous, obstacles which are located in the secondary areas will be considered as obstacles to air navigation when they extend above the secondary obstacle clearance plane. This plane begins at a point 500 feet above the obstacles upon which the primary obstacle clearance area MOCA is based, and slants upward at an angle which will cause it to intersect the outer edge of the secondary area at a point 500 feet higher (see Figure 17-17). Where an obstacle extends above this plane, the normal MOCA shall be increased by adding to the MSL height of the highest penetrating obstacle in the secondary area the required clearance (C), computed with the following formula:

$$\frac{D_1}{D_2} = \frac{500}{C} \text{ or } C = \frac{500 \times D_2}{D_1}$$

D_1 is the total width of the secondary area.

D_2 is the distance from the obstacle to the OUTER edge of the secondary area.

Note: Add an extra 1,000 feet in mountainous regions where 2,000 feet of obstacle clearance is provided and 500 feet in the region where 1,500 feet of obstacle clearance is provided.

D_1 has a total width of 2 NM, or 12,152 feet out to a distance of 51 NM from the en route facility, and then increases at a rate of 236 feet for each additional NM.

Example: An obstacle which reaches 1,875 feet MSL is found in the secondary area 6,170 feet inside the outer secondary area boundary and 46 NM from the facility (see Figures 17-17 and 17-18).

D_1 is 12,152 feet
D_2 is 6,170 feet

$$\frac{500 \times 6{,}170}{12{,}152} = 253.8 \text{ (254 feet)}$$

Obstacle height (1,875) + 254 = 2,129.
MOCA is 2,200 feet.

1722. Obstacle Clearance Graph

Figure 17-19 is a secondary area obstacle clearance graph, designed to allow the determination of clearance requirements without using the formula. The left axis shows the required obstacle clearance; the lower axis shows the distance from the outer edge of the secondary area to the obstacle. The slant lines are facility distance references.

Facility distances, which fall between the charted values, may be found by interpolation along the vertical distance lines.

a. Application. To use the secondary area obstacle clearance chart, enter with the value representing the distance from the outer edge of the secondary area to the obstacle. In the problems above this distance was 6,170 feet. Proceed up to the "51 NM or less" line and read the clearance requirement from the left axis. The chart reads 254 feet, the same as was found using the formula. To solve the second problem, re-enter the chart at 6,170 feet and move vertically to find 68 NM between the 60 and 70 NM facility distance slant lines. The clearance requirement shown to the left is 191 feet, the same as found using the formula.

b. Finding the MOCA. The required clearance, found by using the graph, is now added to the MSL height of the obstacle to get the MOCA.

(1) 46 NM from facility:

254 + 1,875 = 2,129 (2,200 MSL).

(2) 68 NM from facility:

191 + 1,875 = 2,066 (2,100 MSL).

1723—1729. Reserved

SECTION 3. ALTITUDES

1730. Minimum Reception Altitudes (MRA)

It is necessary to establish MRAs in all cases where designated intersections along airways or routes are formed by intersecting radials that require higher altitudes for the reception of that radial than the established MEA along the airway or route segment.

1731. En Route Minimum Holding Altitudes

The criteria contained herein deal with the clearance of holding aircraft from obstacles.

a. Area. The primary obstacle clearance area for holding shall be based on the appropriate holding pattern airspace area specified in Chapter 18. No reduction in the pattern sizes for "on-entry" procedures is permitted. In addition, when holding is at an intersection fix, the selected pattern shall also be large enough to contain at least 3 corners of the fix displacement area (see Paras 284 and 285, and Figure 18-2). A secondary area 2 NM wide surrounds the perimeter of the primary area.

b. Obstacle Clearance. The minimum obstacle clearance of the route shall be provided throughout the primary area. In the secondary area 500 feet of obstacle clearance shall be provided at the INNER edge, tapering to zero feet at the outer edge. For computation of obstacle clearance in the secondary area, the computational formula specified in Para 1721 shall be applied. Allowance for precipitous terrain should be considered as stated in Para 323.a. The altitudes selected by application of the obstacle clearance specified shall be rounded to the next higher 100-foot increment.

c. Communications. The communications on appropriate ATC frequencies (as determined by ATS) shall be required throughout the entire holding pattern area from the MHA up to and including the maximum holding altitude. If the communications are not satisfactory at the minimum holding obstacle clearance altitude, the MHA shall be authorized at an altitude where the communications are satisfactory.

1732. Minimum En Route Altitudes (MEA)

An MEA will be established for each segment of an airway/route from radio fix to radio fix. The MEA will be established based upon obstacle clearance over the terrain or over manmade objects, adequacy of navigation facility performance, and communications requirements. The MEA shall also be at or above the base of controlled airspace. Segments are designated West to East and South to North. Altitudes will be established to the nearest 100-foot increment; i.e. 4,049 feet becomes 4,000 feet; and 4,050 feet becomes 4,100, as long as the minimum required obstacle clearance is not violated.

Note: Care must be taken to insure that all MEAs based upon flight inspection information have been corrected to and reported as true altitudes above mean sea level (MSL).

1733—1739. Reserved

SECTION 4. NAVIGATION GAP

1740. Navigational Gap Criteria

Where a gap in course guidance exists, an airway or route segment may be approved in accordance with the criteria set forth in Para 1740.c, provided:

a. Restrictions.

(1) The gap may not exceed a distance which varies directly with altitude from zero NM at sea level to 65 NM at 45,000 feet MSL;

(2) Not more than one gap may exist in the airspace structure for the airway/route segment;

(3) A gap may not occur at any airway or route turning point, except when the provisions of Para 1740.b.(2) are applied; and

(4) Where the MEA has been established with a gap in navigational signal coverage, the gap area will be identified by distance from the navigation facilities on the chart, depicting the airway/route segments.

b. Authorization. MEAs with gaps shall be authorized only where a specific operational requirement exists. Where gaps exceed the distance in Para 1740.a.(1), or are in conflict with the limitations in Para 1740.a.(2) or (3), the MEA must be increased as follows:

(1) For straight segments:

(a) To an altitude which will meet the distance requirement of Para 1740.a.(1), or;

(b) When in conflict with Para 1740.a.(1) or (2) to an altitude where there is continuous course guidance available.

(2) For turning segments. Turns to intercept radials with higher MEAs may be allowed provided;

(a) The increase in MEA does not exceed 1500 feet; and

(b) The turn does not exceed 90°.

(3) When in conflict with Para 1740.b.(1) or (2) to an altitude where there is continuous course guidance available.

c. Use Of Steps. Where large gaps exist which require the establishment of altitudes that obviate the effective use of airspace, consideration may be given to the establishment of MEA "steps". These steps may be established at increments of not less than 2,000 feet below 18,000 feet MSL, or not less than 4000 at 18,000 and above, provided that a total gap does not exist for the segment within the airspace structure. MEA steps shall be limited to one step between any two facilities to eliminate continuous or repeated changes to altitude in problem areas. MEA changes shall be identified by designated radio fixes.

d. Gaps. Allowable navigational gaps may be determined by reference to the graph in Figure 17-23.

EXAMPLE: The problem drawn on the chart shows the method used to determine the allowable gap on a route segment with a proposed MEA of 27,000 feet. Enter the graph at the left edge with the MEA of 27,000 feet. Move to the right to the interception of the diagonal line. Move to the bottom of the graph to read the allowable gap. In the problem drawn, a 39 NM gap is allowable.

1741—1749. Reserved

SECTION 5. LOW FREQUENCY AIRWAYS OR ROUTES

1750. LF Airways Or Routes

a. Usage. LF navigation facilities may be used to establish en route airway/route segments.

b. Obstacle Clearance Areas (see Figures 17-24 and 17-25).

(1) The primary obstacle clearance area boundaries of LF segments are lines drawn 4.34 NM (5 statute miles) on each side of and parallel to the segment centreline. These boundaries will be affected by obstacle clearance area factors shown in Para 1750.c.

(2) The LF secondary obstacle clearance areas extend laterally for an additional 4.34 NM on each side the primary area. The boundaries of the secondary areas are also affected by the obstacle clearance areas factors shown in c. below.

c. Obstacle Clearance Area Factors (see Figures 17-24 and 17-25).

(1) The primary of LF segments is expanded in the same way as for VHF airways/routes. Lines are drawn at 5° off the course centreline from each facility. These lines meet at the mid point of the segment. Penetration of the 4.34 NM boundary occurs 49.61(50) NM from the facility.

(2) The secondary areas are expanded in the same manner as the secondary areas for VHF airways/routes. Lines are drawn 7.5° on each side of the segment centreline. These 7.5° lines will intersect the original 8.68 NM secondary area boundaries at 65.93 (66) NM from the facility.

d. Obstacle Clearance

(1) Obstacle clearance in the primary area of LF airways or routes is the same as that required for VOR airways/routes. The areas over which the clearances apply are different, as shown in Para 1750.c.

(2) Secondary area obstacle clearance requirements for LF segments are based upon distance from the facility and location of the obstacle relative to the inside boundary of the secondary area.

(a) Within 25 NM of the facility the obstacle clearance is based upon a 50:1 plane drawn from the primary area boundary 500 feet above the obstacle, which dictates its MOCA and extending to the edge of the secondary area. When obstacles penetrate this 50:1 plane, the MOCA for the segment will be increased above that dictated for the primary area obstacle as detailed in Table 17-1.

(b) Beyond the 25 NM distance from the facility, the secondary obstacle clearance plane is flat. This plane is drawn from the primary area boundary 500 feet above the obstacle, which dictates its MOCA and extending to the edge of the secondary area. If an obstacle penetrates this surface the MOCA for the segment will be increased so as to provide 500 feet of clearance over the obstacle (see Figure 17-27 and Para 1750.d.(2)(c)).

(c) Obstacle clearance values shown in (a) and (b) above are correct for non-mountainous, areas only. For areas designated as mountainous add 1,000 feet, or 500 feet, as applicable.

1751. LF/MF Facility to VHF/UHF Facility Airway or Air Route

Airways and air routes may be constructed between LF/MF and VHF/UHF facilities. The criteria for area construction and obstacle clearances are contained in the appropriate section within this chapter. However, due to the different system accuracies (primary area 4.5° for VHF/UHF and 5.0° for LF/MF and secondary area 6.7° for VHF/UHF and 7.5° for LF/MF), to ensure proper obstacle assessment for the entire airway or air route, primary and secondary LF/MF system accuracy criteria shall be applied for the entire length of the airway or air route between the LF/MF and VHF/UHF facility.

This means that when constructing the airway or air route, the LF/MF primary obstacle clearance area of 4.34 NM each side of centerline and the secondary obstacle clearance area of 4.34 NM each side of the primary area shall be applied for the entire airway or air route. In addition, the LF/MF primary area shall be expanded 5.0° off the course centerline from each facility and the secondary area shall be expanded 7.5° off the course centerline from each facility for the entire airway or air route.

1752. Application Of Variation To Calculate LF/MF Tracks

When calculating airway or air route tracks, the appropriate variation shall be applied to the LF/MF segment true bearing to ensure that the aircraft will be positioned on the desired inbound radial at the COP. Proper application of variation is necessary to minimize track error and to ensure the aircraft is positioned on course at the changeover point. This calculation is made from facility to facility and NOT redone for each airway segment between fixes.

If midpoint variation were to be used (see Figure 17-29A) this does not happen. The aircraft heading would initially overcorrect, based on the difference between local variation at the site and the midpoint variation. This over correction will decrease as the aircraft proceeds toward the midpoint, at which time the aircraft would be flying on the proper heading but has not corrected back to the desired track .On a long leg, the resulting track error can be greater than 20nm.

Therefore, to minimize this error and to position the aircraft on the desired track at the midpoint of the airway/air route, ¼ point variation shall be used (see Figure 17-29B). Due to the difference between the local variation at the aircrafts position and the ¼ point variation, the aircraft heading will initially overcompensate, resulting in a track error. As the aircraft proceeds, this error will decrease until at the ¼ point the aircraft will be flying the proper heading but now be just parallel to the desired track. As the aircraft proceeds toward the midpoint it will begin to correct back and ideally be on the desired track at the midpoint (see Figure 17-29B).

Using the same basic rational, in the instance of a dogleg or published COP, the variation to the LF/MF leg shall be the variation at the mid point of that particular segment (see Figure 17-29C).

In summary, the variation(s) to apply to the LF/MF track calculations shall be as follows:

a. LF/MF to LF/MF

¼ point variation (see Figure 17-29B).

b. LF/MF to VHF/UHF

¼ point variation for the LF/MF segment (see Figure 17-29C).

The VHF/UHF Radial shall be calculated based on the calibrated variation used for that facility. These values are published in the Canada Flight Supplement, Part D.

c. COP/Dogleg Segment

Mid-point variation for the LF/MF-COP segment shall be used to calculate the track (see Figure 17-29C).

The VHF/UHF-COP segment track will be calculated in accordance with Para 1752.b.2.

1753—1759. Reserved

SECTION 6. MINIMUM DIVERGENCE ANGLES

1760. General

a. Governing Facility. The governing facility for determining the minimum divergence angle depends upon how the fix is determined.

(1) Where the fix is predicated on an off-course radial or bearing, the distance from the fix to the facility providing the off-course radial or bearing is used.

(2) Where the fix is predicated on the radials or bearings of two intersecting airways or routes, the distance between the farthest facility and the fix will be used to determine the angle.

b. Holding. Where holding is to be authorized at a fix, the minimum divergence angle is 45°.

1761. VHF Fixes

a. The minimum divergence angle for those fixes formed by intersecting VHF radials are determined as follows:

(1) When both radio facilities are located within 30 NM of the fix, the minimum divergence is 30°.

(2) When the governing facility is over 30 NM from the fix, the minimum allowable angle will be increased at the rate of 1° per NM up to 45 NM (45°).

(3) Beyond 45 NM, the minimum divergence angle increases at the rate of ½° per NM.

EXAMPLE: Distance from fix to governing facility is 51 NM.

51 - 45 = 6 NM. x ½ = 3 additional degrees.

Add this 3° to the 45° required at 45 NM and get 48° minimum divergence angle at 51 NM.

b. Figure 17-28 may be used to define minimum divergence angles. Using the foregoing example, enter the chart at the bottom with the facility distance (51 NM). Move up to the "VHF Fix" conversion line. Then move to the left to read the angle – 48°.

1762. LF or VHF/LF Fixes

a. Minimum divergence angles for LF or integrated (VHF/LF) fixes are determined as follows:

(1) When the governing facility is within 30 NM of the fix, the minimum divergence angle is 45°.

(2) Beyond 30 NM the minimum angle must be increased at the rate of 1° for each NM, except for fixes on long over water routes where the fix will be used for reporting purposes and not for traffic separation.

EXAMPLE: The distance from the governing facility is 51 NM.

51 - 30 = 21

Add 21° to 45° required at 30 NM to get the required divergence angle, 66°.

b. Figure 17-28 may be used to define minimum angles for LF or VHF/LF fixes. Using the foregoing example, enter at the bottom of the chart with the 51 NM distance between the facility and fix. Move up to the "LF or INTEGRATED FIX" conversion line, then left to read the required divergence angle, 66°.

1763—1799. Reserved

Distance from Primary Boundary	Height added to Obstacle in the Secondary Area
0 – 1 SM (0.00 – 0.87 NM)	500 feet
> 1 – 2 SM (0.87 – 1.74 NM)	400 feet
> 2 – 3 SM (1.74 – 2.61 NM)	300 feet
> 3 – 4 SM (2.61 – 3.48 NM)	200 feet
> 4 – 5 SM (3.48 – 4.34 NM)	100 feet
Note: See Figure 17-23 for cross section view. Also Para 1750.d.(2)(c)	

Table 17-1: Increase To MOCA When 50:1 Obstacle Clearance Plane Penetrated. Para 1750.d.(2)(a)

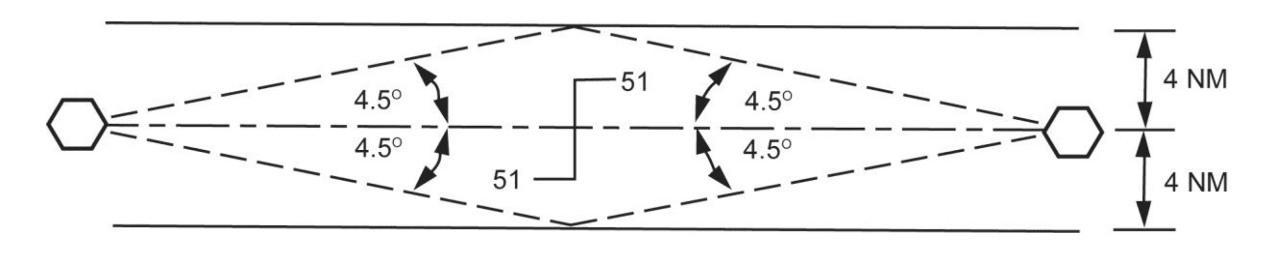


Figure 17-1: Primary Obstacle Clearance Area. Para 1711.a.

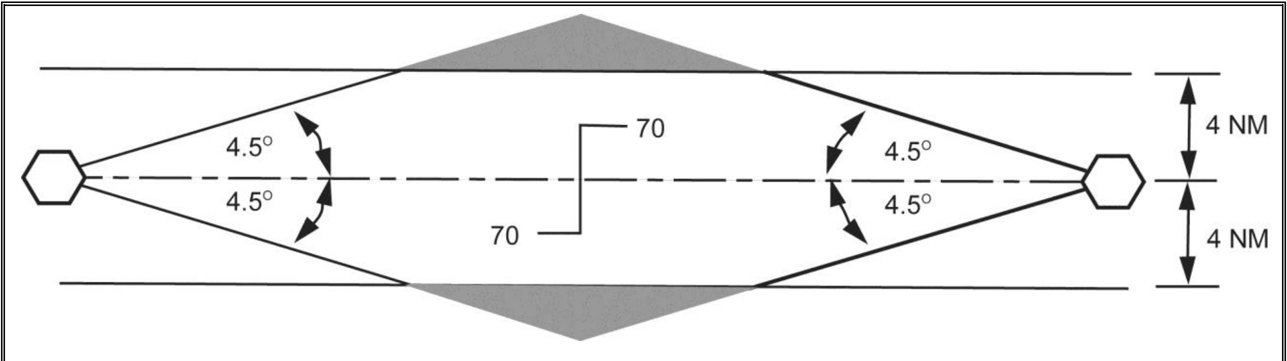


Figure 17-2: Primary Obstacle Clearance Area. Para 1711.b.

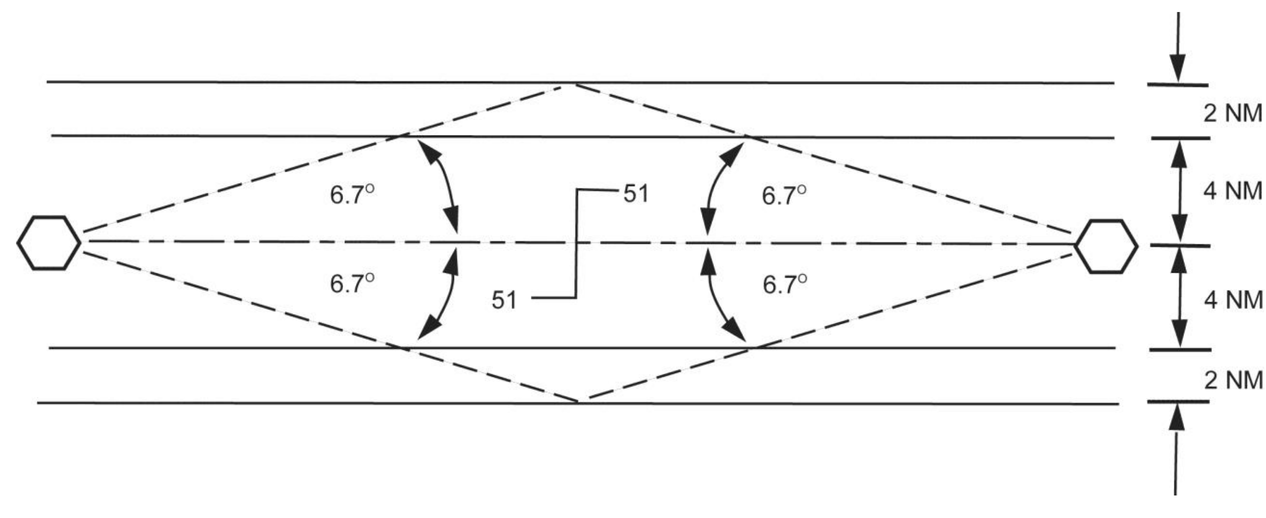


Figure 17-3: Secondary Obstacle Clearance Areas. Para 1712.a.

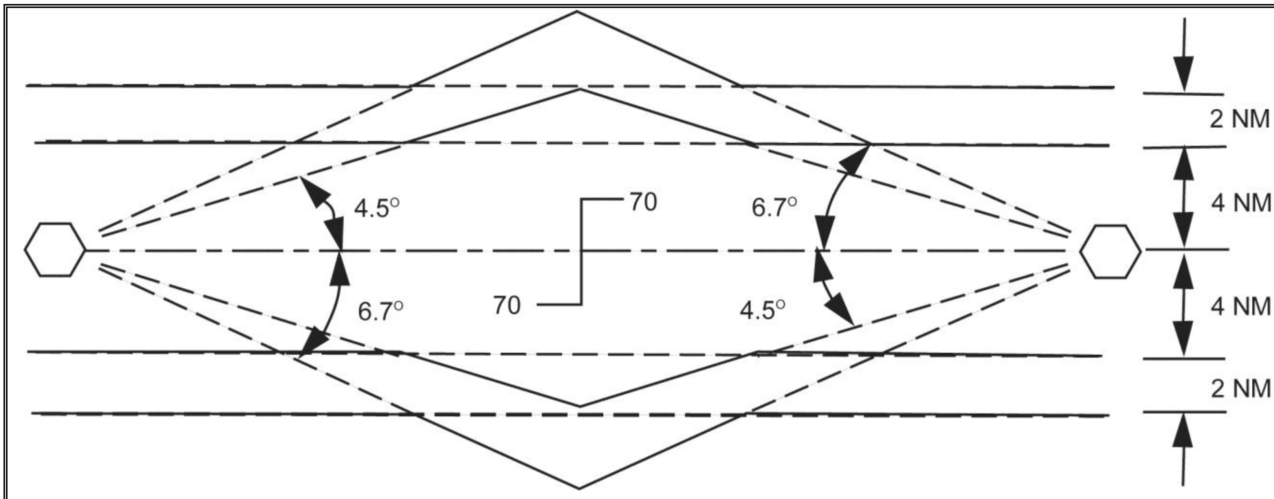


Figure 17-4: secondary obstacle clearance areas. Application of system accuracy lines. Para 1712.b.

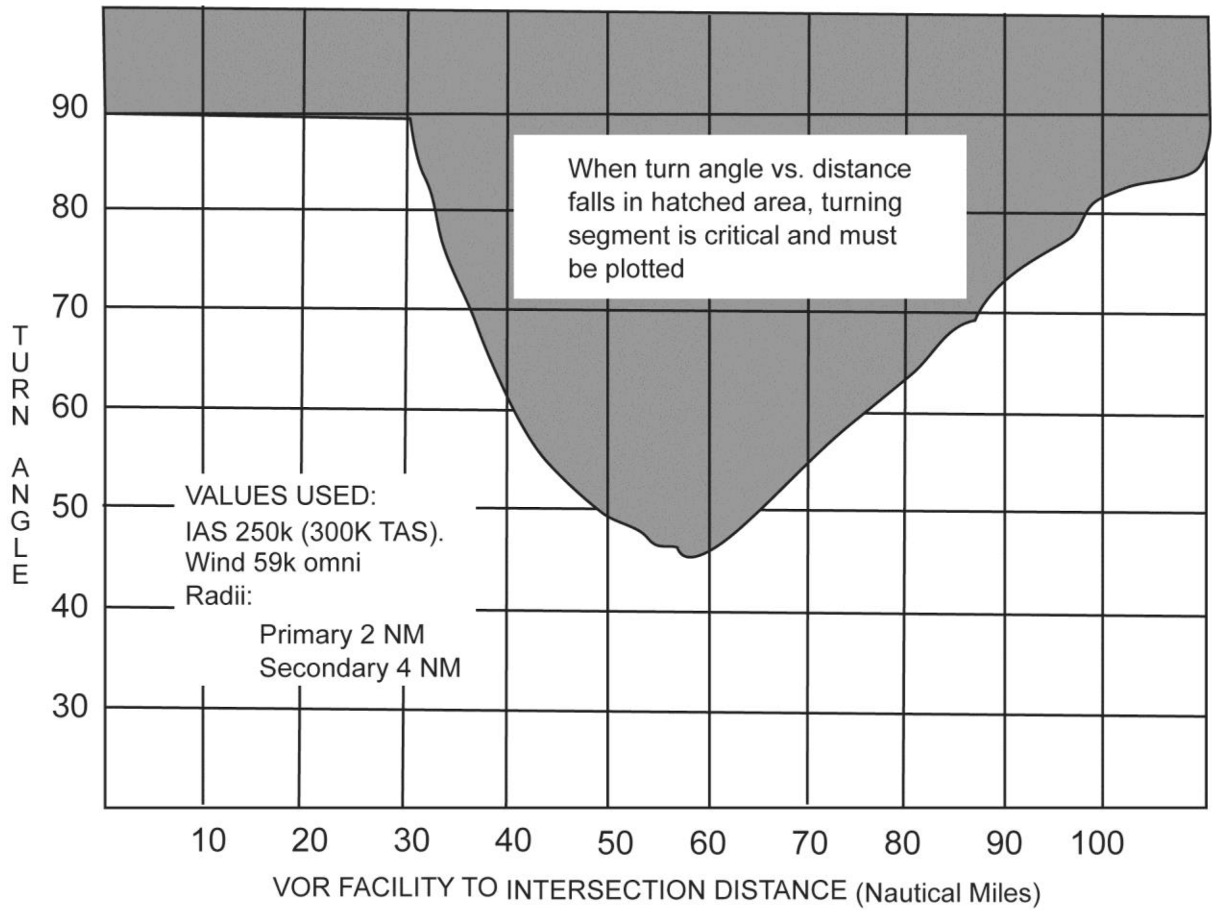


Figure 17-5: Turn Angle vs Distance. Para 1713.b (1) and (2).

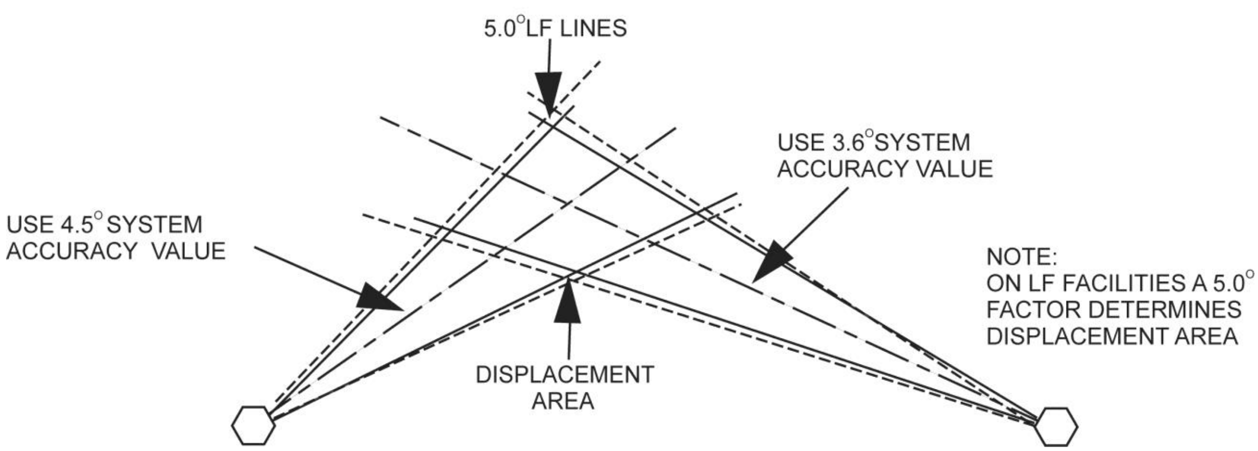


Figure 17-6: Fix Displacement. Para 1713.e.

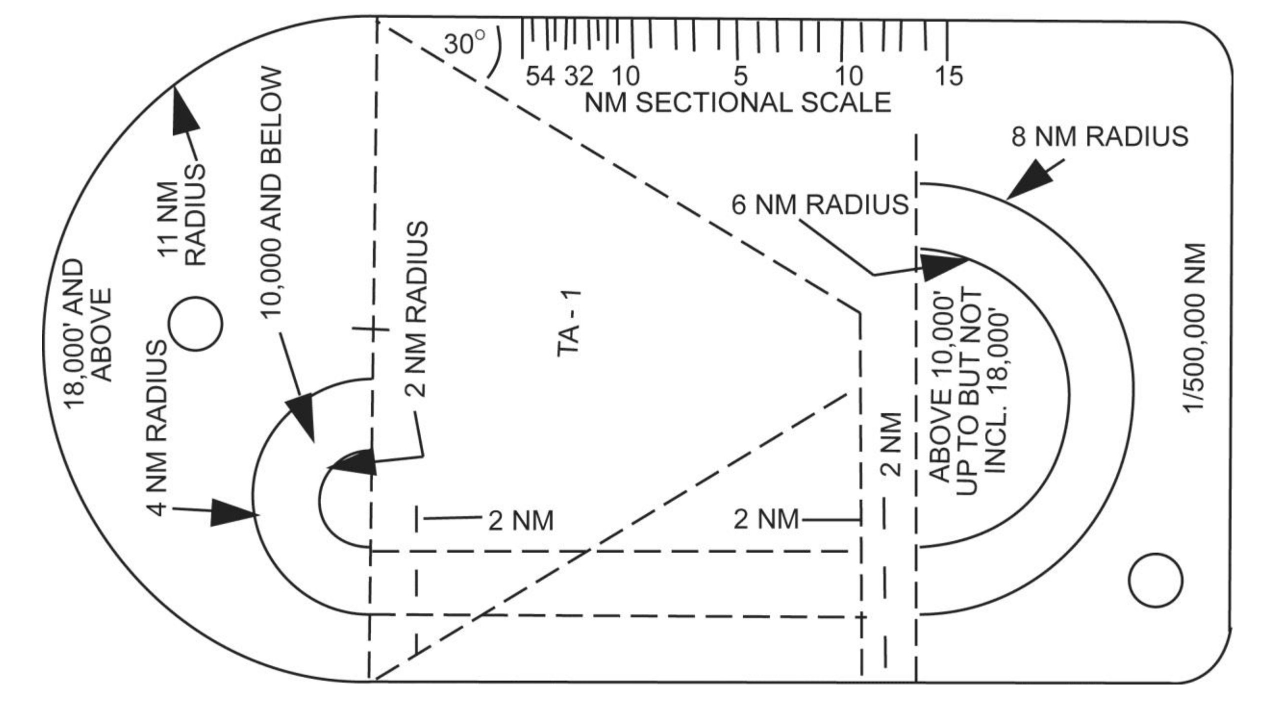


Figure 17-7: Turning Segment Template. Para 1715.

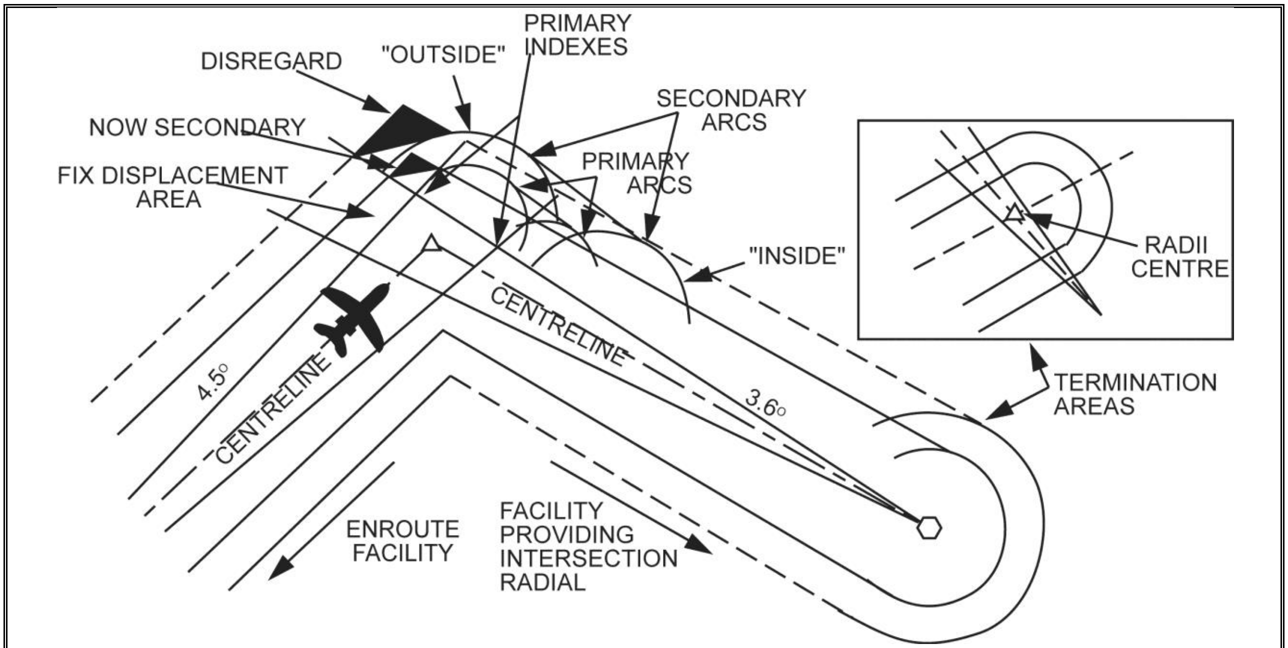


Figure 17-8: turning segment, intersection fix. Facility distance less than 51 nm. Para 1715.a and b.

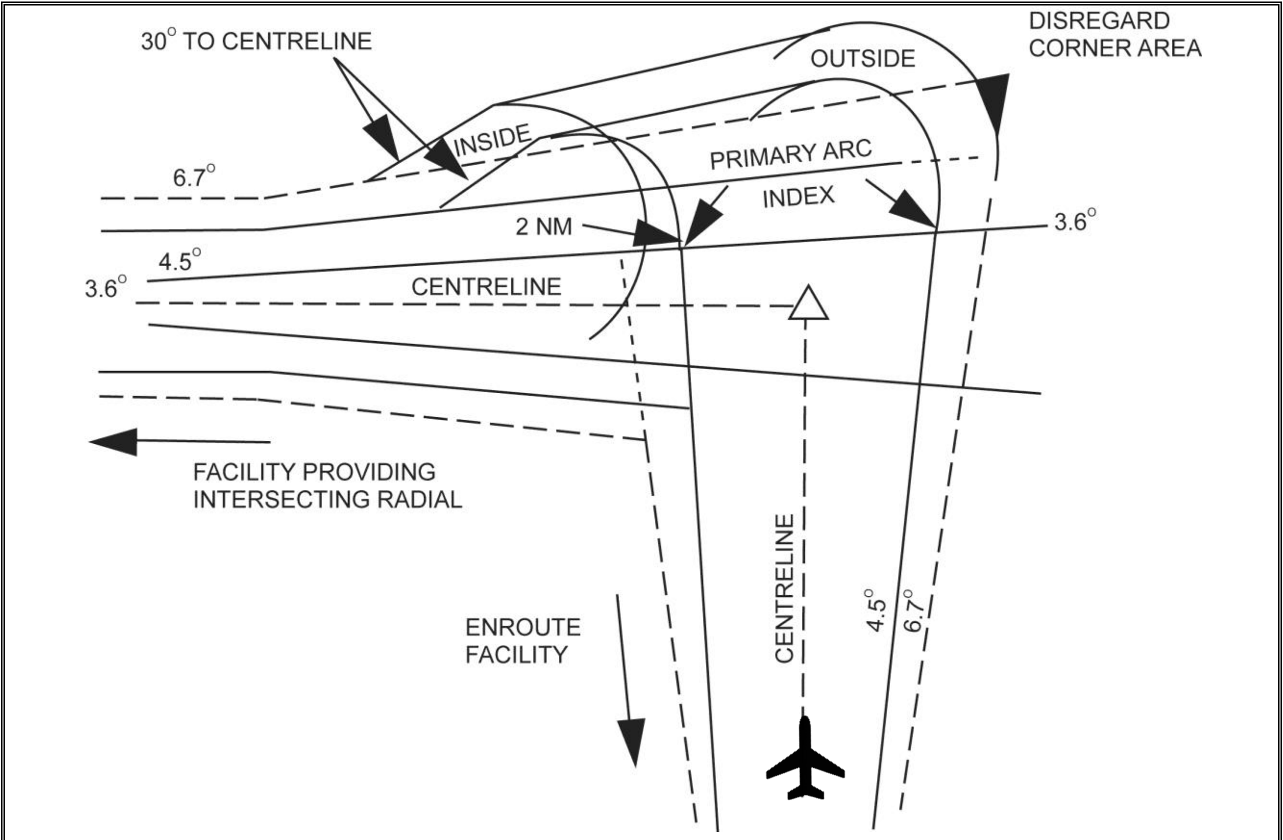


Figure 17-9: turning segment, intersection fix. Facility distance beyond 51 nm. Para 1715.a and b.

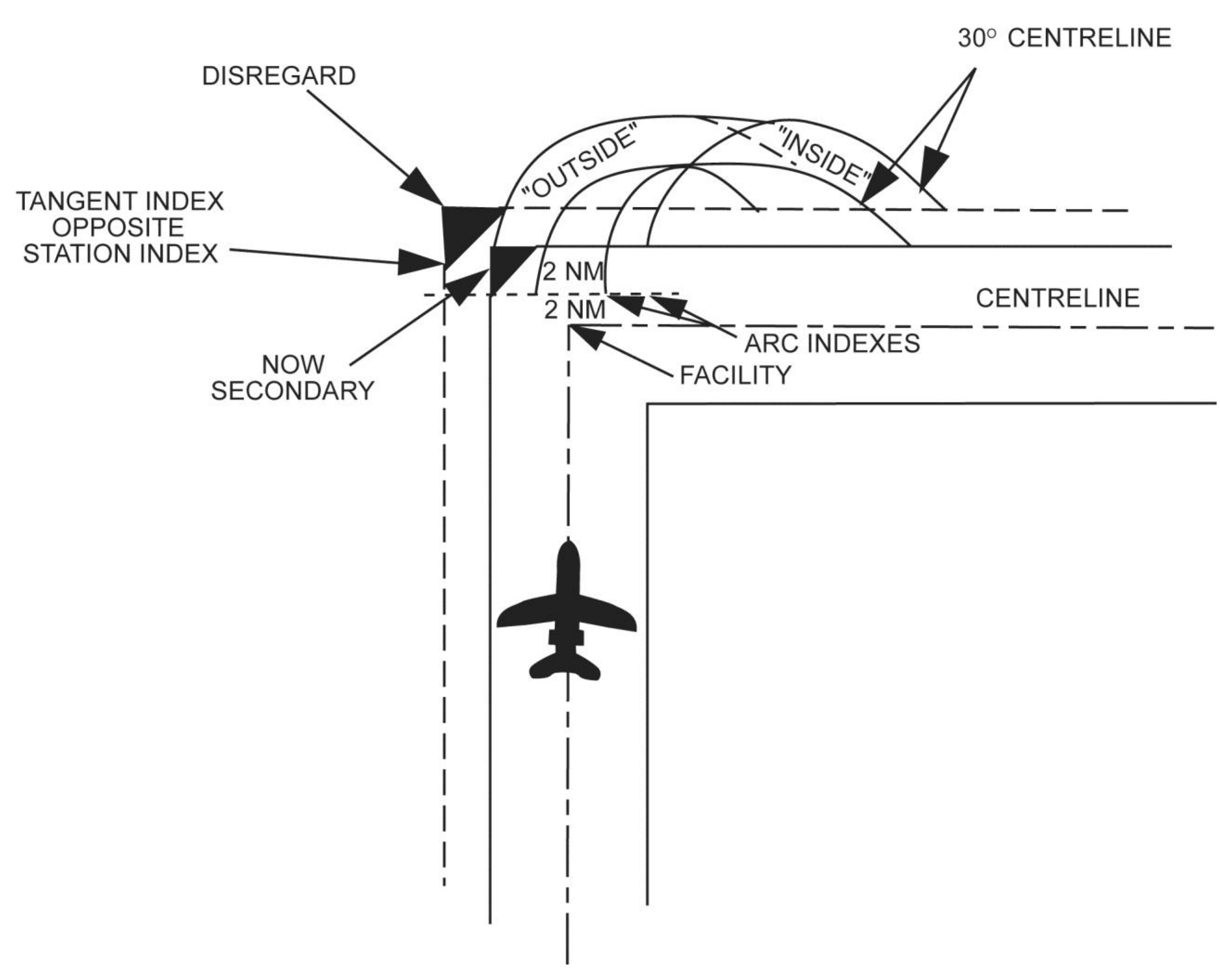


Figure 17-10: Turning Segment Overhead The Facility. Para 1715.b.

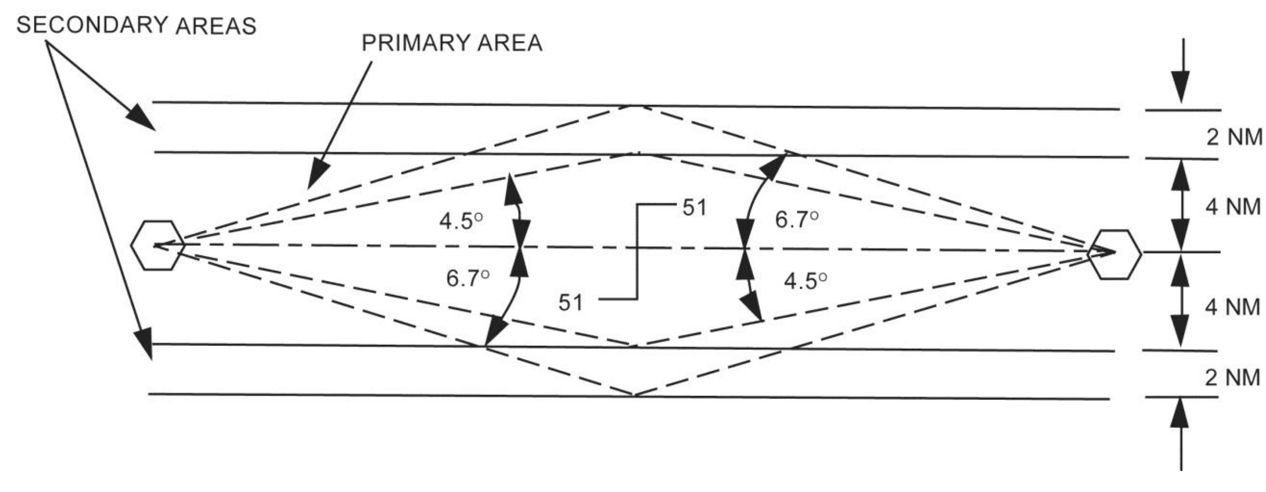


Figure 17-11: COP effect. Short airway or route segment. Para 1716.a.

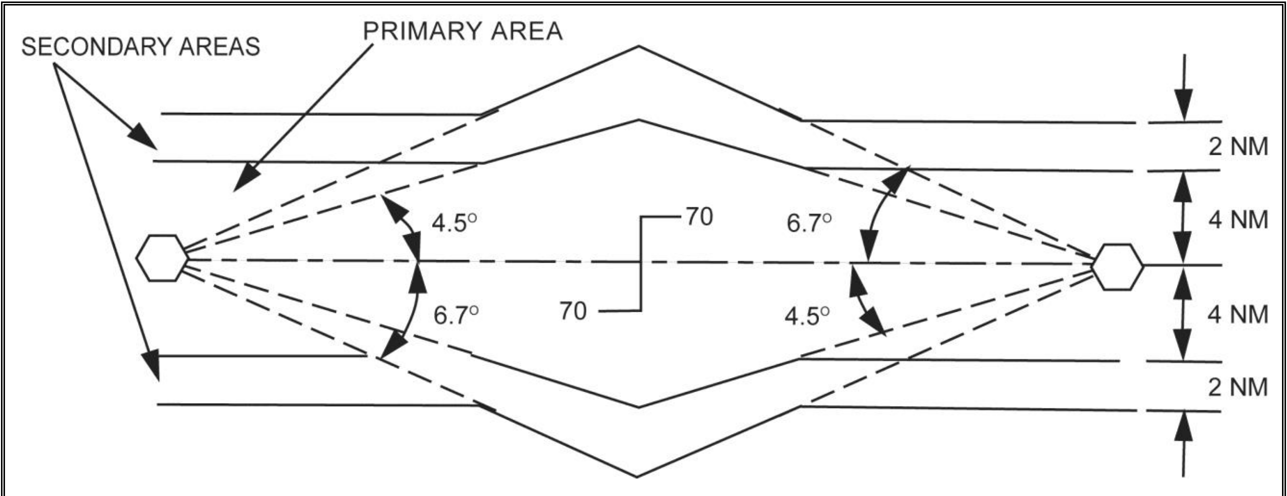


Figure 17-12: COP Effect. Long Airway Or Route Segment. Para 1716.b.

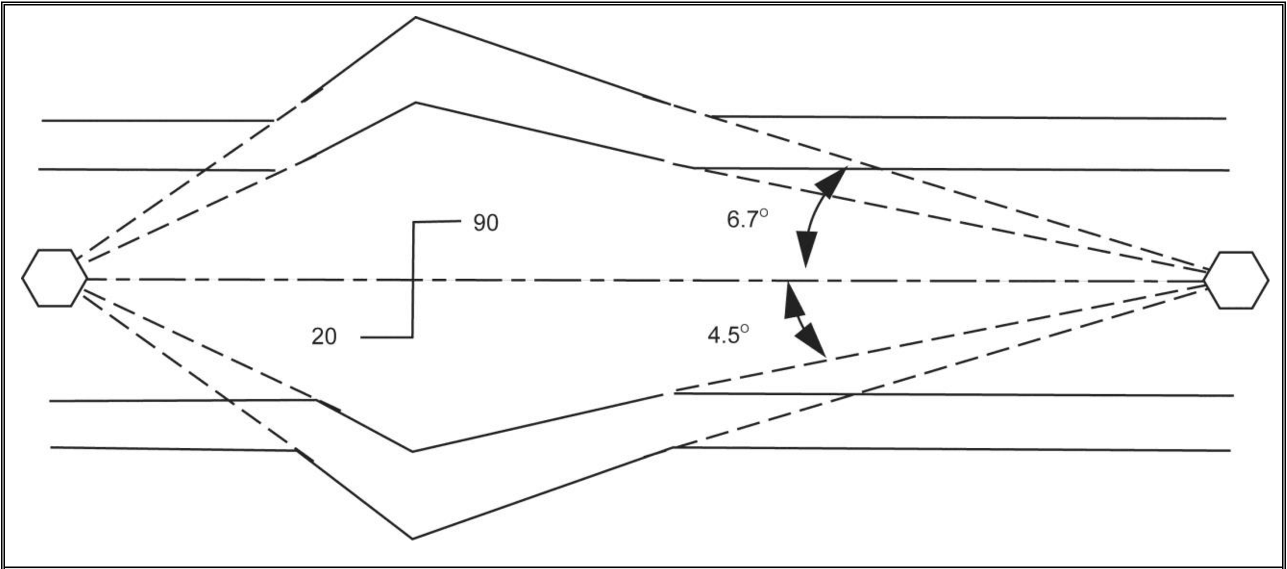


Figure 17-13: Offset COP. Para 1716.c.

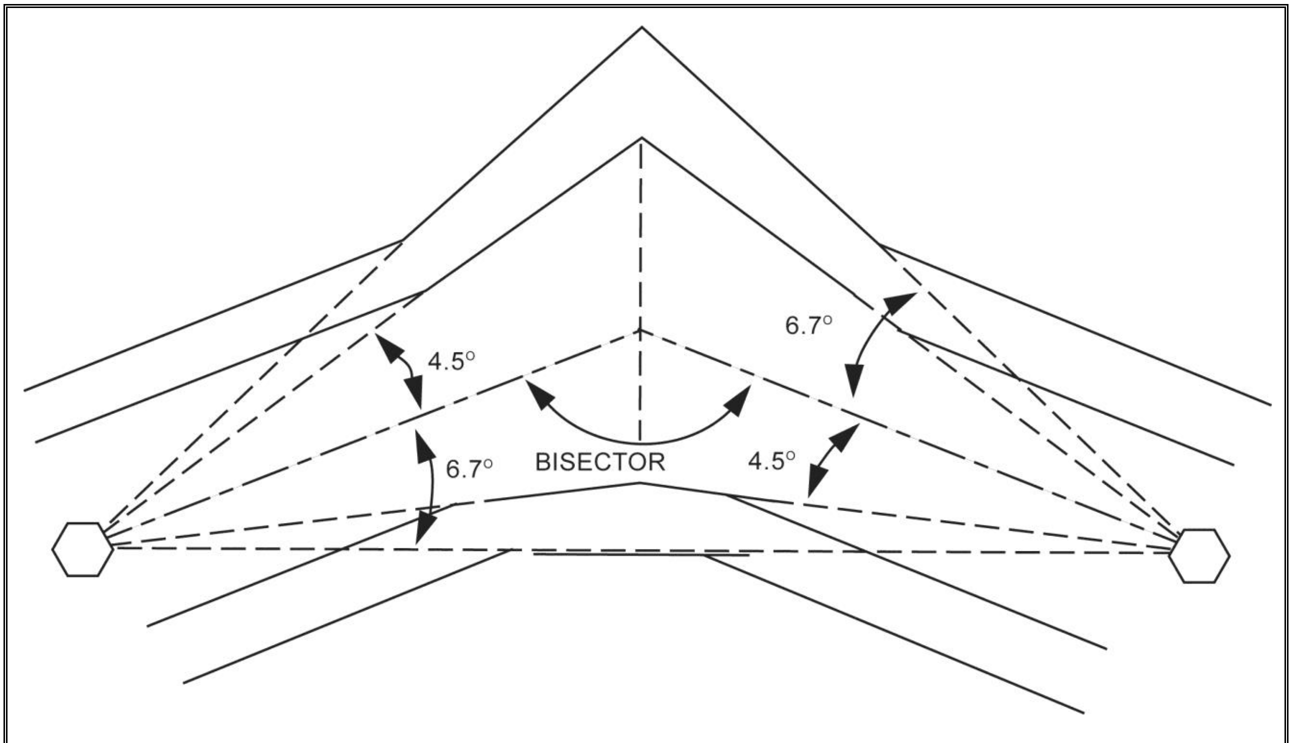


Figure 17-14: Dogleg Segment. Para 1716.d.

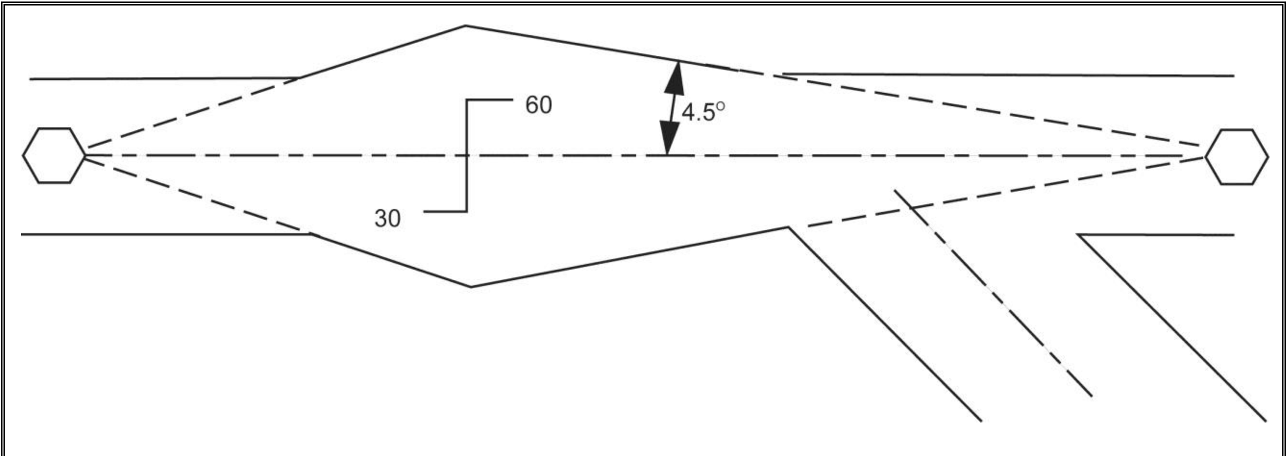


Figure 17-15: Course Change Effect. Para 1717.

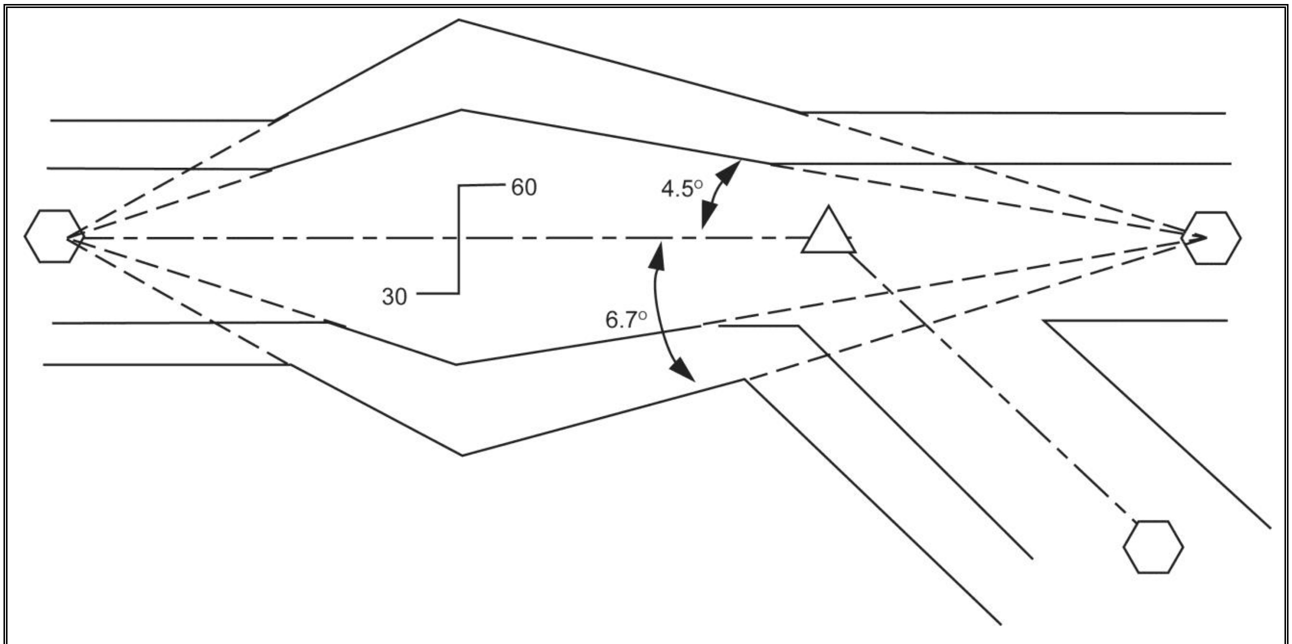


Figure 17-16: Application Of Secondary Areas. Para 1717.

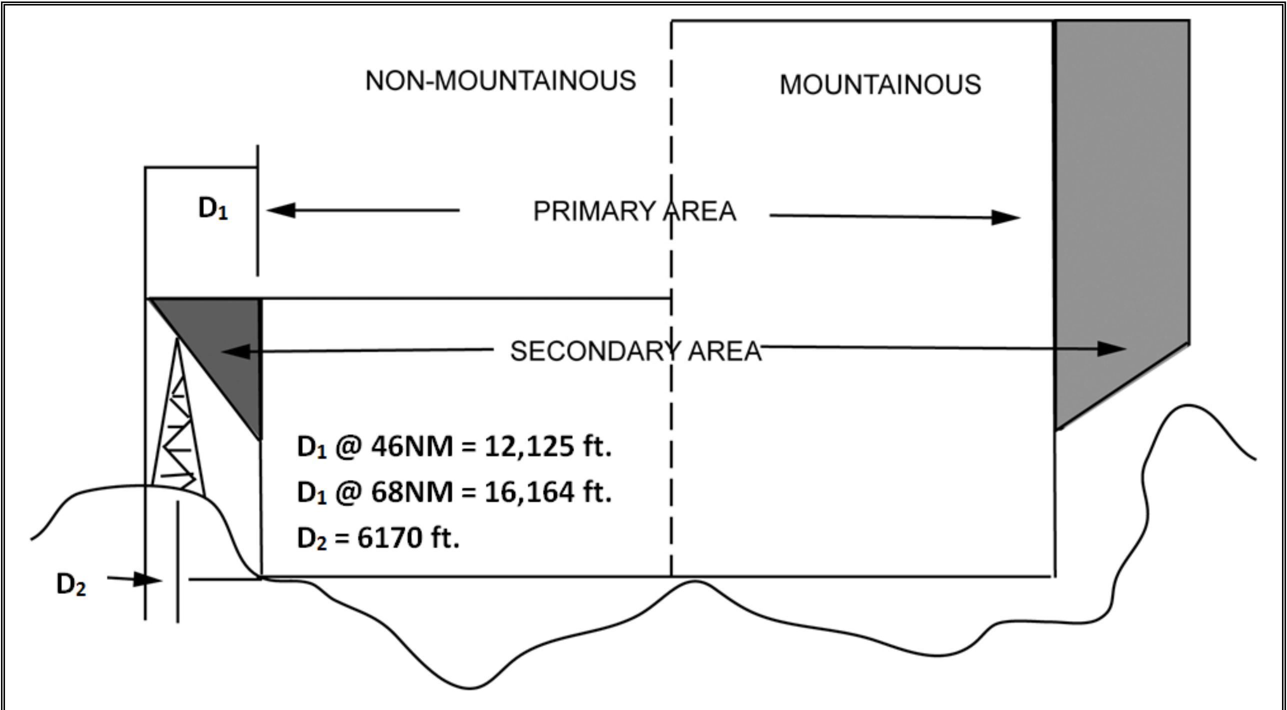


Figure 17-17: Cross Section, Secondary Area Obstacle Clearances. Para 1721.

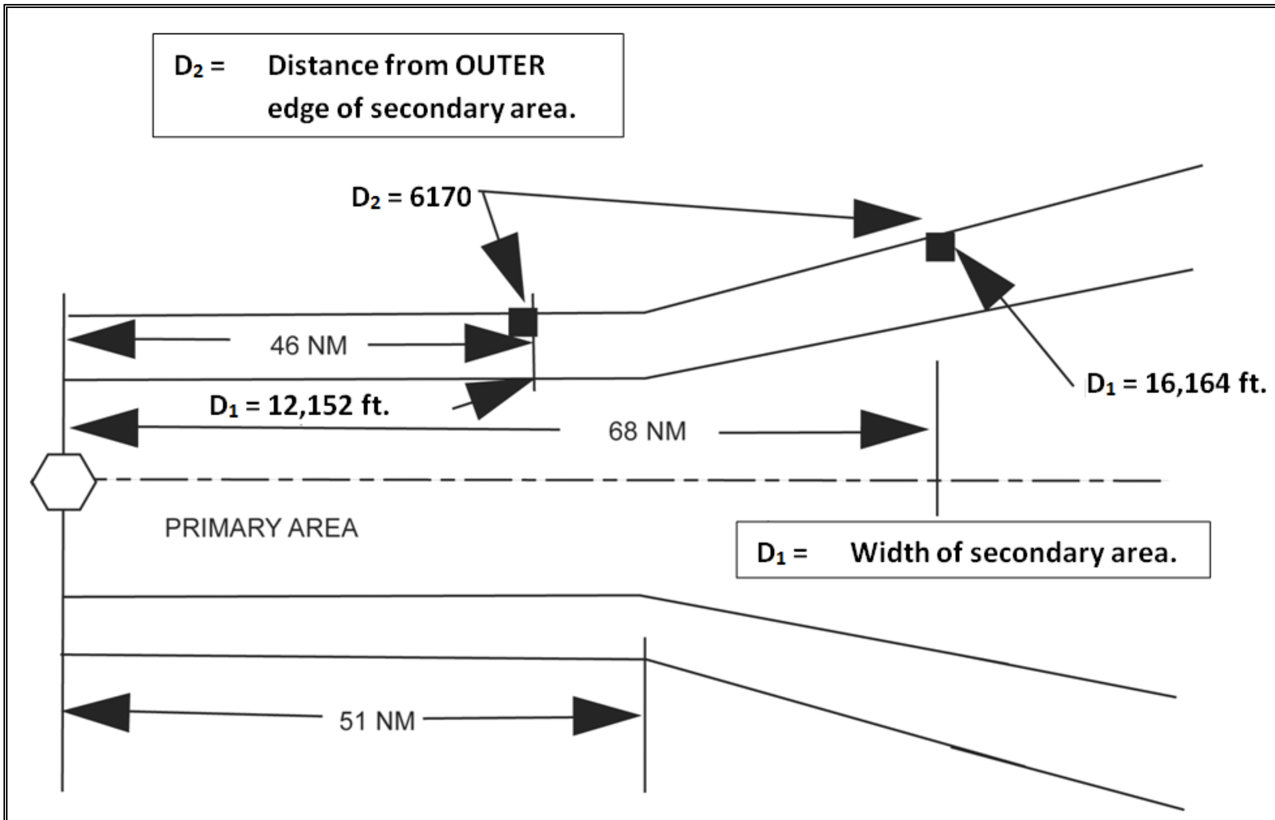


Figure 17-18: Plan View, Secondary Area Obstacle Clearances. Para 1721.

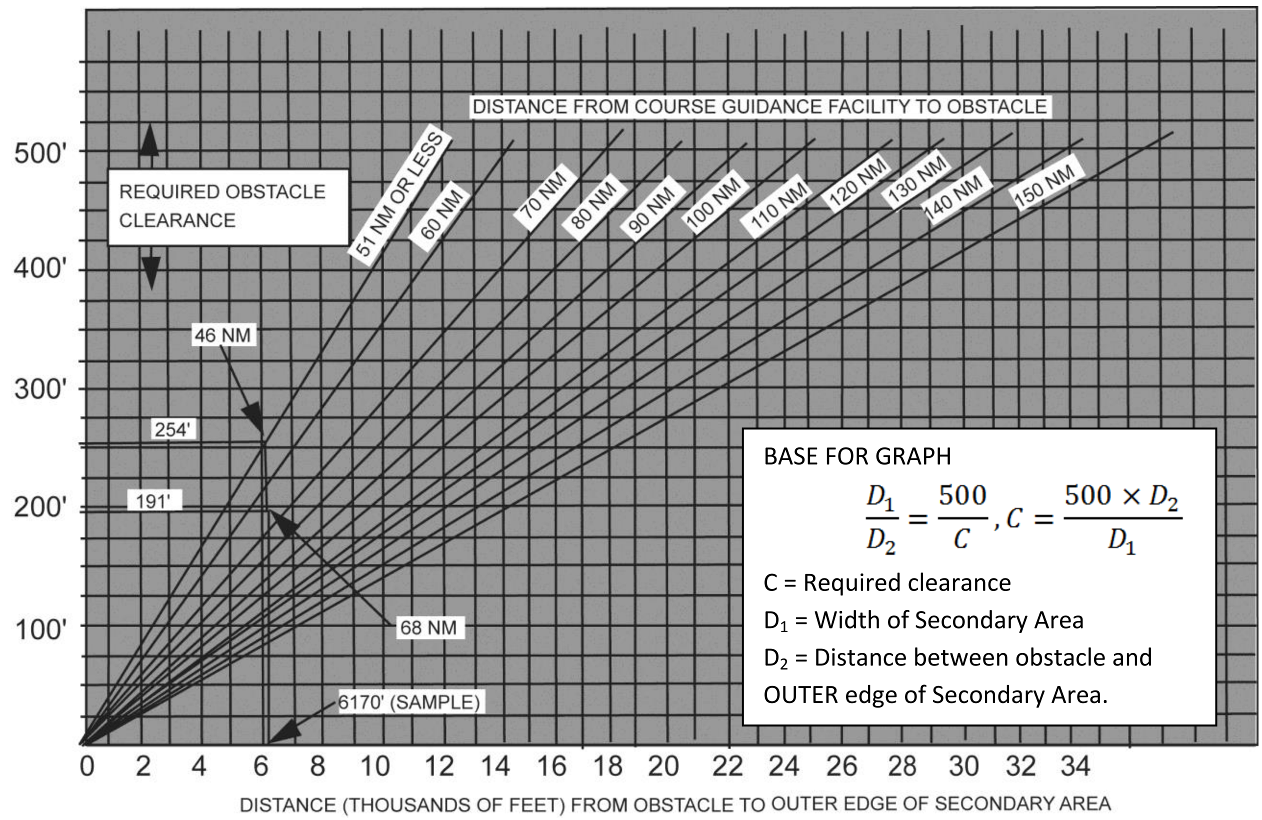
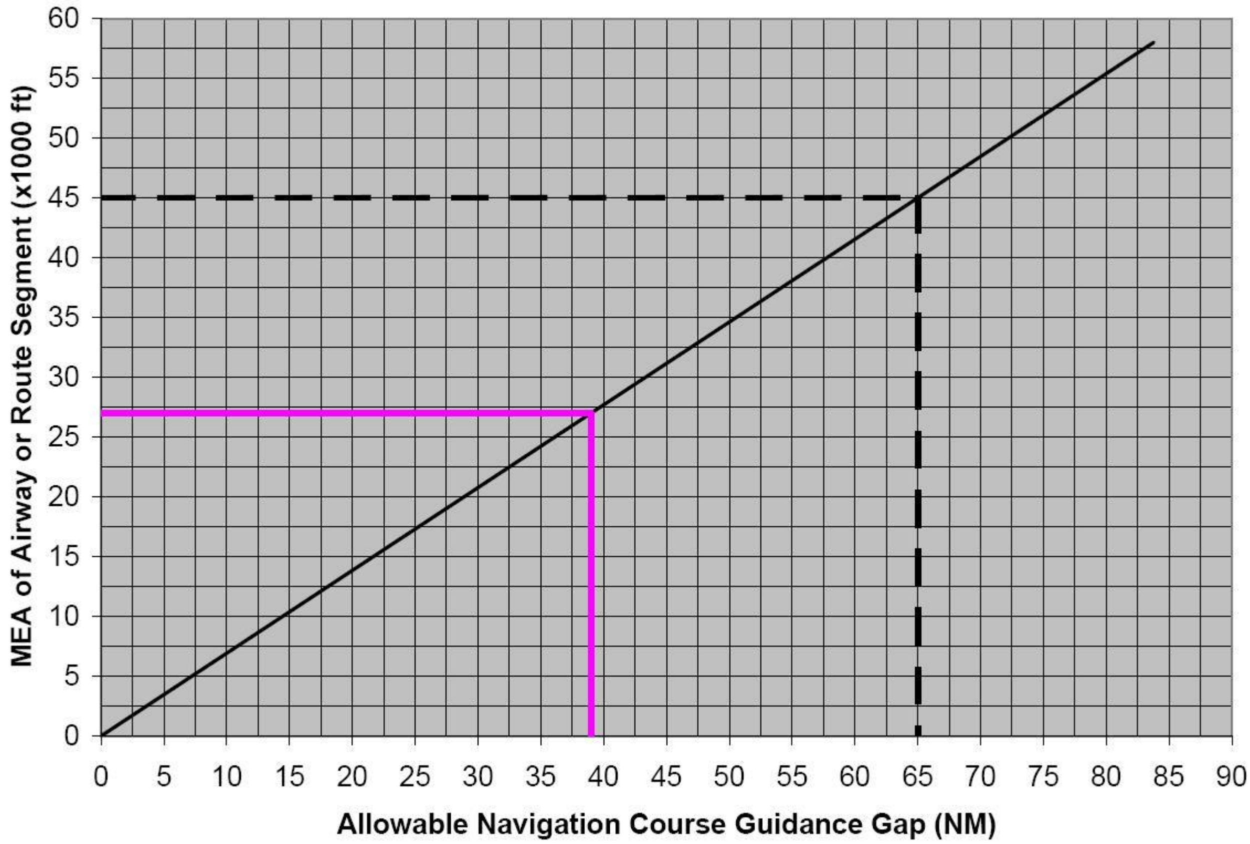


Figure 17-19: Secondary Obstacle Clearance. Para 1722.

Figures 17-20 to 17-22: Reserved



Example: Enter with MEA of 27,000’, Read Allowable Gap 39 NM

Figure 17-23: Allowable Navigation Course Guidance Gaps. Para 1740.

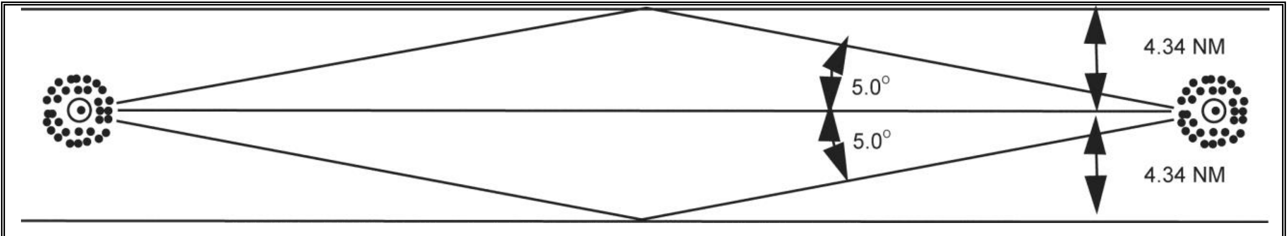


Figure 17-24: LF Segment Primary Obstacle Clearance Area. Para 1750.b.

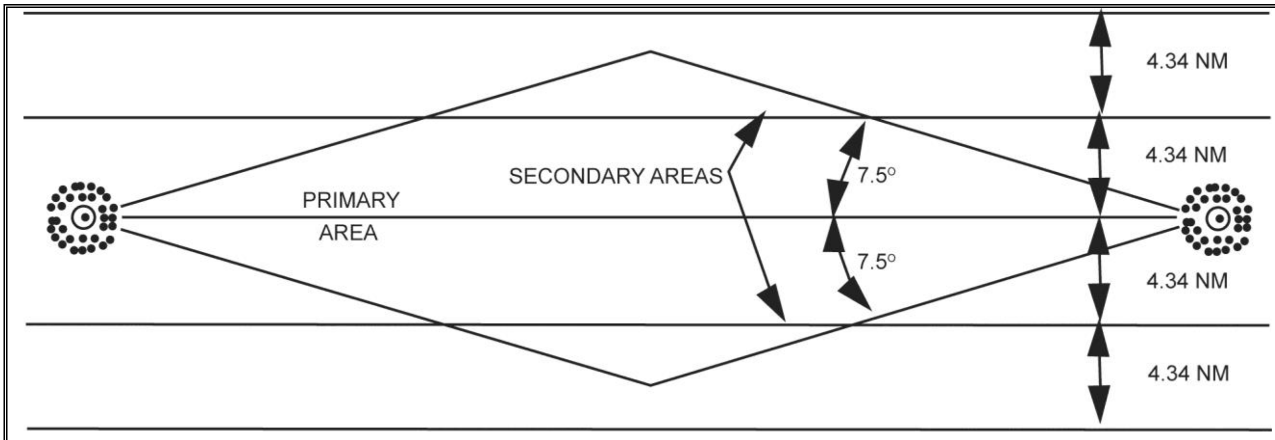


Figure 17-25: LF Segment Secondary Obstacle Clearance Area. Para 1717.B.

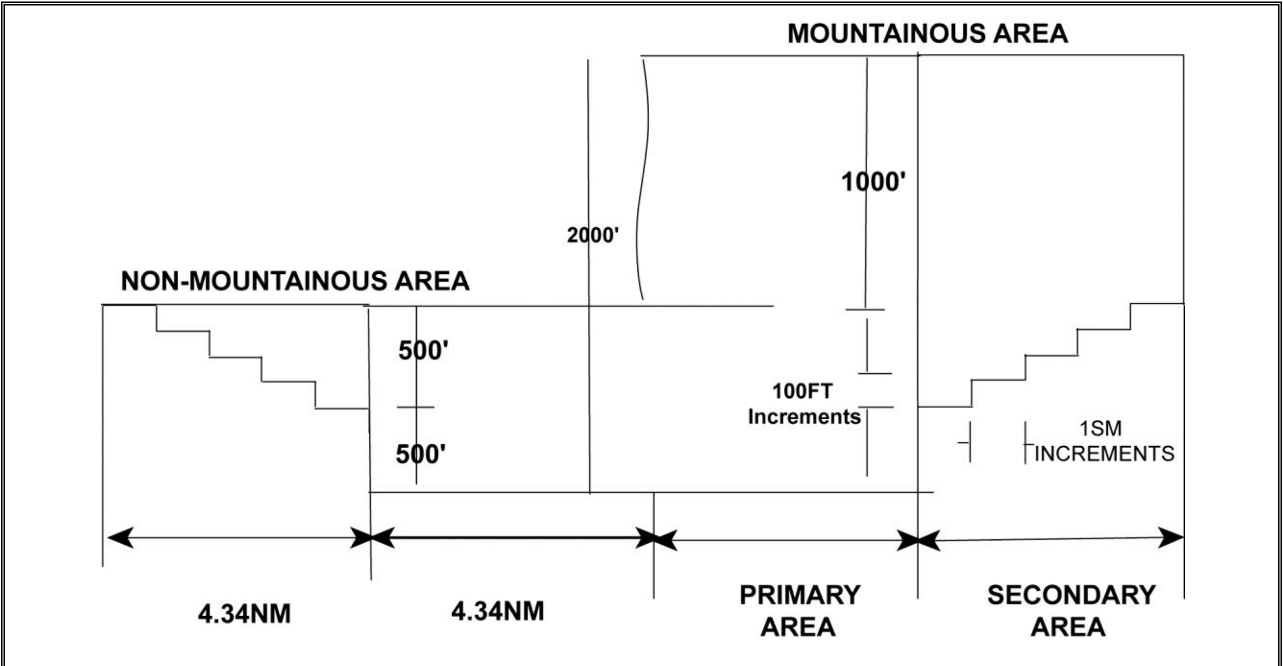


Figure 17-26: LF Segment Obstacle Clearance Within 25 NM Of Enroute Facility. Para 1750.d.

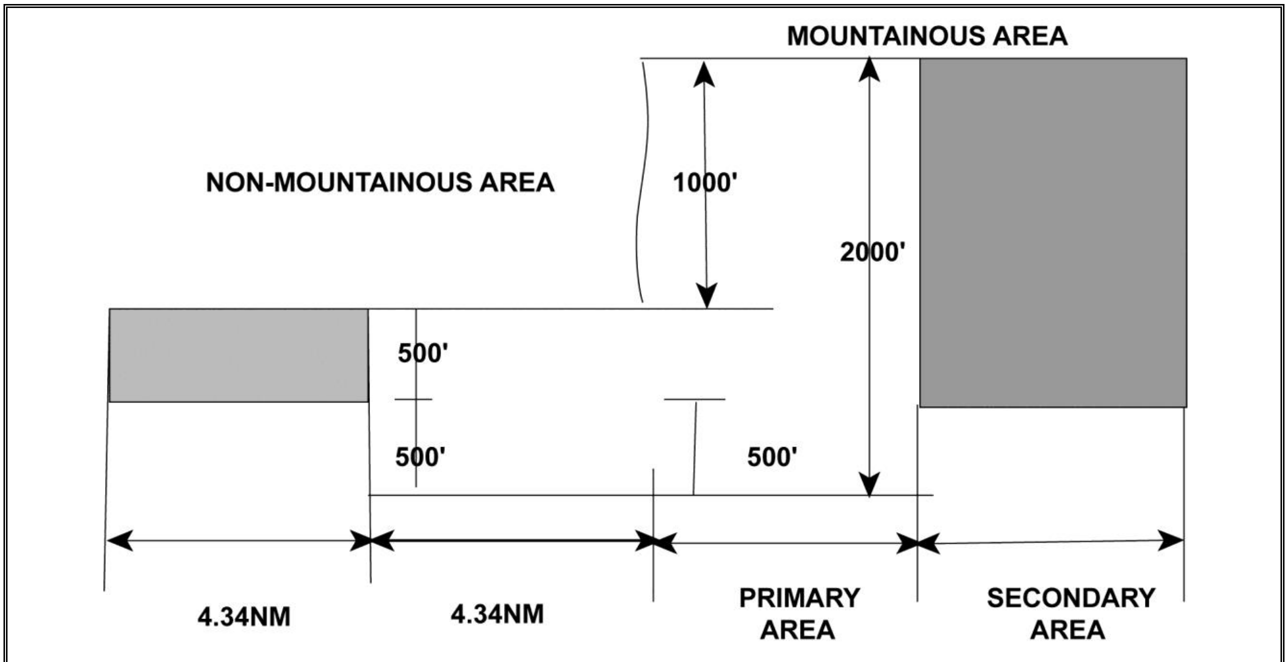


Figure 17-27: LF Segment Obstacle Clearance Area beyond 25 NM From Enroute Facility. Para 1750.d.

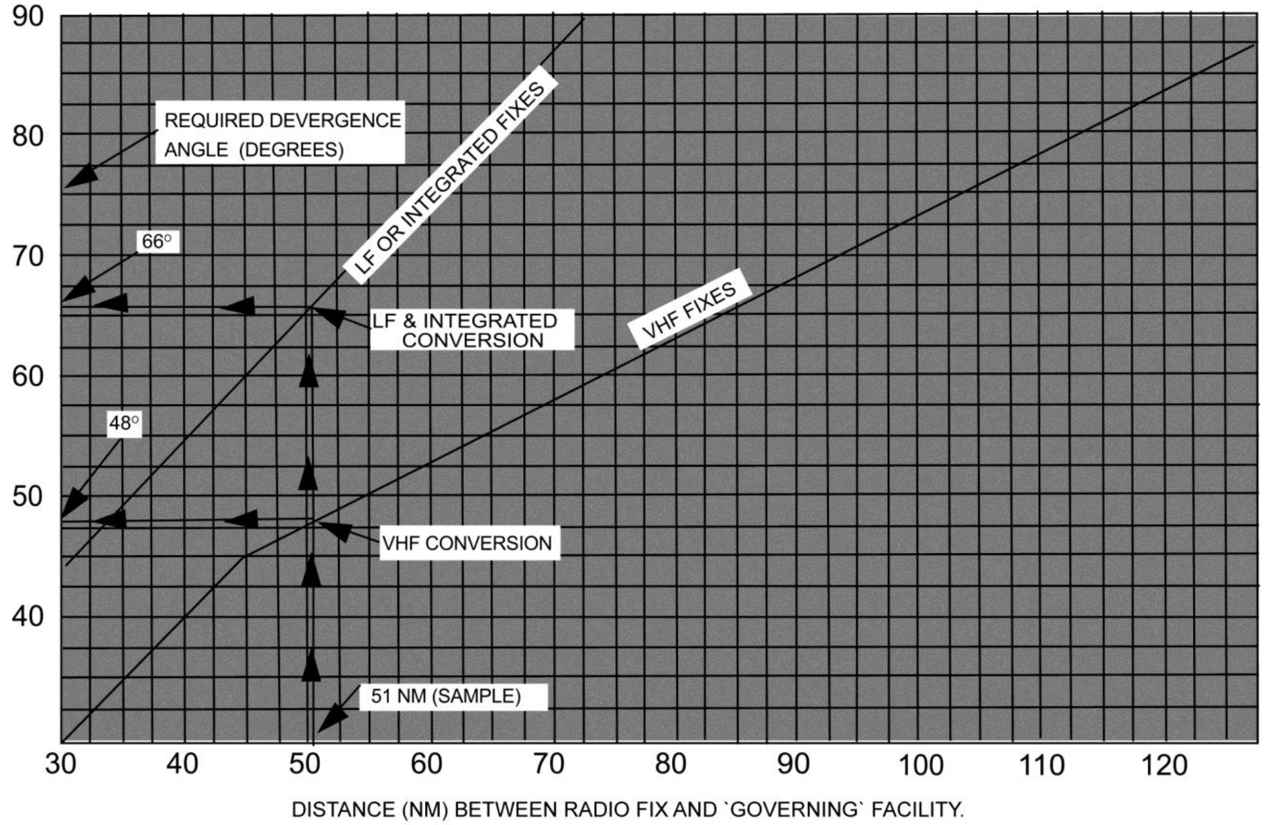


Figure 17-28: Minimum Divergence Angle For Radio Fix. Para 1761.b and 1762.b.

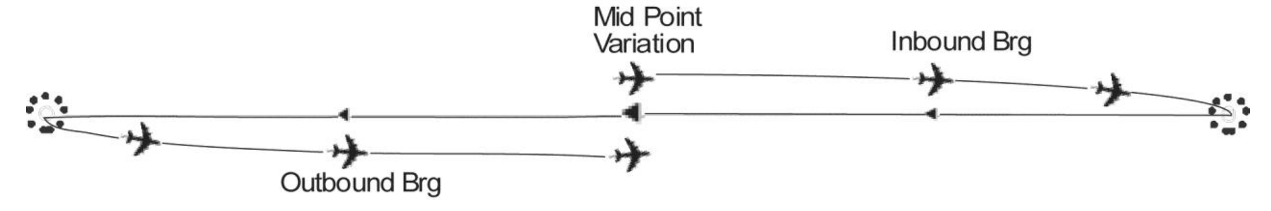


Figure 17-29a: Track Using Midpoint Variation. Para 1752.

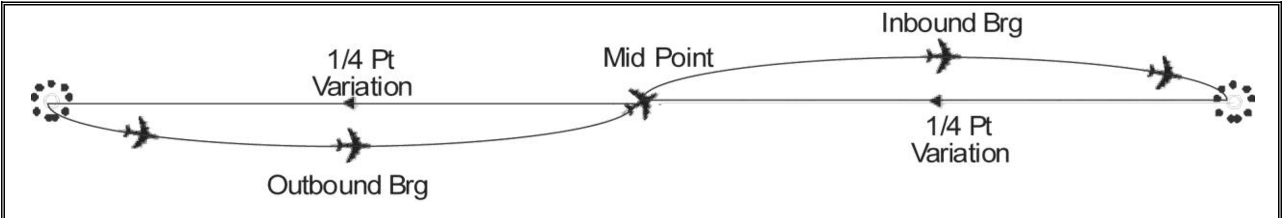


Figure 17-29b: Track Using Quarterpoint Variation. Para 1752.

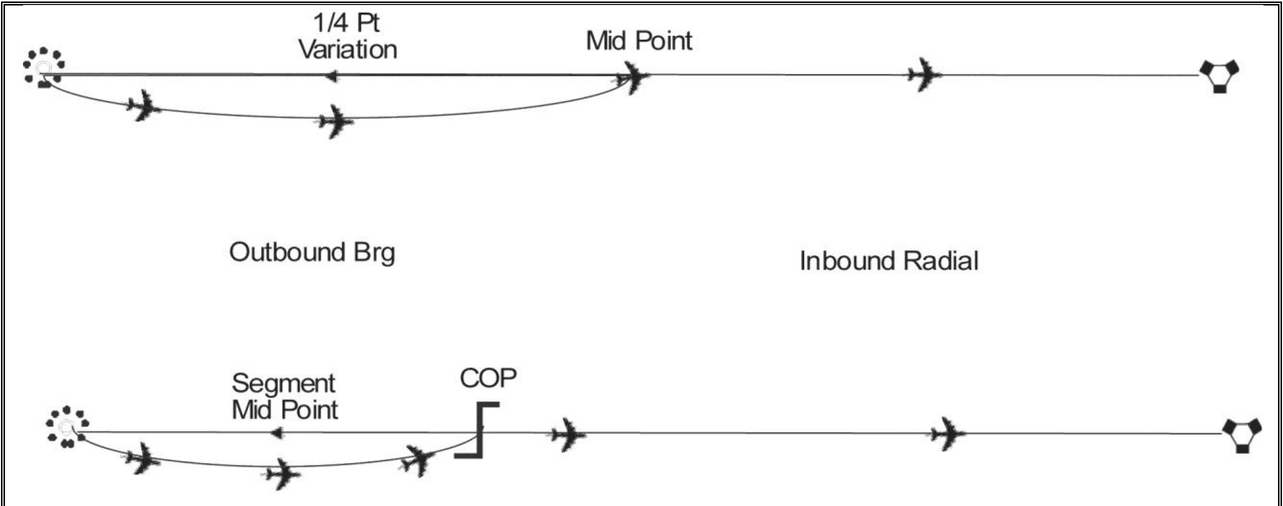


Figure 17-29c: Application Of Quarter point Variation For LF/MF to VHF/UHF Facilities. Para 1752.

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CHAPTER 18. HOLDING CRITERIA

1800. General

This chapter specifies the criteria for determining the dimensions of airspace to be protected for holding aircraft.

1801. Terminology

a. Holding Area. The airspace required at a particular altitude to contain aircraft performing specified entry and holding procedures based on allowances for wind effect, timing errors, fix characteristics, etc.

b. Holding Pattern. The race track pattern to be flown by a holding aircraft.

c. Minimum Holding Altitude (MHA). The lowest altitude prescribed for a holding pattern, which assures navigational signal coverage, communications, airspace requirements and meets obstacle clearance requirements.

d. Reduction Area. For ATC purposes only, that portion of a holding area for which airspace protection may or may not be required, depending upon the direction of entry to the holding pattern, position of the aircraft or length of DME leg used. When assessing a holding pattern for obstacle clearance, the full size of the holding pattern shall be evaluated.

e. Shuttle Procedure. A shuttle procedure is a manoeuvre involving a descent or climb in a pattern resembling a holding pattern.

1802. Development Concept

The following factors have been incorporated into the criteria:

a. Winds. An analysis of winds at various levels over a 5 year period led to the adoption of a scale of velocities beginning with 50 knots at 4,000 feet ASL and increasing at a rate of 3 knots for each additional 2,000 feet of altitude to a maximum of 120 knots.

b. Airspeed. Holding patterns are developed based upon the maximum airspeeds shown in Table 18–1.

c. Angle of Bank. The criteria are based upon a bank angle of at least 25° or a rate of turn of 3° per second, whichever requires the lesser bank.

A. Propeller Aircraft (including turbo-prop)	
(1) MHA to 30,000 feet	175 KT IAS
B. Civil Turbo-jet	
(1) MHA to 14,000 feet	230 KT IAS
(2) Above 14,000 feet	265 KT IAS
C. Military Turbo-jet	
(1) all except those aircraft listed below in 2, 3 and 4	265 KT IAS
(2) F-4	280 KT IAS
(3) B-1, F-111 and F-5	310 KT IAS
(4) T-37 and CT-114	175 KT IAS

Table 18-1: Maximum Holding Airspeeds. Para 1802.b and 1822.a (1).

1803. Navigation Aid And Airborne System Tolerance

The criteria in this section apply to conventional navigation aids such as VOR, VOR/DME and/or NDB. Allowances have been made for the following factors:

a. **Cone of ambiguity**. Related to altitude, system error (± 5°) and aircraft track indication (±10° for full instrument deflection). Total tolerance is 15°.

b. **Intersection disparity**. Related to system error and distance between the holding point and the farthest navigation aid used to form it.

c. **Station passage** TO-FROM error: ±4°.

d. **Delay** in recognizing and reacting to fix passage. 6 seconds for entry turn, applied in the direction most significant to protected airspace.

1804. Holding Fixes

Any terminal area fix, except overhead a TACAN, may be used for holding. If that fix is an intersection formed by courses or radials, the following conditions apply:

a. The angle of divergence of the courses or radials shall not be less than 45 degrees. See Figure 18-1.

b. If the facility which provides the crossing course is not an NDB, it may be as much as 45 miles from the point of intersection.

c. If the facility which provides the crossing course is an NDB, it must be within 30 miles of the intersection point.

d. These distances may be exceeded provided the minimum angle of divergence of the intersecting courses is increased at the following rate:

(1) If an NDB is involved, increase the angle 1 degree for each mile over 30 miles.

(2) If an NDB is not involved, increase the angle ½ degree for each mile over 45 miles.

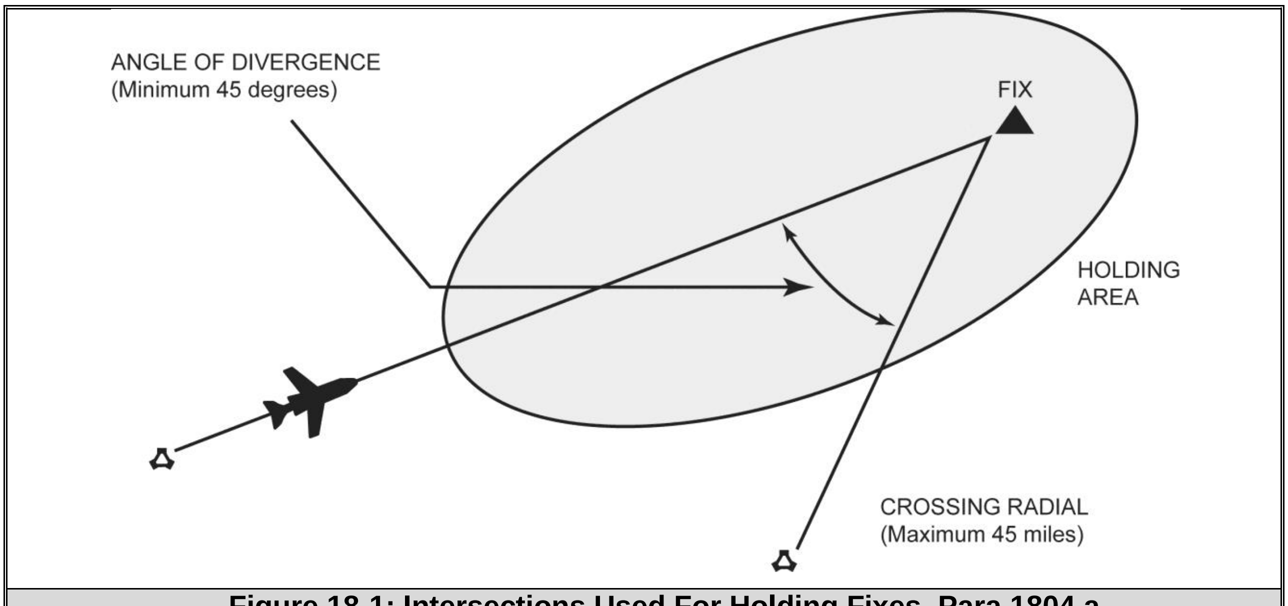


Figure 18-1: Intersections Used For Holding Fixes. Para 1804.a.

1805—1809. Reserved

SECTION 1. RESERVED

1810 – 1819 Reserved

SECTION 2. HOLDING CRITERIA

1820. Level Holding

There are 31 holding airspace sizes. Each area is related to one or more even-numbered altitudes/flight levels and is identified by a template number for easy reference. See Table 18-2.

Templates are drawn to a scale of 1:500,000 (1 inch = approx. 6.9 NM) for use with aeronautical charts having the same scale. Details for tracing templates are contained in Section 3, Para 1831. When use of a different scale is necessary, holding areas may be constructed manually as outlined in Section 3, Para 1832.

a. Alignment. Whenever practical, holding patterns should be aligned to coincide with the flight course to be flown after leaving the holding fix. However, when the flight path to be flown is along an arc, the holding pattern should be aligned on a radial. When a holding pattern is established at a final approach fix and a procedure turn is not used, the inbound course of the holding pattern shall be aligned to coincide with the final approach course unless the final approach fix is a facility. When the final approach fix is a facility, the inbound holding course and the final approach course shall not differ by more than 30 degrees.

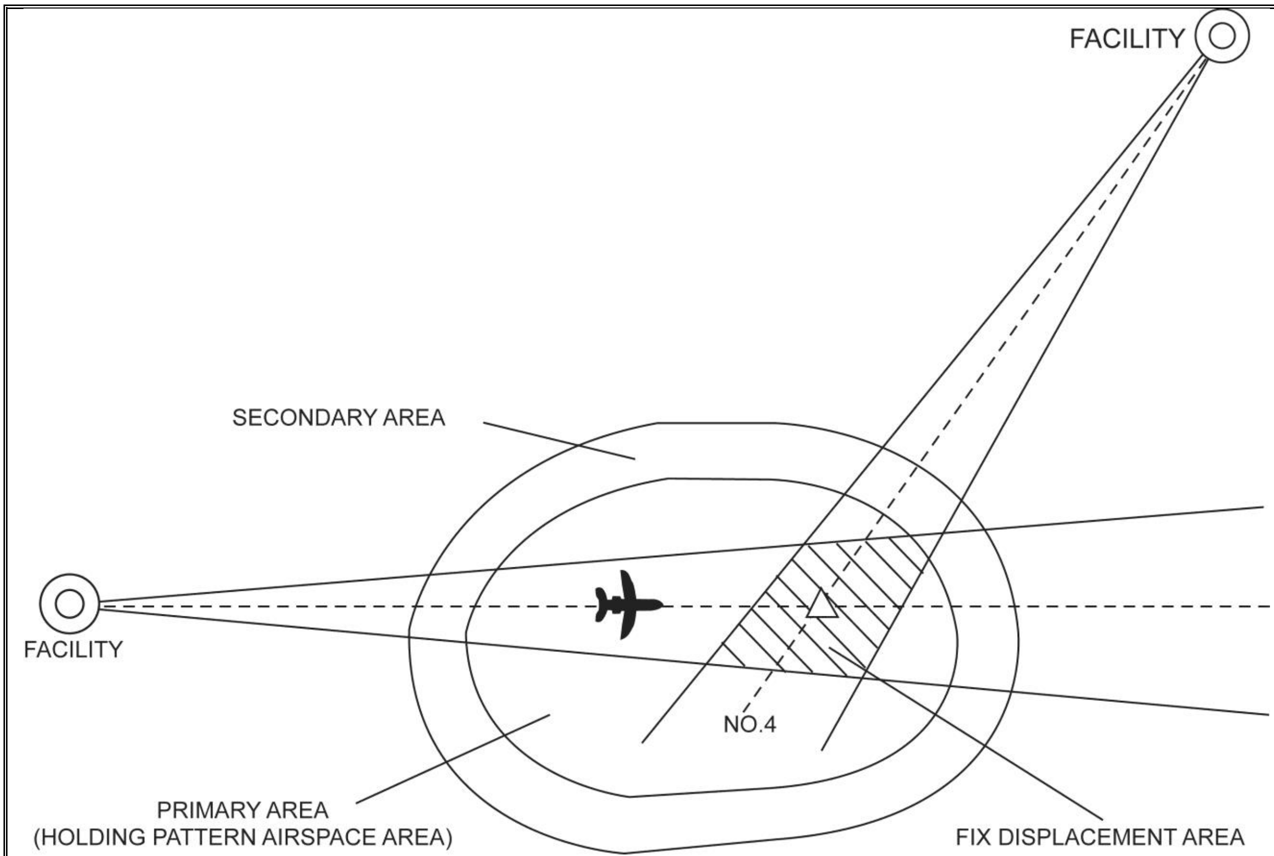


Figure 18-2: Holding Pattern Template Application. Para 1820.b.

b. Area. Pattern number 4 is normally the minimum size authorized for the primary area. When holding is at an intersection fix, the selected pattern primary area shall be large enough to contain at least 3 corners of the fix displacement area. See Chapter 2, Paras 284 and 285, and Figure 18-2. A secondary area 2 miles wide surrounds the perimeter of the primary area. If using a template smaller than pattern number 4, then the appropriate speed restriction shall be published.

(1) Altitude. Holding altitudes from 2,000 feet ASL to FL480 are listed. Holding at an even altitude requires the use of the appropriately numbered holding area/template shown opposite the altitude. Holding at odd altitudes above 2,000 feet requires use of the numbered holding area/template for the next higher altitude.

(2) Template Categories. Table 18–2 shall be used to determine the holding template required. Fix distance is the measured ground distance in nautical miles from the holding fix to the NAVAID. Template sizes are shown for three ranges of fix-to-NAVAID distances: 0-14.9 NM, 15-29.9 NM, and 30 NM and over. Holding overhead a NAVAID requires the use of the 0-14.9 NM group. When a fix is based on information from two navigation aids, the greatest fix-to-NAVAID distance shall be used to determine the correct holding area/template size. This applies to any type or combination of navigation aids used to establish a holding fix.

c. Obstacle Clearance. A minimum of 1,000 feet of obstacle clearance shall be provided throughout the primary area. In mountainous regions apply additional obstacle clearance for en route holding. In the secondary area 500 feet of obstacle clearance shall be provided at the inner edge, tapering to zero feet at the outer edge. For computation of obstacle clearance in the secondary area see Annex C, Para 5 and Figure C-3. Allowance for precipitous terrain should be considered as stated in Para 323. Altitudes selected by application of the obstacle clearance specified in this paragraph may be rounded to the nearest 100 feet provided the ROC is not violated. See Para 231.

d. Altitude Selection. If an approach is made from a properly aligned holding pattern, vice from a procedure turn (see Para 234.e), the holding pattern shall be established over a final or intermediate approach fix and the following conditions shall apply:

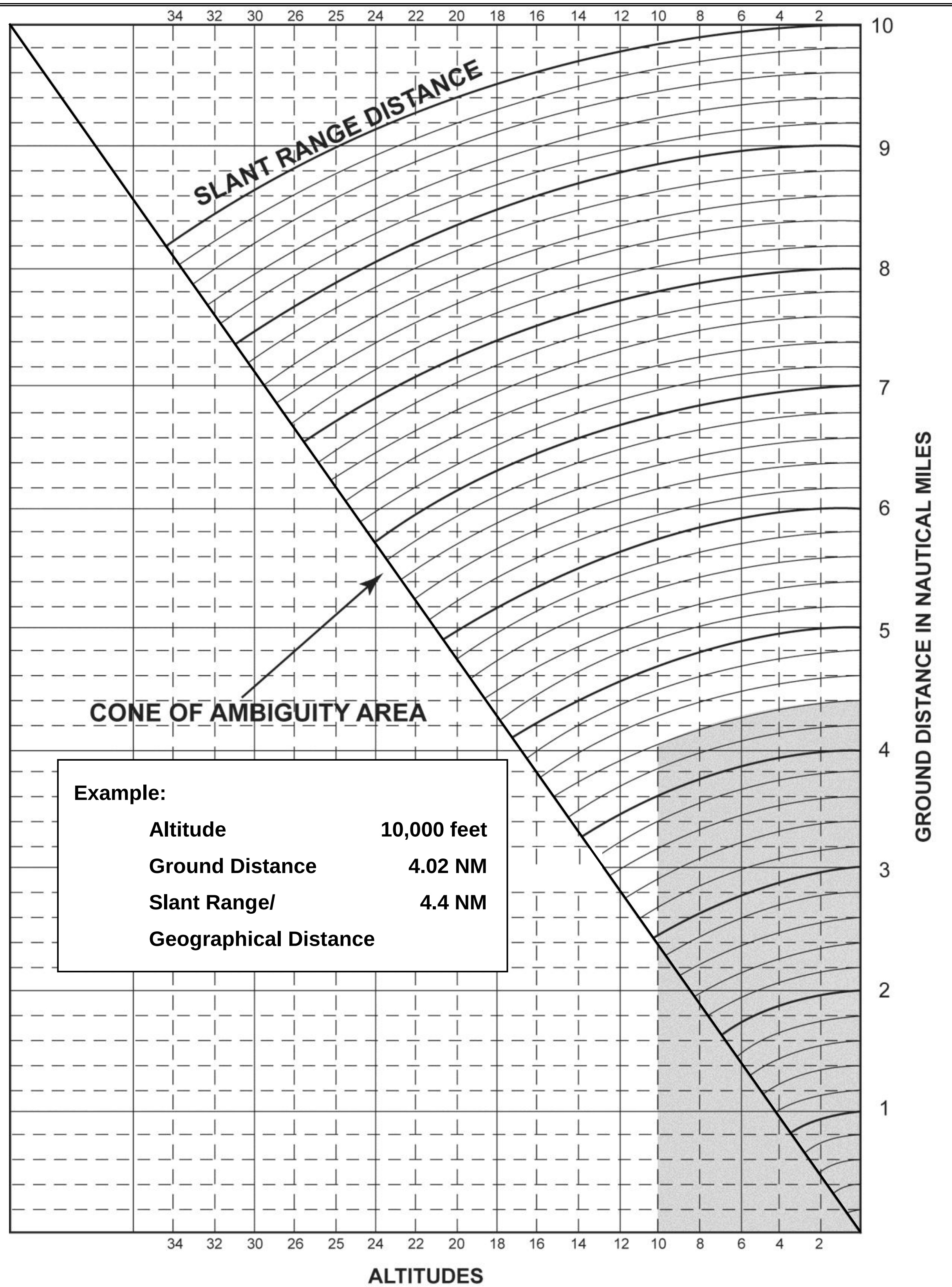
(1) If the holding pattern is established over the final approach fix, the minimum holding altitude shall not be more than 300 feet above the altitude specified for crossing the final approach fix inbound; or

(2) If the holding pattern is established over the intermediate fix, the minimum holding altitude shall permit descent to the final approach fix altitude within the descent gradient tolerances prescribed for the intermediate segment. See Para 243.d.

ALT	175 KIAS			200 KIAS			210 KIAS		
	0 - 14.9 NM	15 - 29.9 NM	30 NM and over	0 - 14.9 NM	15 - 29.9 NM	30 NM and over	0 - 14.9 NM	15 - 29.9 NM	30 NM and over
2	1	1	2	3	4	5			
4	1	2	3	4	5	6			
6	2	3	4	5	6	7			
8	3	4	5				6	7	8
10	4	5	6				7	8	9
12	5	6	7				7	8	9
14	6	7	8				8	9	10
16	7	8	9						
18	8	9	10						
20	8	9	10						
22	9	10	11						
24	10	11	12						
26	11	12	13						
28	12	13	14						
30	13	14	15						
32									

ALT	230 KIAS			265 KIAS			310 KIAS		
	0 - 14.9 NM	15 - 29.9 NM	30 NM and over	0 - 14.9 NM	15 - 29.9 NM	30 NM and over	0 - 14.9 NM	15 - 29.9 NM	30 NM and over
2	5	6	7	7	8	9	11	12	13
4	6	7	8	8	9	10	12	13	14
6	7	8	9	9	10	11	13	14	15
8	8	9	10	10	11	12	14	15	16
10	9	10	11	11	12	13	15	16	17
12	9	10	11	12	13	14	17	18	19
14	10	11	12	13	14	15	18	19	20
16	12	13	14	15	16	17	19	20	21
18	13	14	15	16	17	18	20	21	22
20	14	15	16	17	18	19	21	22	23
22	15	16	17	18	19	20	22	23	24
24	16	17	18	19	20	21	22	23	24
26	17	18	19	20	21	22	24	25	26
28	18	19	20	21	22	23	24	25	26
30	19	20	21	22	23	24	25	26	27
32				23	24	25	26	27	28
34				24	25	26	27	28	29
36				25	26	27	28	29	30
38				26	27	28	29	30	31
40				27	28	29	30	31	
42				28	29	30			
44				28	29	30			
46				29	30	31			
48				31					

Table 18-2: Holding Area Template Selection Chart. Para 1820, 1821.c, and 1824.



Example:

Altitude	**10,000 feet**
Ground Distance	**4.02 NM**
Slant Range/ Geographical Distance	**4.4 NM**

Figure 18-3: DME Slant Range Distance / Cone Of Ambiguity Area Chart. Para 1821.a.

1821. DME Holding

a. Cone of Ambiguity. Cone of ambiguity information is depicted on the DME Slant Range Distance/Cone of Ambiguity Area Chart. See Figure 18-3.

(1) DME fixes shall not be established within the cone of ambiguity above the navigation aid providing DME information.

(2) DME holding may be accomplished either toward or away from a DME navigation aid. When the DME inbound holding track leads toward the navigation aid, the fix end of the holding area, but not the DME fix, may lie within the cone of ambiguity, provided entry to the pattern is normally made from a direction other than through the cone. If entry is usually made through the cone of ambiguity, the entire holding area must lie outside the cone. When the inbound DME holding track leads away from the navigation aid, no part of the holding area may lie within the cone of ambiguity. See Figure 18-4.

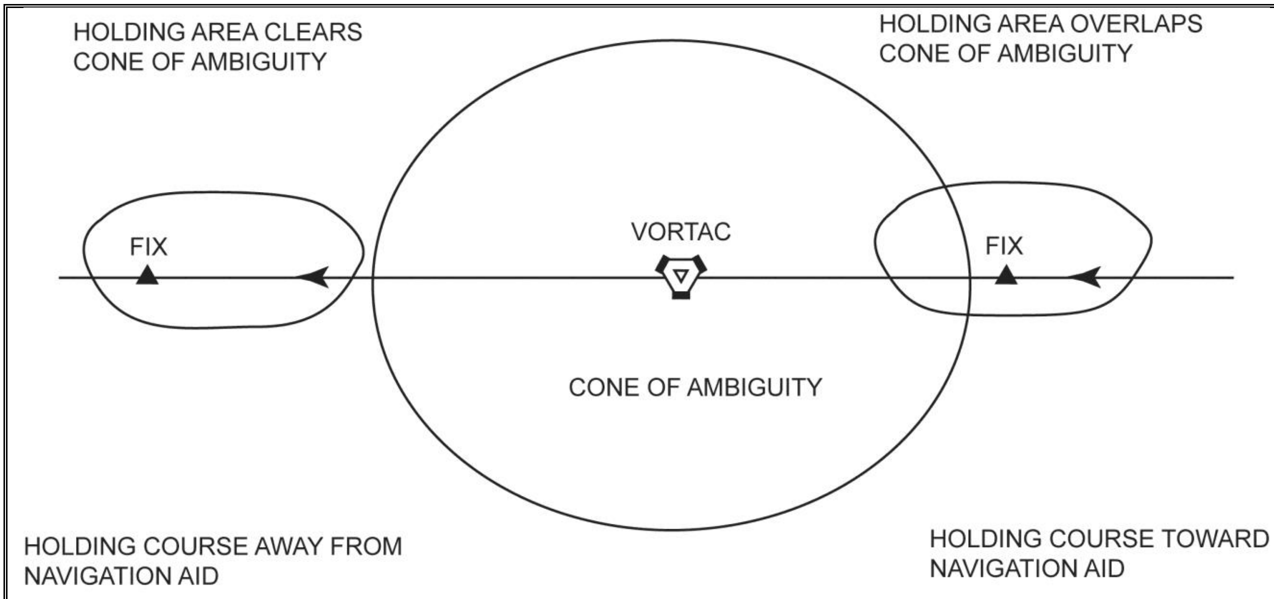


Figure 18-4: DME Holding - Cone Of Ambiguity. Para 1821.a.(2).

b. Effect of Slant Range. An airborne DME reading of 5 NM at 30,000' would indicate that an aircraft is directly over the navigation aid. If the aircraft maintained the 5 NM DME distance during descent, its flight path would form an arc beginning over the navigation aid to a point on the surface 5 NM horizontal distance from the navigation aid. Therefore, near the surface a holding fix could be 5 NM horizontally from the navigation aid, but at 13,000' it would be 4.5 NM horizontally from the navigation aid. In this instance, 5 NM is the fix-to-navigation aid distance, and 4.5 NM is the slant range/geographical distance. See Figure 18-5. When establishing a DME holding fix, the difference between fix-to-navigation aid and slant range/geographical distance shall be determined. DME holding fix distance differences shall be governed by the following:

(1) When establishing a DME hold, fix differences between fix-to-navigation aid and slant range/geographical distance shall be determined using the DME Slant Range Distance/Cone of Ambiguity Area Chart. See Figure 18-3.

(2) Use whole nautical miles for slant range distance. For example: the minimum DME distance to hold an aircraft at 10,000 feet occurs at a slant-range distance of 2.9 NM. Therefore, holding shall be based on a 3 NM DME fix.

(3) When the slant range/geographical distance differs 0.25 NM or less from the fix-to-navigation aid distance at the highest altitude to be used for holding, the difference may be disregarded for altitudes at or below 14,000 feet. A difference of 0.5 NM or less may be disregarded above 14,000 feet.

Example: A DME fix is required for holding at and below 10,000 feet at a geographical distance of 8 NM. Figure 18-3 shows that the 8 NM slant range at 10,000 feet is 7.84 NM horizontally from the navigation aid. The difference of 0.16NM may be disregarded when plotting protected airspace. If the holding altitude in the same example is changed to FL200, the horizontal distance at FL200 would be 7.3 NM, creating a difference of 0.7 NM. In this case, protected airspace should be based on a distance of 7.3 NM.

(4) Collocation of DME and Non-DME fixes. When a DME holding fix is to be collocated with another established fix, and the horizontal distance between the established fix and the navigation aid providing DME information is to be used as the DME slant range distance, significant distance differences may exist. Differences shall be governed by the following:

(a) When it is desirable to use a single distance with respect to both DME and VOR intersection holding, plot the holding area based on the VOR intersection. Then replot the slant range/geographical distance from the navigation aid for the highest holding altitude. The combined perimeter of the two plots determines the airspace to be protected.

(b) When it is desirable to contain DME and non-DME holding within a single pattern size, use a slant range distance different from the distance between the non-DME fix and the navigation aid providing DME information. Select a slant range distance, for the highest altitude to be used for holding, which is coincident with the distance between the non-DME fix and the navigation aid providing DME information. See Figure 18-6.

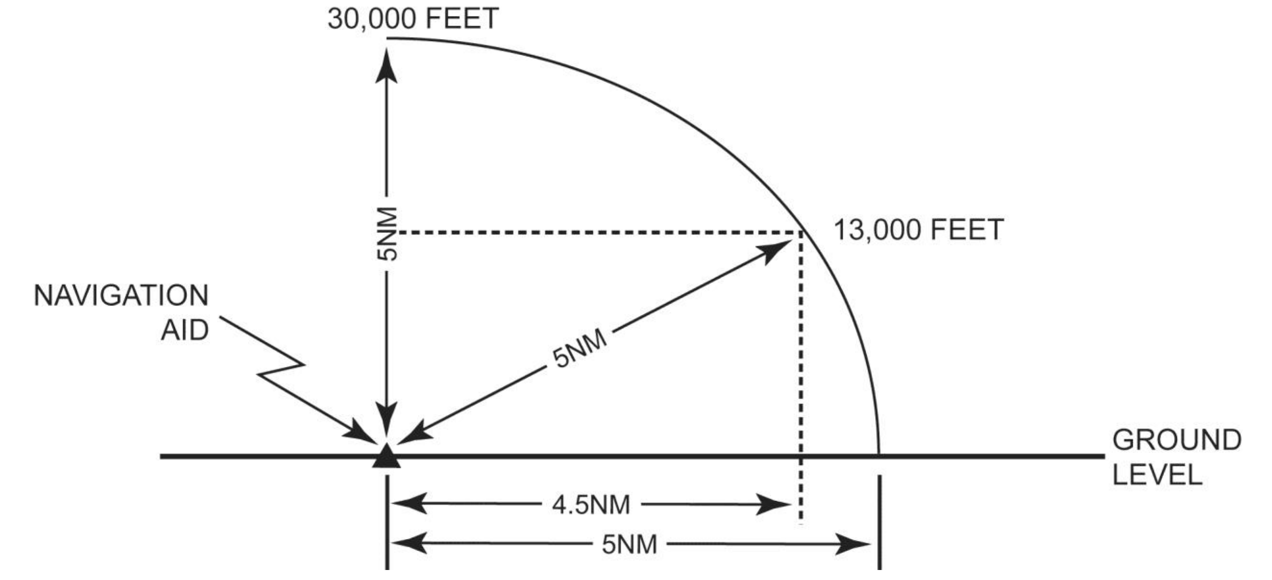


Figure 18-5: Slant Range/Geographical Distance. Para 1821.b.

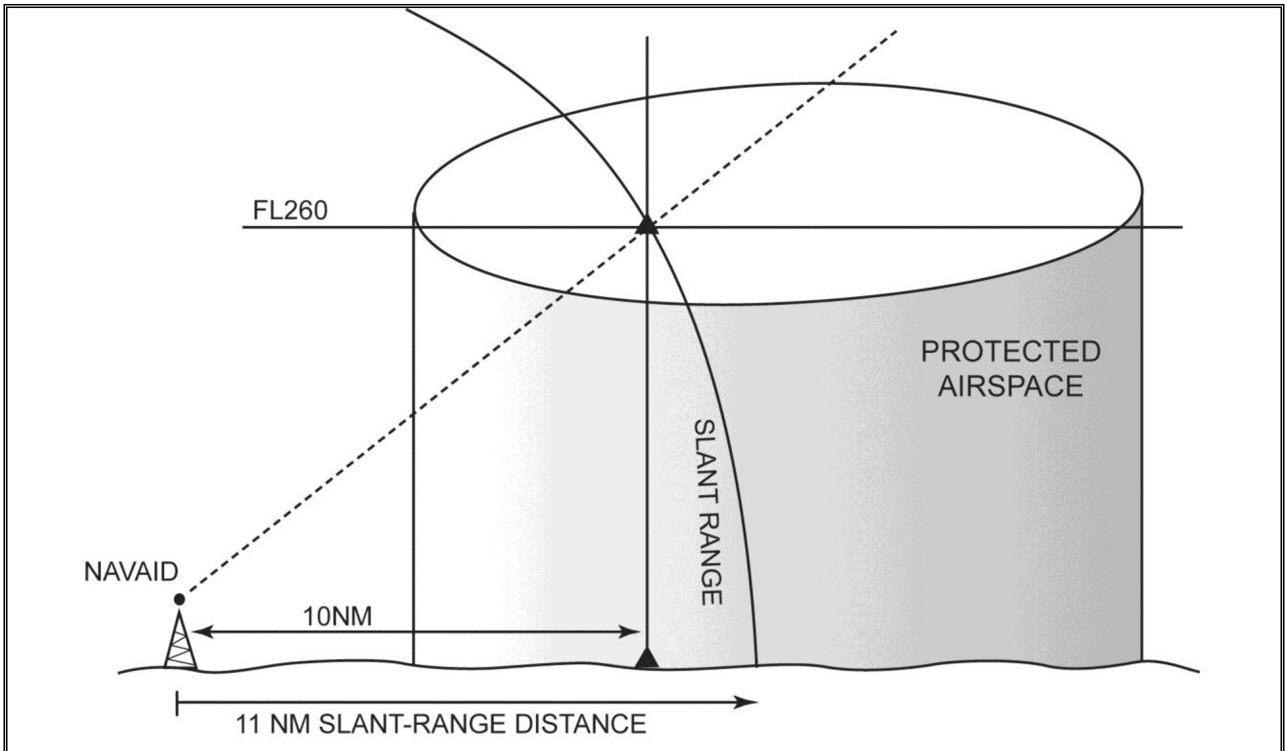


Figure 18-6: Collocated Fix (Single Holding Area). Para 1821.b.(4)(b).

1822. Shuttle Procedures

A shuttle procedure is a manoeuvre involving a descent or climb in a pattern resembling a holding pattern. Shuttles are generally used on procedures located in mountainous areas. In the approach phase, it is normally prescribed where a descent of more than 2,000 feet is required during the initial or intermediate approach segments. In may also be required when flying a missed approach or departure procedure from certain aerodromes.

a. Shuttle Climb.

(1) Area. When a shuttle climb is used, the primary holding area shall encompass the departure or missed approach segment width at the holding fix. See Figure 18-7. A secondary area 2 miles wide surrounds the perimeter of the primary area.

The holding area/speed relationship in Table 18–1 is not adequate for climbing aircraft primarily because climb speeds exceed level holding speeds. Shuttle climb areas may be assessed using the following templates:

(a) If using the 200 KT or 210 KT template, publish a speed restriction of 175 KIAS.

(b) If using the 230 KT template, publish a speed restriction of 200 KIAS.

(c) If using the 265 KT template, publish a speed restriction of 250 KIAS.

(d) If using the 310 KT holding pattern, no speed restriction is required.

Example: A departing turbo-jet aircraft must shuttle climb to 16,000 feet at an NDB. Table 18–2 (310 KT at 16,000 feet) indicates template number 19 will provide the necessary protected airspace.

(e) When developing a shuttle climb, it is acceptable to begin obstacle assessment using the smallest template appropriate for the altitude that the shuttle starts and increase the template size appropriate for altitude as the aircraft climbs and true airspeed increases.

Example: A departure, within mountainous terrain, requires the aircraft to shuttle climb to 16,000 feet before proceeding on course. The field elevation is 2,600 feet. The holding facility is within 5 NM of the departure aerodrome. The speed in the climb will be restricted to 200 KIAS.

Start the obstacle assessment using template number 6, which is appropriate for 4,000 feet and 230 KIAS. Then reassess the procedure using the templates appropriate for 6,000 feet, 8,000 feet, 10,000 feet, 12,000 feet, 14,000 feet and finally 16,000 feet. As the aircraft climbs, the size of the holding area will increase to accommodate the increase in aircraft true airspeed.

(2) Obstacle Clearance. When a shuttle climb is used, as in a departure or missed approach, no obstacle shall penetrate the holding surface. This surface begins at the end of the segment leading to the holding fix. Its elevation is that of the departure OIS or missed approach surface at the holding fix. It rises at a 40:1 rate to the edge of the primary area, then at a 12:1 rate to the outer edge of the secondary area. The distance to any obstacle is measured from the obstacle to the nearest point on the end of the segment at the holding fix. See Figure 18-7.

b. Shuttle Descent.

(1) Alignment. When a holding pattern is established at a final approach fix and a procedure turn is not used, the inbound course of the holding pattern shall be aligned to coincide with the final approach course unless the final approach fix is a facility. When the final approach fix is a facility, the inbound holding course and the final approach course shall not differ by more than 30 degrees.

(2) Area. Shuttle descent areas may be assessed using the following templates:

(a) If using the 200 KT or 210 KT template, publish a speed restriction of 175 KIAS.

(b) If using the 230 KT template, publish a speed restriction of 200 KIAS.

(c) If using the 265 KT template, publish a speed restriction of 250 KIAS.

(d) When assessing a shuttle descent, it is acceptable to reduce the template size appropriate for altitude as the aircraft descends, similar to the shuttle climb.

(3) Obstacle Clearance. A minimum of 1,000 feet of obstacle clearance shall be provided throughout the primary area. In the secondary area 500 feet of obstacle clearance shall be provided at the inner edge, tapering to zero feet at the outer edge.

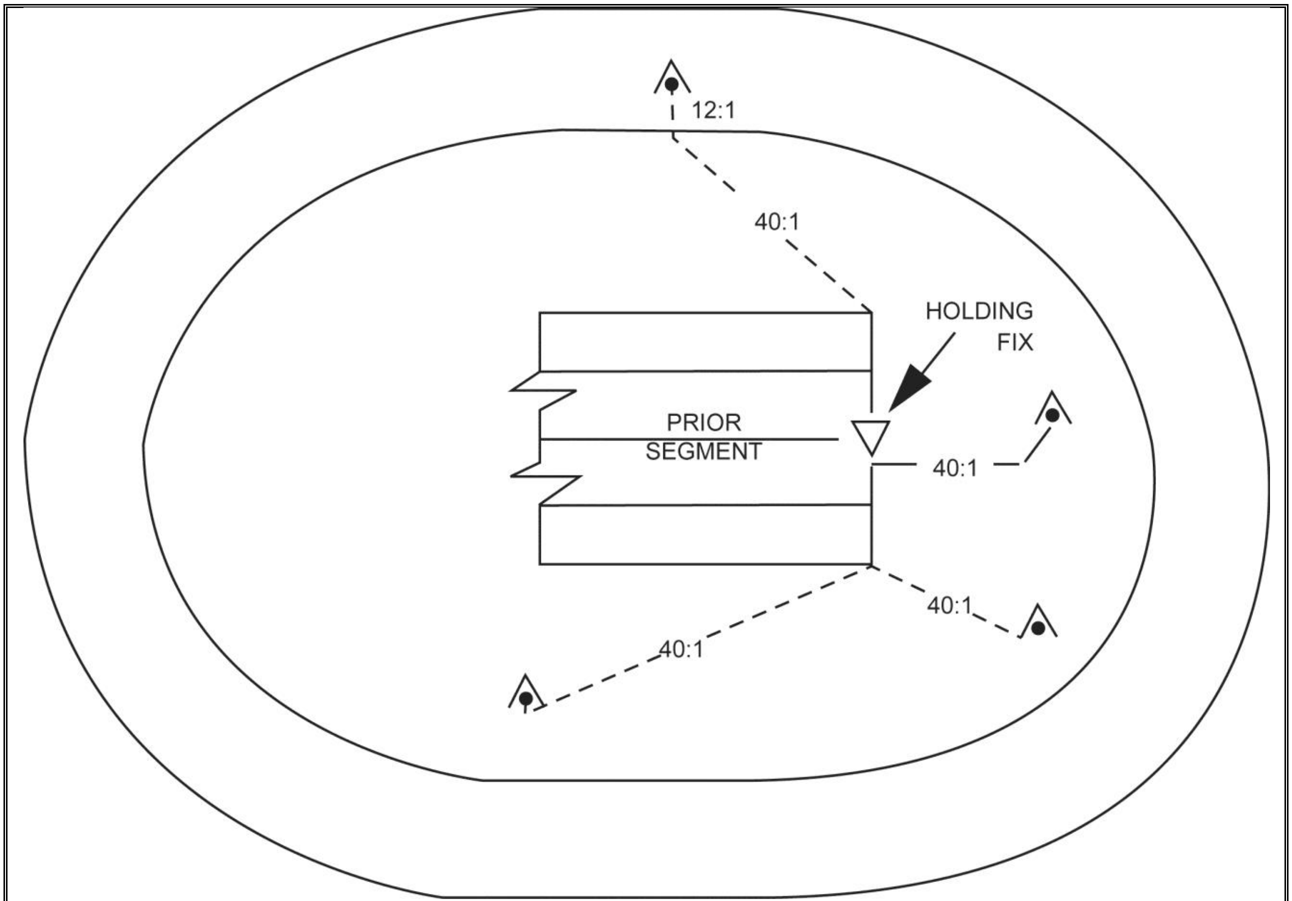


Figure 18-7: Climbing In A Holding Pattern. Para 1822.a.(2).

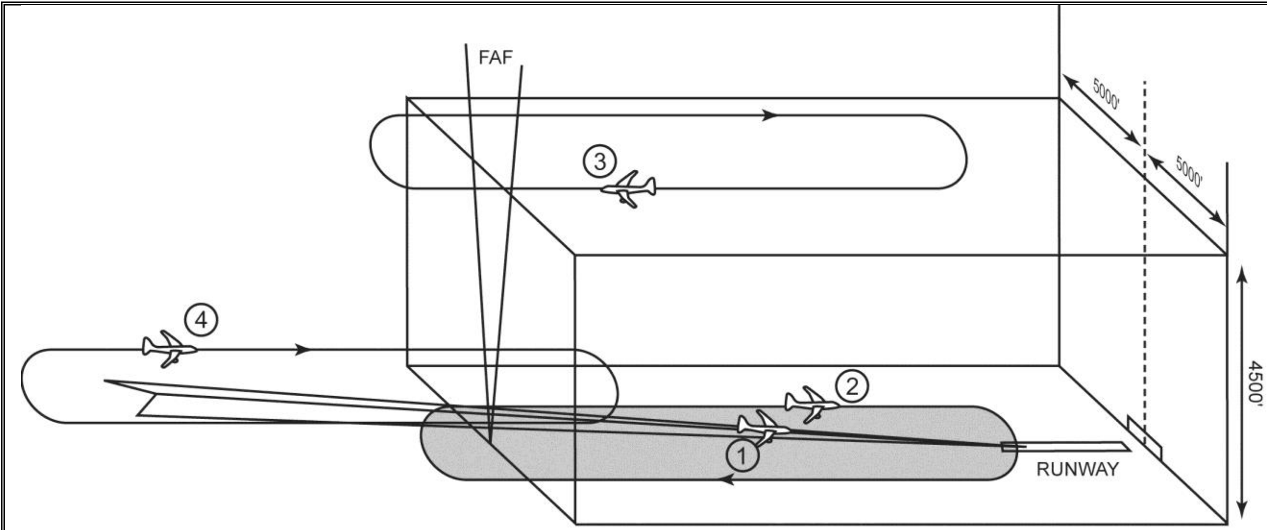
1823. Holding Patterns On ILS Courses

Holding patterns shall not be established inbound on an ILS localizer between the FAF and the localizer antenna below 5,000 feet above the antenna elevation, in order to avoid creating unwanted reflected signals. Holding patterns opposite to the inbound course are acceptable. See Figure 18-8. Ensure localizer signal coverage when establishing the hold.

1824. GPS Holding

The airspace to be protected for GPS holding is the same as per the template areas in Table 18–2. When holding is at a GPS waypoint the primary area of the selected pattern shall be large enough to contain the entire waypoint displacement area (see Table 16–1). Use the 15 NM distance for terminal holding procedures and 30 NM distance for en route holding.

1825—1829. RESERVED



(1) Aircraft inbound on ILS - OK.

(2) Inbound holding course is coincident with course of aircraft (1), thus unwanted localizer signals are being reflected - NOT PERMITTED.

(3) Inbound holding course is opposite course of aircraft (1) - OK.

(4) Inbound holding course is outside reflected signal area - OK.

Figure 18-8: Reflected Signal Area. Para 1823.

SECTION 3. CONSTRUCTION OF HOLDING AREAS

1830. Reserved

1831. Tracing Of Templates

a. Primary Area. The perimeter of the template contains four radii and two straight lines. Position the holding fix grommet hole over the fix, and align the solid black line with the inbound holding track. Trace the pattern perimeter. See Figure 18-9.

(1) Right Turn Pattern. The numbers on the template should be face-up and readable.

(2) Left Turn Pattern. The numbers on the template should be face-down.

b. Secondary Area. Manually draw the secondary area 2 miles from the edge of the primary area.

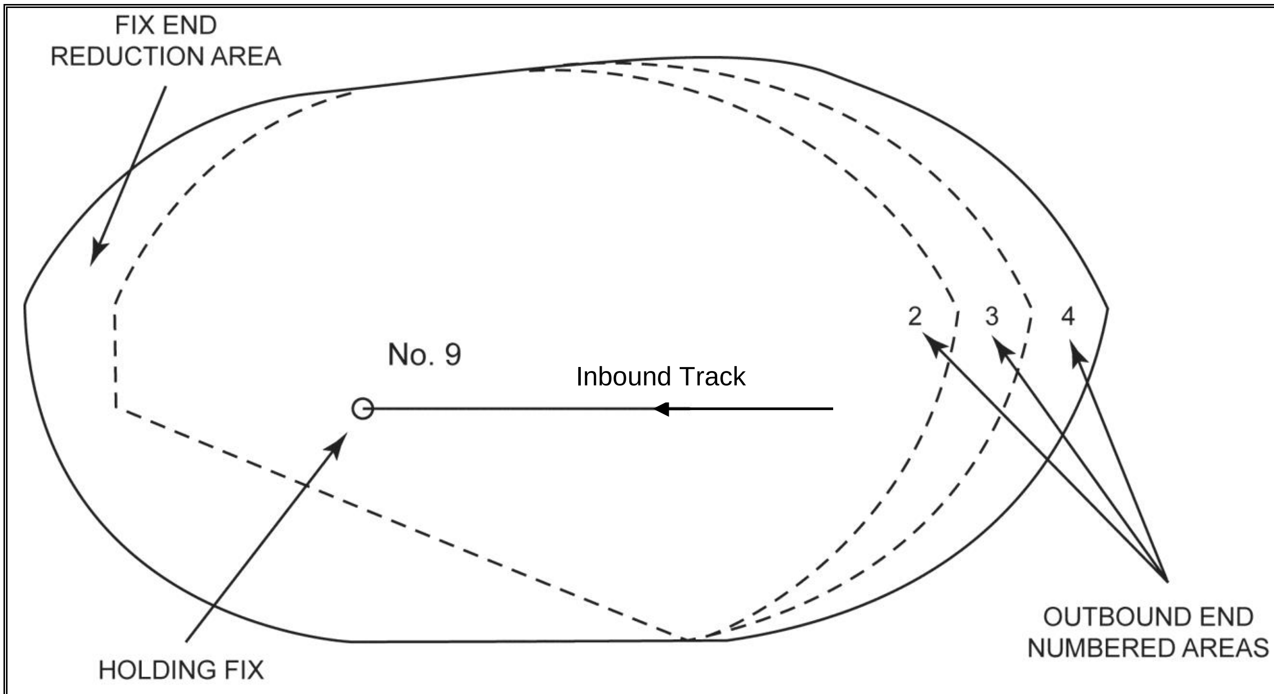


Figure 18-9: Holding Template. Para 1831.a.

1832. Manual Construction Of Holding Areas

Each holding area may be manually constructed by applying the dimensions for the area concerned, as provided in Table 18–3 and using the reference points depicted in Figure 18-10, and in accordance with the following directions:

- **a.** Locate and mark the holding fix with the letter L.
- **b.** Draw the inbound track; A to L, L to M, and M to G.
- **c.** At a 90° angle from the inbound track locate and mark Points B above A, F above G, E above M, H below M and I below L.
- **d.** Connect I and H with a straight line.
- **e.** Set the compass for distance L-B; place the compass center at L and draw an arc from B to beyond C. (Note: C is a general location above L.)
- **f.** Draw a straight line from E tangent to the arc B-C.
- **g.** Set the compass for distance L-B; place the compass center at B and draw a short arc above L; relocate the compass center at I and draw a short arc through the first arc; relocate the compass center at the intersection of the arcs and connect I-B.
- **h.** Set the compass for distance F-M; Place the compass center at F, draw an arc from above H to below E. Place the compass center at E and draw a short arc below M. Place the compass center at H and draw a short arc above M. The arcs formed from E and H intersect the arc formed from F. Place the compass center at the appropriate intersection of these arcs and connect E-F; place the compass center at the other intersection and connect F-H.

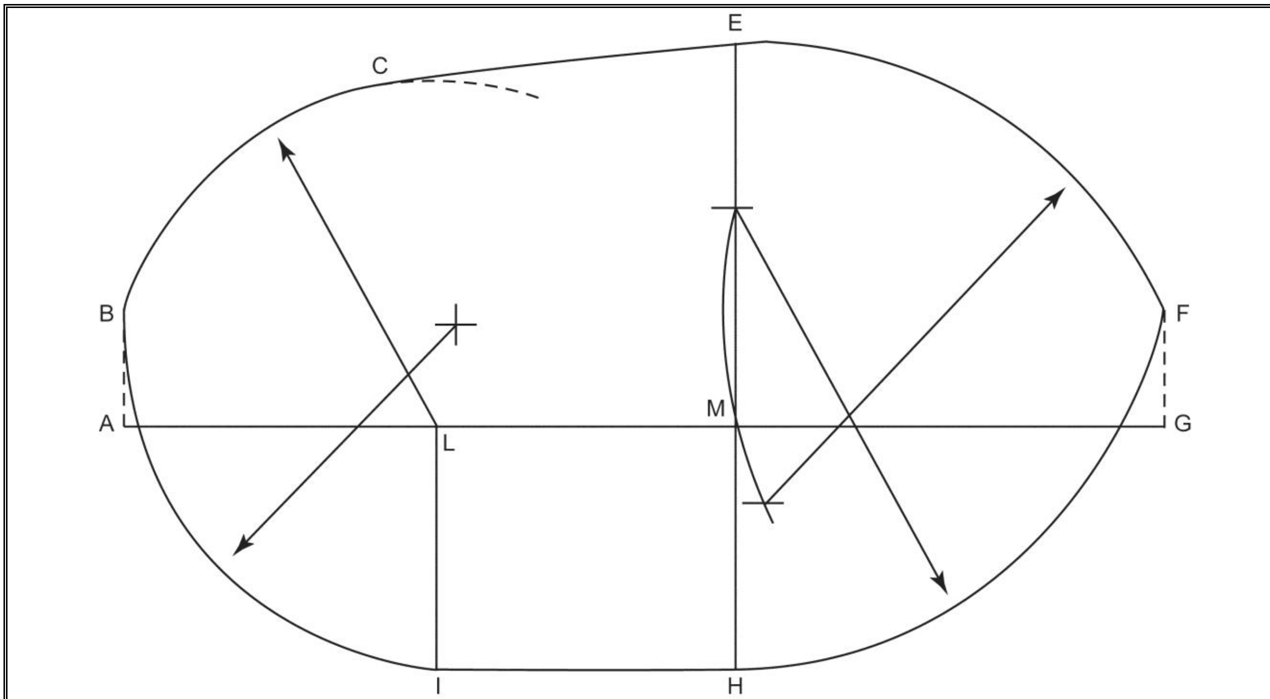


Figure 18-10: Construction Code For Basic Area. Para 1832.

1833—1899. Reserved

Template No.	A-L	L-M	M-G	L-I M-H	M-E	A-B G-F	Total Length	Width
1	3.5	3.7	4.4	2.6	4.1	1.2	11.6	6.7
2	3.8	3.9	4.8	2.9	4.5	1.3	12.5	7.4
3	4.2	4.1	5.2	3.2	4.9	1.4	13.5	8.1
4	4.5	4.3	5.6	3.5	5.3	1.5	14.4	8.8
5	4.9	4.5	6.1	3.8	5.7	1.7	15.5	9.5
6	5.6	4.8	6.5	4.2	6.4	2.0	16.9	10.6
7	6.0	6.6	8.2	4.6	7.2	2.2	20.8	11.8
8	6.5	6.8	9.3	4.9	7.7	2.3	22.6	12.6
9	7.0	7.0	9.7	5.3	8.3	2.5	23.7	13.6
10	7.6	7.3	10.4	5.7	8.9	2.7	25.3	14.6
11	8.0	7.5	11.1	6.2	9.6	2.9	26.6	15.8
12	8.7	7.8	11.7	6.5	10.2	3.1	28.2	16.7
13	9.2	8.6	12.1	7.0	10.9	3.3	29.9	17.9
14	9.9	8.9	12.8	7.5	11.6	3.6	31.6	19.1
15	10.4	9.6	13.1	7.7	12.1	3.8	33.1	19.8
16	11.1	9.9	13.7	8.2	12.8	4.0	34.7	21.0
17	11.9	10.1	14.8	8.6	13.6	4.3	36.8	22.2
18	12.7	10.5	15.7	9.2	14.6	4.5	38.9	23.8
19	13.8	11.1	16.8	9.9	15.7	4.8	41.7	25.6
20	14.5	11.5	18.0	10.5	16.5	5.2	44.0	27.0
21	15.5	11.8	18.8	11.2	17.6	5.5	46.1	28.8
22	16.5	12.1	21.2	11.9	18.8	5.9	49.8	30.7
23	17.6	12.4	21.6	12.7	20.1	6.3	51.6	32.8
24	19.2	12.9	23.4	13.7	21.7	6.9	55.5	35.4
25	21.2	13.3	25.5	14.7	23.4	7.5	60.0	38.1
26	22.9	13.8	27.6	16.1	25.7	8.1	64.3	41.8
27	24.6	14.4	29.5	17.3	27.3	8.8	68.5	44.6
28	26.9	15.2	32.6	18.9	30.2	9.6	74.7	49.1
29	28.0	15.8	34.6	20.1	32.0	10.0	78.4	52.1
30	29.2	16.4	35.3	21.3	33.2	10.4	80.9	54.5
31	30.9	17.0	37.0	22.5	34.5	11.0	84.9	57.0

Table 18-3: Holding Area Airspace Dimensions (NM). Para 1832.

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Government of Canada Gouvernement du Canada

CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

VOLUME 2

PERFORMANCE BASED NAVIGATION (PBN)

TRANSPORT CANADA
NATIONAL DEFENSE

5 January 2017

Canada

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Volume 2: Performance Based Navigation (PBN)

CHAPTER 1: PURPOSE

SECTION 1: PURPOSE

1.1. Purpose.

This volume contains criteria for the formulation, review, approval and publication Performance Based Navigation (PBN) instrument procedures. The criteria were developed by United States Federal Aviation Administration's (FAA).

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VOLUME 2: PERFORMANCE BASED NAVIGATION (PBN)

CHAPTER 2. BASIC CRITERIA INFORMATION

SECTION 1: CRITERIA

2.1. Criteria.

These criteria assumes the use of Global Navigation Satellite System (GNSS) receivers approved for approach operations in accordance with the applicable Technical Standard Order (TSO) or equivalent criteria.

2.1.1. Data Resolution.

Perform calculations using an accuracy of at least 15 significant digits; i.e., floating point numbers must be stored using at least 64 bits. Unless otherwise noted, do not round intermediate results. Round only the final result of calculations for documentation purposes. Required accuracy tolerance is 1 centimeter for distance and 0.002 arc-second for angles. The following list specifies the minimum accuracy standard for documenting data expressed numerically. This standard applies to the documentation of final results only; e.g., a calculated adjusted glide path angle of 3.04178 degrees is documented as 3.05 degrees. The standard does not apply to the use of variable values during calculation. Use the most accurate data available for variable values.

2.1.2. Documentation Accuracy:

a. **All latitudes and longitudes** to the nearest one hundredth (0.01) arc second; [nearest five ten thousandth (0.0005) arc second for Final Approach Segment (FAS) data block entries];

b. Flight Path Alignment Point (FPAP) mean sea level (MSL) elevation to the nearest foot;

c. FPAP height above ellipsoid (HAE) to the nearest tenth (0.1) meter;

d. **Landing Threshold Point (LTP)** mean sea level **(MSL) elevation** to the nearest foot;

e. **LTP height above ellipsoid (HAE)** to the nearest tenth (0.1) meter;

f. Glidepath angle to the next higher one hundredth (0.01) degree;

g. Courses to the nearest one hundredth (0.01) degree;

h. Course width at threshold to the nearest quarter (0.25) meter; and

i. Distances to the nearest hundredth (0.01) unit [except for “length of offset” entry in Final Approach Segment (FAS) data block which is to the nearest 8 meter value].

2.1.3. Mathematics Convention. Formulas in this document (chapters 1 to 7) as depicted are written for radian calculation and chapter 8 are written for degree calculation.

$$y = \frac{x^2}{tan\left(3^o \times \frac{\pi}{180^o}\right)}$$

Where X is a variable value

Note: The value ft-per-NM (fpnm) value for 1 NM was previously defined as 6,076.11548 ft. For the purposes of RNAV criteria, 1 NM is defined as the result of the following calculation:

$$fpnm = \frac{1852}{0.3048}$$

Conversions:

round(a,f) rounds value **a** toward the nearest integ

er to **f** decimal places; e.g., **round(6.2354,2)=6.24, round(10.5645,3)=10.565, round(5241.499,0)=5241, round(5241.5001,0)=5242**

ceiling(a) rounds value **a** to the next integer toward positive infinity; e.g., **ceiling(2.3)=3, ceiling(-2.3)=-2**.The **ceiling** function may be defined

```
function ceiling(x)
if x=int(x) then
            ceiling=x
else
      if x<0 then
            ceiling=int(x)
            else
            ceiling=int(x)+1
      end if
end if
end function
```

floor(a) rounds value **a** to the next integer toward negative infinity; e.g., **floor(**2.3**)**=2, **floor(**-2.3**)**=-3. The **floor** function may be defined as:

```
function floor(x)
if x=int(x) then
            floor=x
      else
            if x<0 then
```

```
                floor=int(x)-1
            else
                floor=int(x)
            end if
    end if
    end function
```

min(x,y) returns the least (closest to negative infinity) of real values x or y; e.g., **min(-3,-5)=-5**, **min(3,5)=3**

max(x,y) returns the greatest (closest to positive infinity) of real values x or y; e.g., **max(-3,-5)=-3, max(3,5)=5**

2.1.4. Definition of Mathematical Constants.

a. e The constant e is the base of the natural logarithm and is sometimes known as Napier's constant, although its symbol (e) honors Euler. With the possible exception of π, e is the most important constant in mathematics since it appears in myriad mathematical contexts involving limits and derivatives. Its value is approximately 2.71828182845904523536028747135266249775 7...

b. r The TERPS constant for the mean radius of the earth for spherical calculations in feet. r = 20890537

2.1.5. Common equation terms. : These terms/variables are common to all calculators.

a. **AMSL** is above mean sea level.

b. **φ** is bank angle.

c. **β** is magnitude of heading change in degrees.

d. **θ** is glidepath angle in degrees.

e. **DA** is decision altitude in feet AMSL.

f. **alt** is altitude in feet AMSL.

g. $\mathbf{ATT_i}$ is the along-track error for the segment initial fix.

h. $\mathbf{ATT_t}$ is the along-track error for the segment termination fix.

i. $\mathbf{V_{KIAS}}$ is knots indicated airspeed.

j. $\mathbf{apt_{elev}}$ is the published airport elevation in feet AMSL.

k. $\mathbf{LTP_{elev}}$ is the published threshold elevation in feet AMSL.

l. **TCH** is threshold crossing height in feet above threshold.

m. **$PFAF_{alt}$** is the minimum intermediate segment altitude in feet AMSL.

n. **O_{MSL}** is the obstacle elevation in feet AMSL.

o. **OBS_X** is the along track distance in feet from LTP to obstacle.

p. **HATh** is the difference between DA and LTP elevation rounded to the next higher foot value.

q. **HAL** is the difference between DA and FHP elevation rounded to the next higher foot value.

Notes on calculator usage:

1. Most calculators are programmed with standard mathematical rules of precedence.

2. When possible, let the calculator maintain all of the available digits of a number in memory rather than re-entering a rounded number. For highest accuracy from a calculator, any rounding that is necessary should be done at the latest opportunity.

2.1.6. Geospatial Standards.

The following standards apply to the evaluation of obstacle and terrain position and elevation data relative to RNAV Obstacle Evaluation Area(s) (OEAs) and Obstacle Clearance Surface(s) (OCSs). Terrain and obstacle data are reported in NAD-83 latitude, longitude, and elevation relative to MSL in Canadian Geodetic Vertical Datum of 1928 (CGVD-28) or Canadian Geodetoc Vertical Datum of 2013 (CGVD 2013) vertical datum. Evaluate obstacles using their NAD-83 horizontal position and CGVD-28 and/or CGVD 2013 elevation value compared to the WGS-84 referenced course centerline (along-track and cross-track), OEA boundaries, and OCS elevations as appropriate.

Supplementary note: All reference to WGS-84 or other datum in TP308 must be interpreted as inclusive to approved equivalent datum by Natural Resources Canada.

2.1.7. OEA Construction and Obstacle Evaluation Methodology.

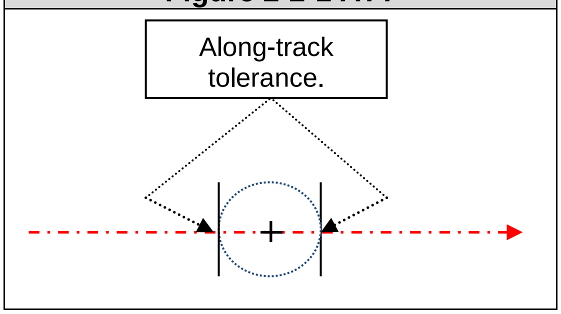
a. Courses, fixes, boundaries (lateral dimension). Construct straight-line courses as a WGS-84 ellipsoid geodesic path. If the course outbound from a fix differs from the course inbound to the fix (courses measured at the fix), then a turn is indicated. Construct parallel and trapezoidal boundary lines as a locus of points measured perpendicular to the geodesic path. (The resulting primary and/or secondary boundary lines do not display a “middle bulge” due to curvature of the ellipsoids surface since they are not geodesic paths.) NAD-83 latitude/longitude positions are acceptable for obstacle, terrain, and airport data evaluation. Determine obstacle lateral positions relative to course centerline/OEA boundaries using ellipsoidal calculations (see Appendix A).

b. Elevations (vertical dimension). Evaluate obstacles, terrain, and airport data using their elevation relative to their orthometric height above the geoid (for our purposes, MSL) referenced to the CGVD-28 and/or CGVD 2013 vertical datum. The elevations of OCSs are determined spherically relative to their origin MSL elevation (CGVD-28 and/or CGVD 2013).

2.1.8. Along Track Tolerance (ATT) Values.

Along Track Tolerance (ATT) is the value used (for segment construction purposes) to quantify position uncertainty of an RNAV fix. The application of ATT can; therefore, be considered “circular;” i.e., the ATT value assigned describes a radius around the plotted position RNAV fix (See Figure 2-2-1 and Table 2-2-1). In order to account for ATT in procedure design, OEAs are constructed and evaluated from the ATT value prior to a segment’s initial fix to the ATT value past the segment termination fix. ATT values are not included in minimum segment length calculations.

Figure 2-2-1 ATT



Note: Cross-track tolerance (XTT) values were considered in determining minimum segment widths and are not considered further in the segment construction.

Table 2-2-1. ATT Values		
GPS	**En Route** Feeder, initial, Intermediate, Missed Approach (> 30 NM)	**2.0 NM**
	Terminal Feeder, initial, Intermediate, Missed Approach (≤ 30 NM)	**1.0 NM**
	Approach (final)	**0.3 NM**
WAAS* **(LPV & LP)**	**Approach** (final)	**40 meters**

Note: * Applies to the final segment only. Apply GPS values to all other segment of the approach procedure.

2.1.9. Terminal Instrument Procedures (TERPS) Standard for Geodetic Constructions.

See Annex: F.

VOLUME 2: PERFORMANCE BASED NAVIGATION (PBN)

CHAPTER 3: GENERAL INFORMATION

SECTION 1: GENERAL INFORMATION

3.1. General Information.

3.1.1. Cancellation. This Volume cancels the TP308/GPH209 Change 6.0 Vol 5 Chap 2.

SECTION 2: DEFINITION AND ACRONYMS

3.2. Definition and Acronyms.

3.2.1. Dimensional (3D). Approach procedures that provide longitudinal, lateral, and vertical path deviation information are 3Dprocedures. Instrument landing system (ILS), microwave landing system (MLS), precision approach radar (PAR), lateral navigation/vertical navigation (LNAV/VNAV), Localizer Performance with Vertical Guidance (LPV), and required navigation performance (RNP) are examples of 3D procedures.

3.2.2. Air Traffic Service (ATS) Route. A generic term that includes airways, air route, jet routes, and RNAV routes. The term “ATS route” does not replace these more familiar route names, but serves only as an overall title when listing the types of routes that comprise the Canadian en-route structure.

3.2.3. Airport Reference Point (ARP). The official horizontal geographic location of an airport. It is the approximate geometric center of all usable runways at an airport.

3.2.4. Along-Track Distance (ATD). A distance specified in nautical miles (NM) along a defined track to an area navigation (RNAV) fix.

3.2.5. Along-Track (ATRK) Tolerance (ATT). The amount of possible longitudinal fix positioning error on a specified track expressed as a ± value.

Note: The acronym ATRKFDT (along-track fix displacement tolerance) has been used instead of ATT in the past. The change to ATT is a step toward harmonization of terms with International Civil Aviation Organization (ICAO) Pans-Ops.

3.2.6. Approach Surface Baseline (ASBL). The ASBL is a line aligned to the runway centerline (RCL) that lies in a plane parallel to a tangent to the WGS- 84 Ellipsoid at the landing threshold point. It is used as a baseline reference for vertical measurement of the height of glidepath and obstacle clearance surface (OCS).

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

3.2.8. Authorization Required (AR). Aircraft may be equipped beyond the minimum standard for public required navigation performance (RNP) criteria and aircrews trained to achieve a higher level of instrument approach performance. AR criteria are based on a higher level of equipage and additional aircrew requirements. Procedures that utilize AR design criteria must be appropriately annotated.

3.2.9. Average Coldest Temperature (ACT). A value in Centigrade (°C) and/or Fahrenheit (°F) scale for the lowest temperature a Baro- VNAV (including RNP) procedure can be utilized. It is derived from historical weather data, or in the absence of historical data, a standardized temperature value below airport ISA is used.

3.2.10. Barometric Altitude. A barometric altitude measured above mean sea level (MSL) based on atmospheric pressure measured by an aneroid barometer. This is the most common method of determining aircraft altitude.

3.2.11. Where a turn area expansion arc(s) may be centered, a line perpendicular to the inbound course after the leg termination fix ATT area. For CA, CI, VA or VI legs, the baseline is located at the leg termination point.

3.2.12. Course Change. A course change is the mathematical difference between the inbound and outbound tracks at a single fix.

3.2.13. Course-to-a-Fix (CF). A defined, repeatable course (track over the ground) to a specific database fix.

3.2.14. Course-to-an-Altitude (CA). A defined, repeatable course to a specific altitude at an unspecified position.

3.2.15. Course-to-an-Intercept (CI). A defined, repeatable course to intercept the subsequent leg.

3.2.16. Cross-Track (XTT) Tolerance. The amount of possible lateral positioning error expressed as a ± value.

Note: The acronym **XTRKFDT** (cross-track fix displacement tolerance) has been used instead of XTT in the past. The change to XTT is a step toward harmonization of terms with ICAO Pans-Ops.

3.2.17. Decision Altitude (DA). The DA is a specified barometric altitude at which a missed approach must be initiated if the required visual references to continue the approach have not been acquired. DA is referenced to MSL. It is applicable to vertically guided approach procedures.

3.2.18. Departure End of Runway (DER). The DER is the end of the runway that is opposite the landing threshold. It is sometimes referred to as the stop end of runway.

3.2.19. Departure Reference Line (DRL). An imaginary line of indefinite length perpendicular to the runway centerline at the DRP.

3.2.20. Departure Reference Point (DRP). A point on the runway centerline 2000ft from the start end of runway.

3.2.21. Descent Gradient (DG). Description of aircraft descent profile specified in feet per nautical mile.

3.2.22. Direct-to-a-Fix (DF). An unspecified non-repeatable track starting from an undefined position to a specific database fix.

3.2.23. Distance of Turn Anticipation (DTA). The distance from (prior to) a fly-by fix at which an aircraft is expected to start a turn to intercept the course/track of the next segment.

3.2.24. Early Turn Point (ETP). Represents the earliest location where a flight track turn may commence.

3.2.25. Earth Curvature (EC). Allowance for the curvature of the earth used in distance calculations based on a spherical earth model with a radius of 20890537 ft.

3.2.26. Fictitious Threshold Point (FTP). The FTP is the equivalent of the landing threshold point (LTP) when the final approach course is offset from the runway centerline. It is not aligned through the LTP. It is located on the final approach course the same distance from the intersection of the final approach course and runway centerline extended as the LTP. FTP elevation is the same as the LTP. For the purposes of this document, where LTP is used, FTP may apply as appropriate.

3.2.27. Final Approach Course (FAC). Magnetic and/or true heading definition of the final approach lateral path.

3.2.28. Final Approach Fix (FAF). A fly-by waypoint (WP) for nonprecision GPS procedures that marks the beginning of the final approach segment.

3.2.29. Final Approach Segment (FAS). The FAS begins at the PFAF and ends at the LTP/FTP. The FAS is typically aligned with the runway centerline extended. The segment OEA normally extends a distance equal to ATT(1RPN) beyond (outside) the segment initial and termination fixes. The FAS is divided into the OCS and the visual segment obstacle identification surface (OIS).

3.2.30. Fix Displacement Tolerance (FDT). FDT is a legacy term providing 2-dimensional (2D) quantification of positioning error. It is now defined as a circular area with a radius of ATT centered on an RNAV fix. The acronym ATT is now used in lieu of FDT.

3.2.31. Flight Control Computer (FCC). Aircraft computers which process information from various inputs to calculate flight path and flight guidance parameters.

3.2.32. Flight Management System (FMS). An FMS is a specialized computer system that automates a wide variety of in-flight tasks, reducing the workload on the flight crew to the point that modern aircraft no longer carry flight engineers or navigators. A primary function is in-flight management of the flight plan. Using various sensors (such as GPS and INS often backed up by radio navigation) to determine the aircraft's position, the FMS can guide the aircraft along the flight plan. From the cockpit, the FMS is normally controlled through a Control Display Unit (CDU) which incorporates a small screen and keyboard or touchscreen. The FMS sends the flight plan for display on the EFIS, Navigation Display (ND) or Multifunction Display (MFD).

3.2.33. Flight Path Alignment Point (FPAP). The FPAP is a 3D point defined by World Geodetic System of 1984/North American Datum of 1983 (WGS-84/NAD-83) latitude, longitude, MSL elevation, and WGS-84 Geoid height. The FPAP is used in conjunction with the LTP and the geometric center of the WGS- 84 ellipsoid to define the final approach azimuth (LPV glidepath’s vertical plane) associated with an LP or LPV final course.

3.2.34. Flight Path Control Point (FPCP). The FPCP is a 3D point defined by the LTP geographic position, MSL elevation, and threshold crossing height (TCH) value. The FPCP is in the vertical plane of the final approach course and is used to relate the glidepath angle of the final approach track to the landing runway. It is sometimes referred to as the TCH point or reference datum point (RDP).

3.2.35. Final Roll-Out Point (FROP). Where a course change is required at or inside the PFAF, the point that the aircraft rolls to a wings-level attitude aligned with the runway centerline extended is considered the FROP.

3.2.36. Fly-By (FB) Fix. Fly-by fixes/waypoints are used when an aircraft should begin a turn to the next course prior to reaching the waypoint separating the two route segments.

3.2.37. Fly-Over (FO) Fix. Fly-over fixes/waypoints are used when the aircraft must fly over the point prior to starting a turn.

3.2.38. Geoid Height (GH). The GH is the height of the Geoid relative to the WGS-84 ellipsoid. It is a positive value when the Geoid is above the WGS-84 ellipsoid and negative when it is below. The value is used to convert a mean sea level (MSL) elevation to an ellipsoidal or geodetic height, the height above ellipsoid (HAE).

Note: The Geoid is an imaginary surface within or around the earth that is everywhere normal to the direction of gravity and coincides with MSL in the oceans. It is the reference surface for MSL heights.

3.2.39. Geographic Positioning Navigation (GPN). Navigation based on geodetic calculation of geographic position referenced to the WGS- 84 ellipsoid. Global positioning system (GPS), wide area augmentation system (WAAS), local area augmentation system (LAAS), flight management system (FMS), RNP, and RNAV are examples of GPN.

3.2.40. Glidepath Angle (GPA). The GPA is the angle of the specified final approach descent path relative to a horizontal line tangent to the surface of the earth at the runway threshold. In this order, the glidepath angle is represented in calculators/formula and figures as the Greek symbol theta (θ).

3.2.41. Glidepath Qualification Surface (GQS). The GQS is a narrow inclined plane centered on the runway centerline that limits the height of obstructions between the DA and LTP. A clear GQS is required for authorization of vertically-guided approach procedure development.

3.2.42. Global Azimuth Reference Point (GARP). Global Navigation Satellite System (GNSS) Azimuth Reference Point. A calculated point 1000 ft beyond the FPAP lying on an extension of a geodesic line from the LTP/FTP through the FPAP. It may be considered the location of an imaginary localizer antenna.

3.2.43. Global Navigation Satellite System (GNSS). A worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring. GNSS is augmented as necessary to support the required navigation performance for the actual phase of operation.

3.2.44. Ground Point of Intercept (GPI). The glidepath intercepts the ASBL at the GPI. The GPI is expressed as a distance in feet from the LTP. The GPI is derived from TCH and glidepath angle values: $\mathrm{GPI} = \frac{\mathrm{TCH}}{\tan(\theta)}$.

3.2.45. Heading-to-an-Altitude (VA). A specified heading to a specific altitude at an unspecified position. The resulting track is not wind corrected.

3.2.46. Heading-to-an-Intercept (VI). A specified heading to intercept the subsequent leg at an unspecified position. The resulting track is not wind corrected.

3.2.47. Height Above Ellipsoid (HAE). The elevation of the glidepath origin (TCH point) for an LPV approach procedure is referenced to the LTP. RNAV avionics calculate heights relative to the WGS-84 ellipsoid. Therefore, it is important to specify the HAE value for the LTP. This value differs from a height expressed in feet above the geoid (essentially MSL) because the reference surfaces (WGS-84 ellipsoid and the geoid) do not coincide. Ascertain the height of the orthometric geoid (MSL surface) relative to the WGS-84 ellipsoid at the LTP. This value is considered the GH. For Westheimer Field, Oklahoma the GH is -87.29 ft. This means the geoid is 87.29 WGS-84 ellipsoid ft below the at the latitude and longitude of the runway 35 threshold.

Note: * Calculate GH using the website: http://www.geod.nrcan.gc.ca/apps/gpsh/gpsh_e.php

3.2.48. Height Above Threshold (HATh). The HATh is the height of the DA above LTP elevation.

3.2.49. Initial Approach Fix (IAF). Normally a fly-by waypoint that marks the beginning of the initial segment and the end of the feeder segment, if applicable.

3.2.50. Initial Climb Area (ICA). A segment variable in length starting at the DER which allows the aircraft sufficient distance to reach an altitude of at least 400 ft above the DER.

3.2.51. Initial Course. The course established initially after take-off beginning at the DER.

3.2.52. Instrument Landing System (ILS). A precision instrument approach system which normally consists of a localizer, glide slope, outer marker (or suitable substitute, inner marker for Category II operations below RVR1600, and an approach lighting system.

3.2.53. Intermediate fix (IF). The fix that identifies the beginning of the intermediate approach segment of an instrument approach procedure. The fix is not normally identified on the instrument approach chart as an IF.

3.2.54. International Standard Atmosphere (ISA). A model of standard variation of pressure and temperature.

3.2.55. Knots Indicated Airspeed (KIAS). The speed shown on the aircraft airspeed indicator.

3.2.56. Landing Threshold Point (LTP). The LTP is a 3D point at the intersection of the runway centerline and the runway threshold (RWT). WGS- 84/NAD- 83latitude, longitude, MSL elevation, and geoid height define it. For WAAS approach procedures, it is used in conjunction with the FPAP and the geometric center of the WGS- 84 ellipsoid to define the vertical plane of an RNAV FAC.

Note: Where an FTP is used, apply LTP elevation (LTPE).

3.2.57. Lateral Navigation (LNAV). LNAV is RNAV lateral navigation. This type of navigation is associated with nonprecision approach procedures (NPA) because vertical path deviation information is not provided. LNAV criteria are the basis of the LNAV minima line on RNAVGPS approach procedures.

3.2.58. Lateral Navigation/Vertical Navigation (LNAV/VNAV). An approach with vertical guidance (APV) evaluated using the Baro VNAV obstacle clearance surfaces conforming to the lateral dimensions of the LNAV obstruction evaluation area (OEA). The final descent can be flown using Baro VNAV, or LPV vertical guidance in accordance.

3.2.59. Localizer Performance (LP). An LP approach is an RNAV NPA procedure evaluated using the lateral obstacle evaluation area dimensions of the precision localizer trapezoid, with adjustments specific to the WAAS. These procedures are published on RNAVGPS approach charts as the LP minima line.

3.2.60. Localizer (LOC). The component of the ILS which provides course guidance to the runway.

3.2.61. Localizer Performance with Vertical Guidance (LPV). An approach with vertical guidance (APV) evaluated using the OCS dimensions (horizontal and vertical) of the precision approach trapezoid, with adjustments specific to the WAAS. These procedures are published on RNAVGPS approach charts as the LPV minima line.

3.2.62. Maximum Allowable Descent Rate (MDR). A vertical velocity limit. .

3.2.63. Missed Approach Point (MAP). A fly-over waypoint that marks the end of the final approach segment and the beginning of the missed approach segment.

3.2.64. Minimum Descent Altitude (MDA). The lowest altitude, expressed in feet above mean sea level, to which descent is authorized on final approach where no glide slope is provided, or during a circle-to-land maneuver.

3.2.65. Minimum En Route Altitude (MEA). The lowest published altitude between radio fixes which assures acceptable navigational signal coverage and meets obstacle clearance requirements between those fixes. The MEA prescribed for a Federal airway or segment thereof, area navigation low or high route, or other direct route applies to the entire width of the airway, segment, or route between the radio fixes defining the airway, segment, or route.

3.2.66. Non-Vertically Guided Procedures (NVGP). Instrument approach procedures without vertical guidance. As used in this Order, NVGP include LNAV and LP approach procedures.

3.2.67. "Obstacle" means an object that could have an adverse effect on the safe operation of aircraft in flight or on the ground.

3.2.68. Obstacle Clearance Surface (OCS). An OCS is an upward or downward sloping surface used for obstacle evaluation where the flight path is climbing or descending. The separation between this surface and specified glidepath angle or minimum required climb path defines the MINIMUM required obstruction clearance at any given point.

3.2.69. Obstacle Evaluation Area (OEA). An area within defined limits that is subjected to obstacle evaluation through application of required obstacle clearance (ROC) or an OCS.

3.2.70. Obstacle Identification Surface (OIS). The OIS is an inclined surface conforming to the lateral dimensions of the OEA used for identification of obstacles that may require mitigation to maintain the required level of safety for the applicable segment. An OIS is normally associated with the visual portion of the FAS.

3.2.71. Obstacle Positions (OBSX,Y,Z). OBSX, Y & Z are the along track distance to an obstacle from the LTP, the perpendicular distance from the centerline extended, and the MSL elevation, respectively, of the obstacle clearance surfaces.

3.2.72. Precise Final Approach Fix (PFAF). The PFAF is a calculated WGS- 84 geographic position located on the final approach course where the designed vertical path (NPA procedures) or glidepath (APV and PA procedures) intercepts the intermediate segment altitude (glidepath intercept altitude). The PFAF marks the beginning of the FAS. The calculation of the distance from LTP to PFAF includes the earth curvature.

3.2.73. Q Routes. 'Q' is the designator assigned to published high altitude RNAV-based ATS routes in Canada.

3.2.74. Radius to Fix (RF) Leg. An RF leg is a constant radius circular repeatable path about a defined turn center that begins and terminates at a fix.

3.2.75. Reference Datum Point (RDP). The RDP is a 3Dpoint defined by the LTP or FTP latitude/longitude position, MSL elevation, and a threshold crossing height (TCH) value. The RDP is in the vertical plane associated with the FAC and is used to relate the GPA of the final approach track to the landing runway. It is also referred to as the TCH point or FPCP.

3.2.76. Reference Fix. A point of known location used to geodetically compute the location of another fix.

3.2.77. Reference Line. For fix turns less than 90 degrees, a line parallel to the course line after the turn fix where an additional set(s) of turn area expansion arcs are centered.

3.2.78. Reference Navigational Aid (NAVAID). A navigational facility required for various leg construction (e.g., CF) to assign a magnetic variation to the course.

3.2.79. Required Navigation Performance (RNP). RNP is a statement of the 95 percent navigation accuracy performance that meets a specified value for a particular phase of flight or flight segment and incorporates associated on-board performance monitoring and alerting features to notify the pilot when the RNP for a particular phase or segment of a flight is not being met.

3.2.80. Required Obstruction Clearance (ROC). Sometimes referred to as required obstacle clearance, ROC is the minimum vertical clearance (in feet) that must exist between aircraft and the highest ground obstruction within the OEA of instrument procedure segments.

3.2.81. Runway Threshold (RWT). The RWT marks the beginning of the portion of the runway usable for landing. It extends the full width of the runway.

3.2.82. Standard Instrument Approach Procedure (SIAP). Instrument approach procedures published in the Canada Air Pilot (CAP) Instrument approach procedures published (IAP).

3.2.83. Standard Instrument Departure (SID). A preplanned instrument flight rule (IFR) air traffic control (ATC) departure procedure printed for pilot/controller use in graphic form to provide obstacle clearance and a transition from the terminal area to the appropriate en route structure. SIDs are primarily designed for system enhancement to expedite traffic flow and to reduce pilot/controller workload. ATC clearance must always be received prior to flying a SID.

3.2.84. Standard Terminal Arrival (STAR). A preplanned instrument flight rule (IFR) ATC arrival procedure published for pilot use in graphic and/or textual form. STARs provide transition from the en route structure to an outer fix or an instrument approach fix/arrival waypoint in the terminal area.

3.2.85. Start of Climb (SOC). The SOC is a point located at a calculated flat-surface length distance from the decision altitude for LNAV/VNAV or the missed approach point for LNAV and LP or at the end of section 1 for LPV/GLS procedures.

3.2.86. Threshold Crossing Height (TCH). The height of the glidepath above the threshold of the runway measured in feet. The LPV glidepath originates at the TCH value above the LTP.

3.2.87. Track to Fix (TF) Leg. A TF leg is a geodesic path between two fixes. The resulting track is wind corrected.

3.2.88. True Airspeed (KTAS). The airspeed of an aircraft relative to undisturbed air. KTAS is the KIAS corrected for air density error. KTAS increases with altitude when KIAS remains constant.

3.2.89. Turn Anticipation. The capability of RNAV airborne equipment to determine the location of the point along a course, prior to a FB fix which has been designated a turn fix, where a turn is initiated to provide a smooth path to intercept the succeeding course.

3.2.90. Turn Fix. A FB or FO fix denoting a course change**.**

3.2.91. Turn Initiation Area (TIA). The straight portion of a missed approach OEA whose end is identified by a turn at a specified altitude.

3.2.92. Vertical Error Budget (VEB). The VEB is a set of allowable values that contribute to the total error associated with a VNAV system. Application of equations using the VEB values determines the minimum vertical clearance that must exist between an aircraft on the nominal glidepath and ground obstructions within the OEA of instrument procedure segments. When the VEB is used in final segment construction, its application determines the OCS origin and slope ratio.

3.2.93. Visual Glide Slope Indicator (VGSI). The VGSI is an airport lighting aid that provides the pilot with a visual indication of the aircraft position relative to a specified glidepath to a touchdown point on the runway. PAPI and VASI are examples of VGSI systems.

3.2.94. Visual Segment. The visual segment is the portion of the FASOEA between the DA and the LTP.

3.2.95. Waypoint (WP). Any single location defined by geographic coordinates.

3.2.96. Wide Area Augmentation System (WAAS). The WAAS is a navigation system based on the GPS. Ground correction stations transmit position corrections that enhance system accuracy and add satellite based VNAV features.

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VOLUME 2: PERFORMANCE BASED NAVIGATION (PBN)

CHAPTER 4: RNAV AND RNP DEPARTURE PROCEDUES

SECTION 1: GENERIC CRITERIA

4.1. Generic Criteria.

4.1.1. Criteria Design Standards. Use these standards to develop RNAV1 and RNP1 departure procedures. RNAV1 is defined in TC AC 700-019 and RNP1operations are described in TC AC 700-025. This Chapter provides flexibility so procedure designers can select fix and leg type as required. Although ARINC leg combinations are included, this Chapter does not contain procedure coding guidance; DPs should be coded as required to achieve the designed flight track. To aid in computer programming, mathematical calculations for area construction are presented as imbedded calculators.

4.1.2. Fix Use. To the extent practical and efficient, use existing fixes/NAVAIDs. FB fixes are recommended for procedure design; use FO fixes only when operationally necessary or for obstacle clearance. Utilize fixes to designate restrictions/changes to course, speed, and/or altitude. ATT values are included in paragraph 2.3.7.

4.1.3. Fix Definition. The depiction below outlines a brief example of where a departure fix is on the extended runway centerline and how coordinates are determined. The coordinates are established using the reciprocal of the opposite direction runway true bearing and the appropriate distance applied from the DER. Where two or more segments are aligned along a continuous geodetic line, align and construct all succeeding fixes based on a true bearing and distance from the first reference fix in the sequence. Where turns are established, use the turn fix as the reference fix to construct succeeding fixes and segments aligned on a continuous geodetic line following the turn (see figure 4-1-1).

4.1.4. Course Change at Fixes. The illustration below provides a course change example and how course is determined. The departure course at a particular fix is the bearing from that fix to the following fix. The arrival course at a particular fix is the reciprocal of the course from that fix to the preceding fix. The difference between the departure course and the arrival course at a fix equals the amount of turn at that fix (see figure 4-1-2).

Figure 4-1-1. Fix Definition Example

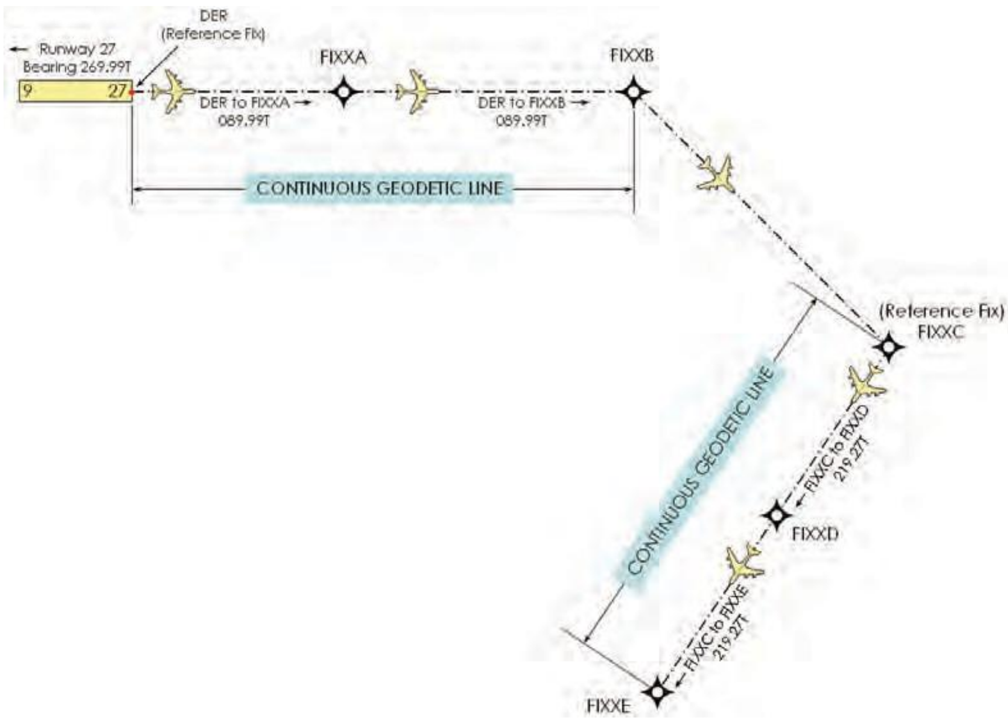
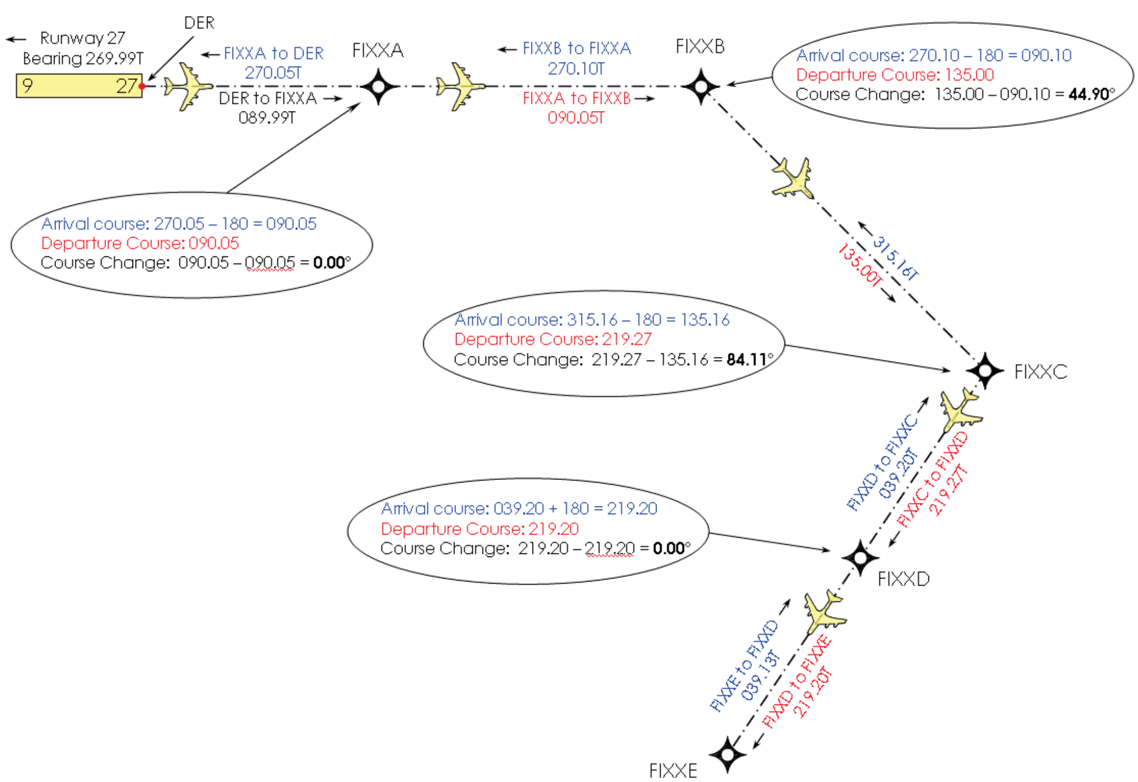


Figure 4-1-2. Course Change Example



4.1.5. VA and VI Leg Length Standards.

a. For LNAV engagement, VA legs must be designed to end at least 500 ft above the airport elevation.

b. The minimum allowable VI leg length is the greater of 1NMfrom DER or the distance required to achieve 500 ft above the airport elevation. To allow a WP less than 2 NM from the DER without a climb gradient imposed, a fly-over WP may be used and published. No turn greater than 15° is permitted at this WP, and a succeeding WP must be established for a DF leg.

c. The maximum allowable VA or VI leg length is 10NM.

4.1.6. Additional Leg Length Standards.

For segment length considerations, turns of 10 degrees or less are considered straight. Comply with minimum leg length standards available in Chapter 7 paragraph 7.1.9 and 7.1.10, unless construction rules require a greater length.

Supplementary note: This standard apply not only to departure but to all PBN leg lengths.

4.1.7. Segment Full Width Standards. Comply with width guidelines defined in Chapter 7 paragraph 7.1.2, except area increases to full en route width crossing 30NM from ARP. See paragraph 4.3.23 to 4.3.27.

4.1.8. Use TP 308 Naming Conventions and refer to NAV CANADA for Computer Codes, Charting, and Documentation Instructions.

SECTION 2: CONSTRUCTION CALCULATIONS

4.2. Construction Calculations.

4.2.1. Projected Altitude ($\mathbf{Alt_{proj}}$). To determine the highest altitude within the turn, determine the projected altitude for a known distance using calculator 2-1. The calculation assumes a climb of 500 ft/NM below 10000 MSL and 350 ft/NM at or above 10000 MSL. Utilize this altitude for applicable construction calculations.

Calculator 2-1. Projected Altitude

(1) $$\boldsymbol{d_{500} = round[d_{500}, 0] \qquad d_{350} = round[d_{350}, 0]}$$

(2) $$\boldsymbol{case \quad (Start_{elev} \geq 10000):}$$

$$Alt_{proj} = (r + Start_{elev}) \times e^{\frac{350xd_{350}}{r}} - r$$

$$\boldsymbol{case \quad (Start_{elev} < 10000):}$$

$$Alt_{proj} = (r + Start_{elev}) \times e^{\frac{500xd_{500}}{r}} - r + (r + 10000) \times e^{\frac{350xd_{350}}{r}} - (r + 10000)$$

(3) $$\boldsymbol{case\ (alt\ is\ not\ null\ AND\ Alt_{proj} \geq alt): Alt_{proj} = alt}$$

Where $Start_{elev}$ = segment starting MSL elevation

d_{500} = distance at climb gradient 500 in NM

d_{350} = distance at climb gradient 350 in NM

alt = published maximum MSL altitude (cap) if applicable

Note: OEAanalysis may result in an altitude greater than the projected altitude. As an alternative, utilize a higher fix crossing altitude where required.

4.2.2. True Airspeed (VKTAS). Determine the true airspeed using Chapter 7 calculator 1-3a and Chapter 7 table 7-1-3.

4.2.3. Tailwind (VKTW). Calculate the tailwind component using Chapter 7 calculator 1-3b.

4.2.4. Turn Radius (R). Establish the Turn Radius using Chapter 7 calculator 1-3c.

4.2.5. Bank Angle. Do not exceed the maximum bank angles listed in Chapter 7 paragraph 7.1.6.

4.2.6. DTA. Distance of Turn Anticipation is a calculated value for use in determining minimum straight segment lengths where a turn is required at the initial and/or termination fix; see Chapter 7 calculator 1-6.

4.2.7. VA Segment Distance. Where necessary, calculate segment distance using calculator 2-2.

Calculator 2-2. VA Segment Distance

(1) **Case (*specified climb gradient*):** $$d = \frac{r \times fpnm \times In\left(\frac{r + TA}{r + DER_{elev}}\right)}{CG}$$

(2) **Case (*specified climb gradient*):** $$d_{200} = \frac{r \times fpnm \times In\left(\frac{r + TA}{r + DER_{elev}}\right)}{200}$$

Where DER_{elev} = DER MSL elevation

TA = Turning (Climb-to) MSL Altitude

CG = climb gradient

4.2.8. VA Segment Termination Altitude. Calculate the termination altitude achieved at the end of a segment using calculator 2-3.

Calculator 2-3. VA Termination Altitude

$$ALt_{term} = ceilling\left[\frac{(\boldsymbol{r} + \boldsymbol{DER_{elev}}) \times e^{\left(\frac{CG \times d}{r}\right)} - r}{100}\right] \times 100$$

Where DER_{elev} = DER MSL elevation

CG = climb gradient

d = VA segment distance in NM

4.2.9. VA-DF Feasibility. Evaluate VA-DF leg lengths using the VA-DF calculator in the "TERPS Tools" section of the Flight Procedure Standards Branch web site.

4.2.10. ROC, CG, and Climb Gradient Termination Altitude Calculation. Determine ROC, CG, and climb gradient termination altitude (CGterm) using calculator 2-4.

Calculator 2-4. ROC, CG, and Climb Gradient Termination Altitude

(1) Note: CG is calculated in ft/NM. To convert to a percentage, use CG% = (ft/NM) x 30.48/1852
Where d_{OBS} = shortest primary area distance to obstacle in NM
OBS_{elev} = obstacle MSL elevation
$Start_{elev}$ = Start MSL elevation
d_{SOBS} = perpendicular distance (feet) in the secondary area from primary area boundary, zero (0) if not in secondary area

(2) $h = OBS_{elev} - Start_{elev}$

(3) Remark - Calculate ROC, CG, CG_{term}

case*(obstacle located in primary):* $ROC = ceiling\left[\frac{h}{0.76} - h\right]$

case*(obstacle located in primary):* $ROC = ceiling\left[\left(\frac{h}{0.76} - h\right) - \frac{d_{SOBS}}{12}\right]$

(4)

$$CG = ceiling\left[\frac{\mathrm{r}}{\mathrm{d_{OBS}}} \times \mathrm{In}\left(\frac{\mathrm{r} + \mathrm{OBS_{elev}} + \mathrm{ROC}}{\mathrm{r} + \mathrm{Start_{elev}}}\right)\right]$$

(5)

$$CG_{term} = 100 \times ceiling\left[\left(\frac{\mathrm{OBS_{elev}} + \mathrm{ROC}}{100}\right)\right]$$

SECTION 3: AREA CALCULATION

4.3. Area Calculation.

4.3.1. Segment Areas. Area construction is dependent upon segment leg lengths, turn magnitudes and established calculations. Ensure area construction meets leg length and turn magnitude criteria standards. Where the fix outbound course differs by more than 0.03degrees from the fix inbound course (courses measured at the fix), a turn is indicated.

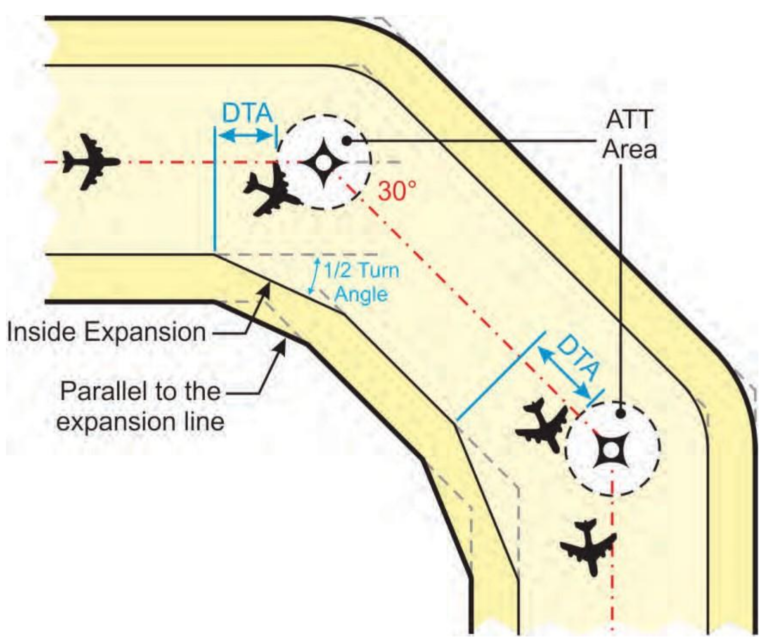
4.3.2. Course Change Limitations. For turns to join a CF or TF leg, the maximum allowable course change or magnitude of heading change below FL195is 90 degrees (+/- 0.03 degrees) ; course changes at or above FL195must not exceed 70 degrees (+/- 0.03 degrees).

4.3.3. Fly-By Fix Turn Construction.

4.3.4. Inside Expansion Area. DTA areas vary and are based upon the altitude at each fix.

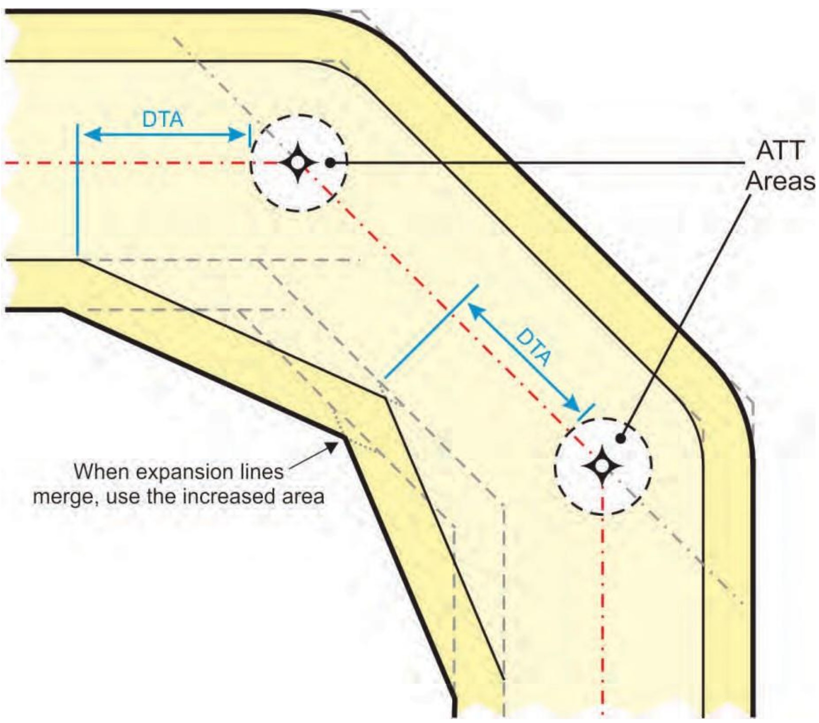
a. **Known as the fix ETP**, the inside expansion origin is based on the calculated DTA, Chapter 7 calculator 1-6. DTA is measured parallel to the course along the primary area boundary from the beginning of the ATT area. Increase the primary area at the ETP by an angle equal to one-half of the course change at the fix. Construct the secondary area boundary, parallel with the primary expansion boundary, using the full secondary area width (see figure 4-3-1).

Figure 4-3-1. FB Fix Turn



b. In some cases, the calculated DTA may cause the expansion lines to merge, increasing the size of the expanded areas. This construction is permissible; utilize the increased area (see figure 4-3-2).

Figure 4-3-2. FB Fix Turns, Merging Expansion Lines



c. **Outside Area Structure.** The outside area structure does not expand. From the fix, draw the primary boundary arc with a radius equal to the area half width and secondary area boundary arc equal to the primary area half width plus the width of the secondary.

4.3.5. Fly-Over Fix Turn Construction.

4.3.6. Inside Area Structure. Inside primary and secondary area segment boundaries intersect, no expansion is required.

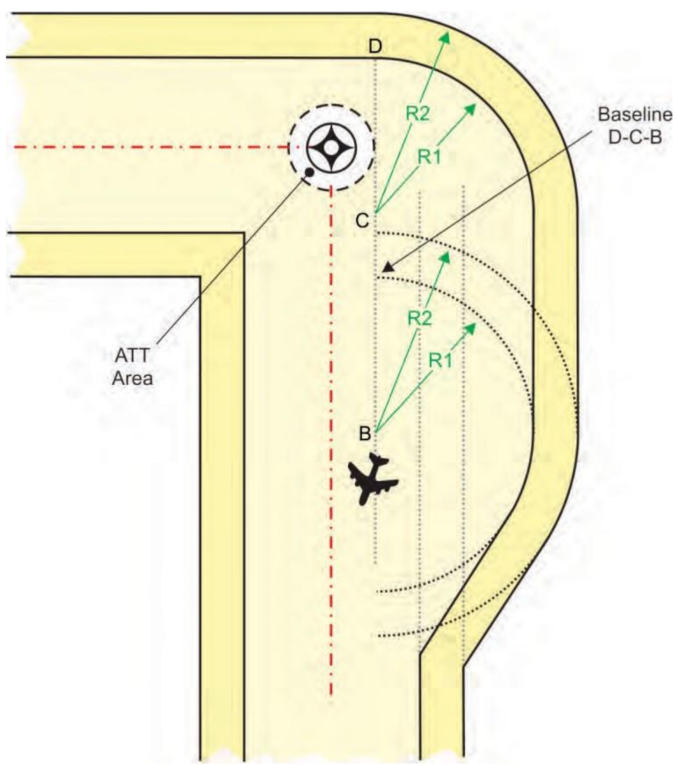
4.3.7. Outside Expansion Area, TF, or CF Legs. The primary area boundary (R1) is the calculated Turn Radius, Chapter 7 calculator 1-3c, based on the altitude at the fix. The secondary area boundary (R2) is the calculated Turn Radius value plus 1NMor, where beyond 30NMfrom the ARP, the calculated Turn Radius plus 2NM. Where the R1and R2 boundary arcs cannot connect tangentially with lines 30 degrees relative to the outbound track, continue the arcs until intersecting the outbound standard-width boundaries.

a. **Turns less than 90 degrees.** After the ATT area, construct a baseline perpendicular to the inbound course to construct an arc(s) to establish boundaries of the outside expansion areas. Locate point C on the baseline based on the R2 value from the inbound segment boundary. Using point C as a center point, draw an arc with a radius equal to the R2 value from the inbound segment boundary. Draw a second arc with a radius equal to the R1 value, using C as a center point, from the baseline (point D). The point C arcs connect tangentially with lines 30 degrees relative to the outbound track that joins with the primary and secondary area boundaries.

Note: For turns near 90 degrees, additional outside turn protection may be required. Construct another set of R1 and R2 arcs using point B as the center point as outlined in paragraph 4.3.7.b. Where these additional arcs penetrate the tangent 30 degree lines from the point C arcs, they shall be included in OEA construction.

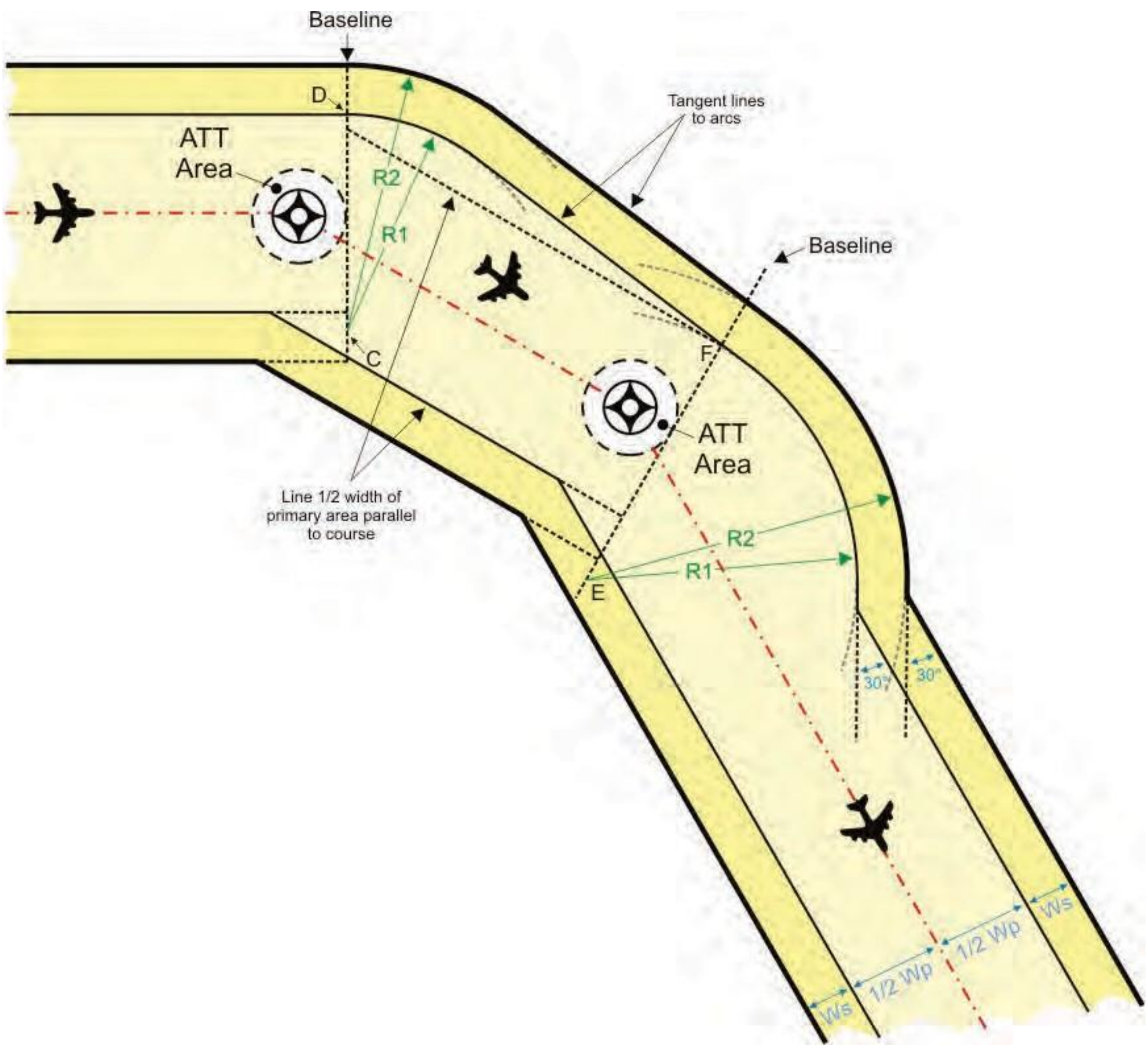
b. 90 degree turns. Construct R1 and R2 arcs from point C as defined in paragraph 4.3.7.a. From where the inbound primary boundary would intersect the baseline, locate point B on the baseline at a distance equal to the R2 value. Draw another set of R1 and R2 arcs for additional outside turn protection, using point B as the center point, in the same manner as the arcs from point C; the point B arcs are the same calculated values as the point C arcs. Connect the outside arcs with tangent lines to form the outside expanded area. The arcs of point B connect tangentially with lines 30 degrees relative to the outbound track that joins with the primary and secondary area boundaries (see figure 4-3-3).

Figure 4-3-3. FO Fix Turn, TF or CF Leg, 90 degree Turn



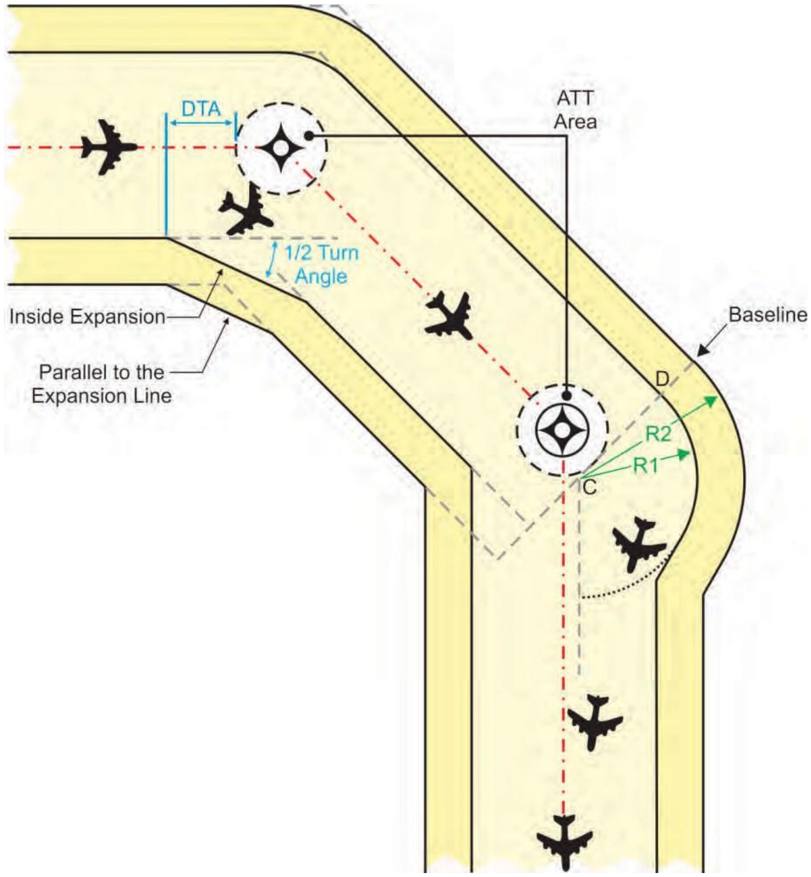
c. **Successive FO Fixes.** Applicable to successive FO fixes in close proximity, construct another baseline after the ATT area of the subsequent fix for the outside expansion boundaries. Construct a line on the outside of the turn, parallel to the course, offset by a distance one-half the segment width. Locate point F where the baseline intersects the segment one-half width line. Locate point E on the baseline at a distance of R1 from point F, based upon the altitude at the subsequent fix, from point F. Using E as a center point, draw arcs R1 and R2. Connect, via tangent lines, the arcs centered at C and E. The arcs of point E connect tangentially with lines 30 degrees relative to the outbound track that joins with the primary and secondary area boundaries (see figure 4-3-4).

Figure 4-3-4. Successive FO Fix Turns



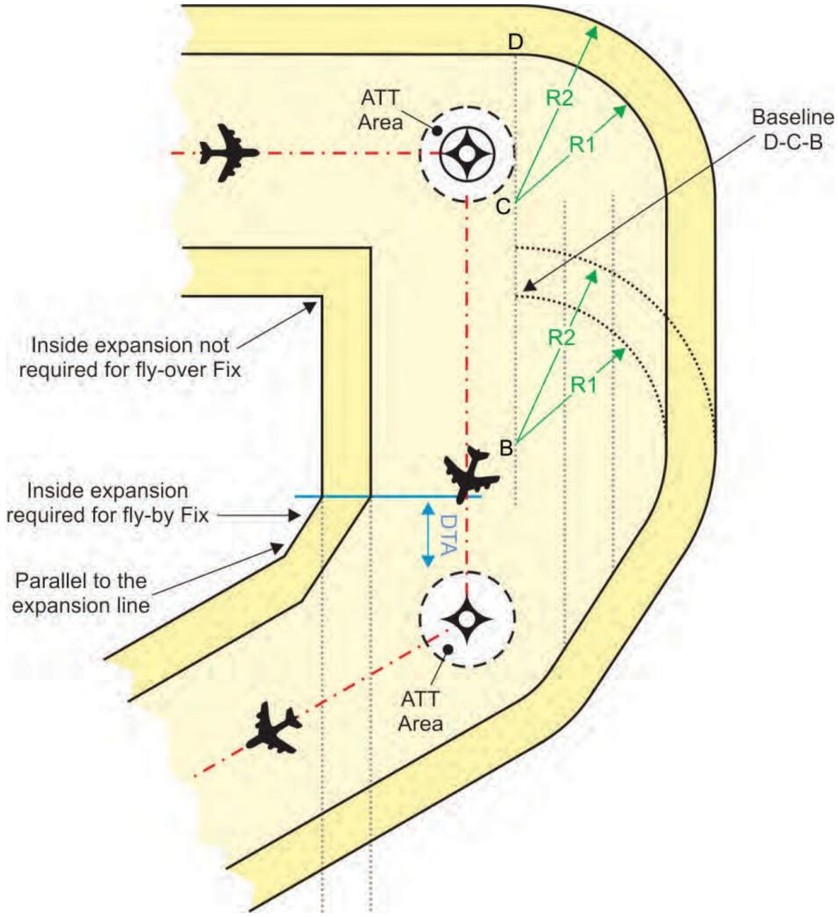
4.3.8. Expansion Areas for FB Fix to FO Fix. Apply paragraph 4.3.3 for FB area construction and paragraph 4.3.5 for FO area construction (see figure 4-3-5).

Figure 4-3-5. FB Fix to FO Fix Turns



4.3.9. Expansion Areas for FO Fix to FB Fix. Apply paragraph 4.3.5 for FO area construction and paragraph 4.3.3 for FB area construction (see figure 4-3-6).

Figure 4-3-6. FO Fix to FB Fix Turns



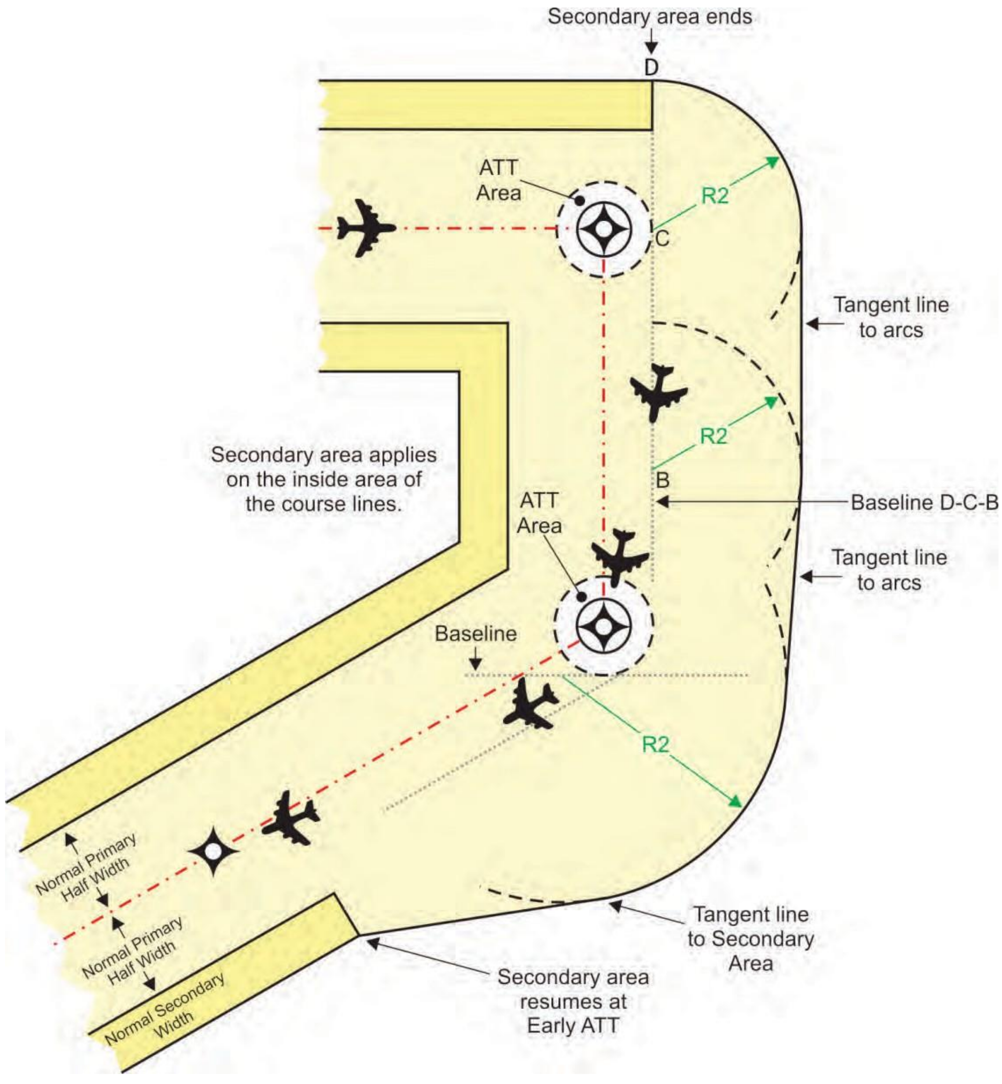
4.3.10. DF Leg FO Turn Construction.

a. **After turning at a FO fix,** obstacle clearance is provided as if the aircraft rolls out and flies direct from the rollout point to another fix, either FB or FO. The outside expansion area is all-primary area and encompasses areas of successive FO fixes; outside secondary areas are not applicable. Based upon the altitude at the fix, the outside boundary R2 arc is the calculated Turn Radius, Chapter 7 calculator 1-3c, plus 1 or 2 NM as appropriate.

b. **After the ATT area,** construct a baseline to establish an arc for the outside boundary; label the secondary boundary on this baseline as point D. Locate point C at a distance of R2 from point D on the baseline. Using point C as a center point, swing the arc from point D. Draw a tangent line from the arc to the subsequent leg outer boundary to complete the outside boundary.

c. **For turns near 90 degrees,** locate point B on the baseline measured from the inside-turn primary boundary at the same R2 distance. Draw another R2 arc, using point B as the center point, from the inbound leg primary area width distance on the baseline to form a second expansion arc. Where this arc intersects the tangent line from the point C arc to the subsequent leg outer boundary, it must also be included. Join the two arcs by a tangent line to create the outside boundary. For 90 degree turns, construct the R2 arc, using point B as the center point, from the inbound leg primary area width distance on the baseline and join the two arcs by a tangent line to create the outside boundary (see figure 4-3-7).

Figure 4-3-7. DF Leg, FO Turn Construction 90 degrees or Less

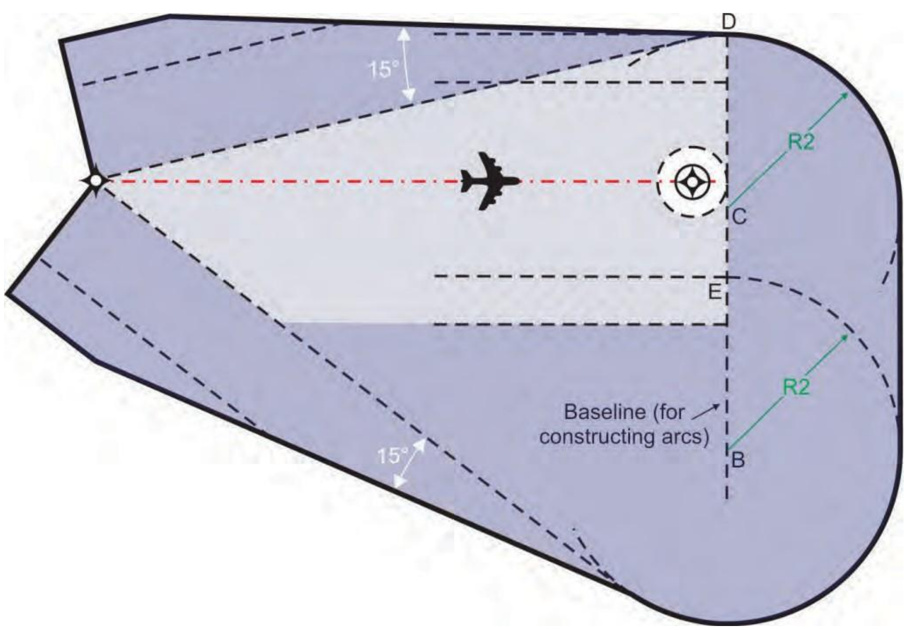


d. For turns more than 90 degrees, all inbound primary and secondary boundaries continue until the ATT area baseline. Locate point B at the same R2 distance from the inbound leg primary area width on the baseline (point E). Draw another R2 arc, using point B as the center point, from point E to form a second expansion arc. Join the two arcs by a tangent line to create the outside boundary.

i. Draw a tangent line from the point B arc direct to the subsequent leg termination fix. From this line, splay 15 degrees to construct the outer boundary line until it reaches the combined dimensions of the primary and secondary width. The splay ends at the combined width and the boundary line then parallels the tangent line from the second arc until abeam the subsequent leg termination fix. Where a 15-degree splay does not reach the combined primary and secondary area width dimensions prior to or abeam the subsequent leg termination fix, create the boundary with a tangent line drawn from the combined width abeam the termination fix to the point Barc.

ii. On the non-turning side from the subsequent leg termination fix, draw a tangent line to the point Carc. From this line, splay 15degrees to construct the outer boundary line until it reaches the combined dimensions of the primary and secondary width. The splay ends at the combined width and the boundary line, then parallels the tangent line from the termination fix until abeam the fix. Where a 15-degree splay does not reach the combined primary and secondary area width dimensions prior to or abeam the subsequent leg termination fix, create the boundary with a tangent line drawn from the combined width abeam the termination fix to the point Carc (see figure 4-3-8).

Figure 4-3-8. DF Leg, FO Turn Construction 180 degrees



4.3.11. ICA. Where the first departure leg terminates at a fix, the ICA ends at the fix ETP. Where a CF or DF is the first procedure leg and the leg terminates at a FB fix, utilize

VI-CF leg construction in paragraph 4.3.19 or 4.3.20. Where a CF or DF is the first procedure leg and the leg terminates at a FO fix, apply paragraph 4.3.5 and 4.3.15.

4.3.12. VA Legs. Unless a higher gradient is required for obstacle clearance, utilize a standard climb gradient for area construction to determine the distance required to reach the designated climb-to altitude, see calculator 2-2 for distance calculation. See calculator 2-3 to calculate an altitude for a designated segment distance. The location where the climb-to altitude is reached concludes the ICA and is the leg termination point. Based upon the climb-to altitude at the leg termination point, the outside turn arc R2 is the calculated Turn Radius, Chapter 7 calculator 1-3c, plus 1 NM.

4.3.13. VI Legs. VI legs are normally associated with CF legs as part of an initial DP design with a turn to intercept the CF leg constructed similar to a FB fix turn. The VI leg terminates at the intercept point to conclude the ICA. Due to possible Flight Management System route discontinuity, course changes of less than 10 degrees to intercept the CF leg are not authorized without approval from Flight Standards Service.

4.3.14. VA or VI Leg Construction. VA and VI leg segments are all-primary areas and the departure course is aligned on the extended runway centerline. As a minimum, the ICA 15-degree splays continue until leg termination; draw a perpendicular line where the leg terminates to conclude the ICA.

4.3.15. VA-DF Leg Combinations (see chapter 5 for leg length analysis). The OEA consists of the ICA, section 1 and section 2. Excluding the ICA, section 1 is defined as the OEA on the DER side of the DRL. Section 2 is the OEA on the SER side of the DRL. The subsequent DF leg, including inside and/or outside turn expansion areas, is an all-primary area and segment width is equal to the primary and secondary width dimensions combined abeam the DF leg termination fix (point S and point T).

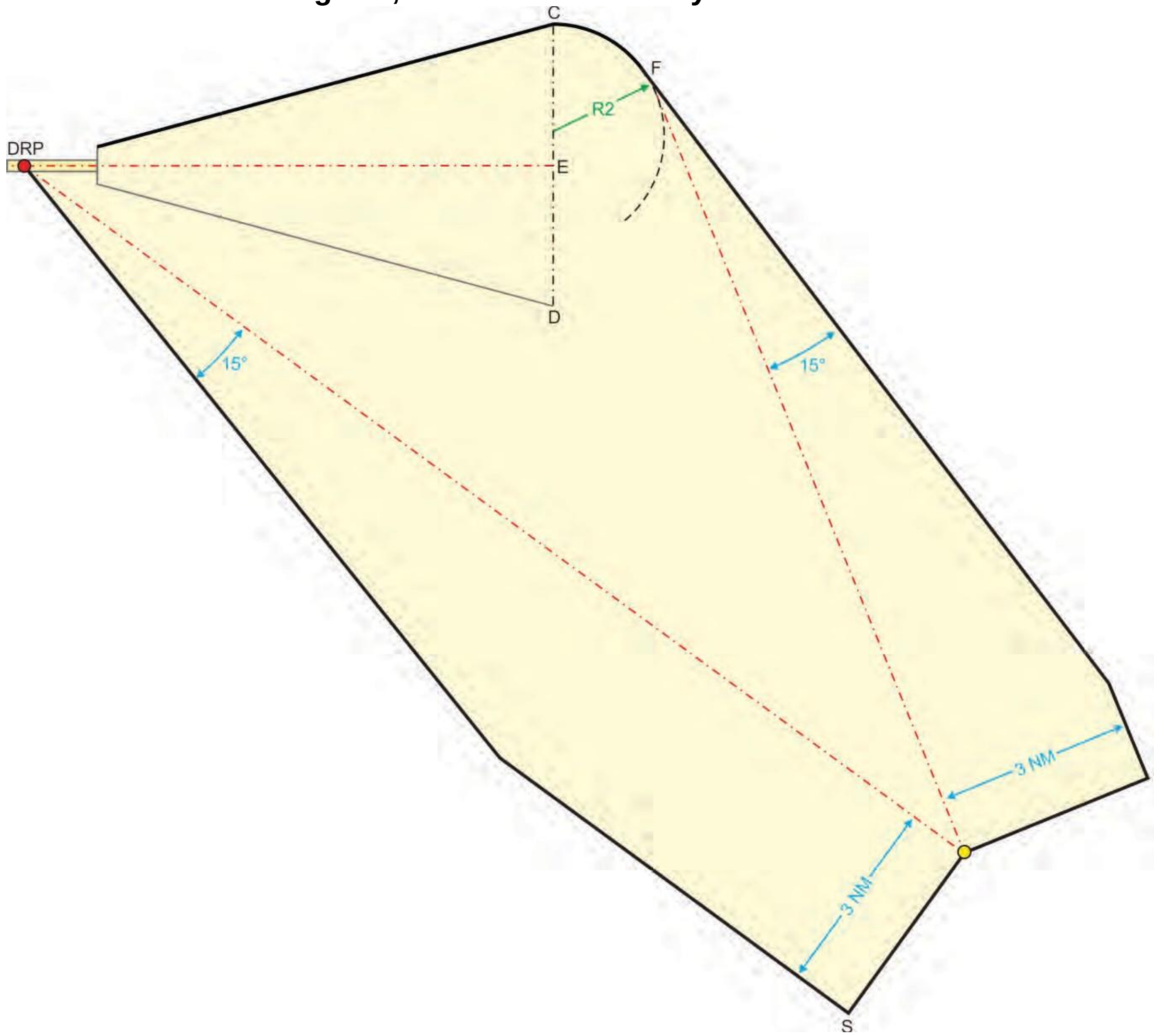
4.3.16. VA-DF Leg Combinations, Turns Less Than 90 degrees.

a. **Inside Expansion Area.**

i. From the DRP, draw a line to the subsequent leg termination fix. Create an outer 15-degree splay from this line to establish the inside turn boundary. The boundary continues to splay 15 degrees until area width equals full primary and secondary area width dimensions combined then the boundary parallels the DRP line until abeam the subsequent leg termination fix (point S) (see figure 4-3-9).

ii. Where the inside turn boundary does not reach the combined primary and secondary area width dimensions prior to or abeam the subsequent leg termination fix, create the boundary with a line drawn from the DRP to point S.

Figure 4-3-9. VA-DF Construction
Turn less than 90 degrees, DRP Inside Boundary Line



iii. Where the inside turn boundary intersects the ICA inside 15-degree splay line (see figure 4-3-10A), the boundary shall be a line beginning from point S, drawn back to point A and another line drawn from point A to the DRP (see figure 4-3-10B).

Figure 4-3-10A. VA Leg Construction Alternate Inside Boundary

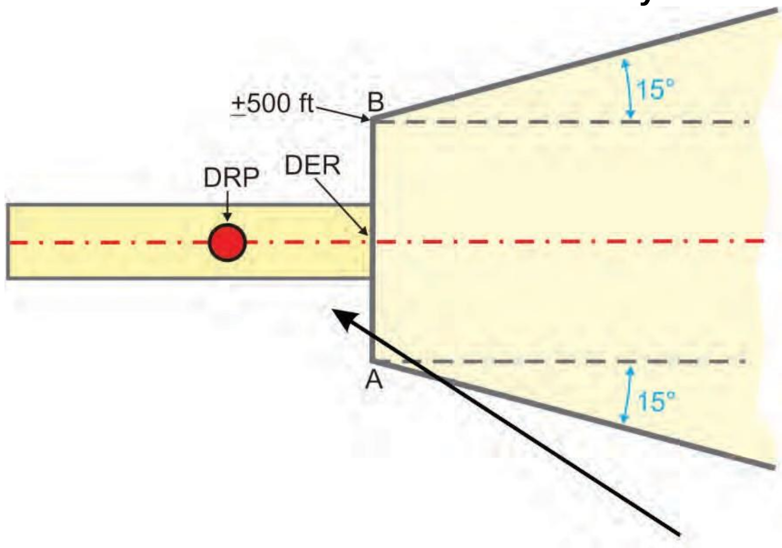
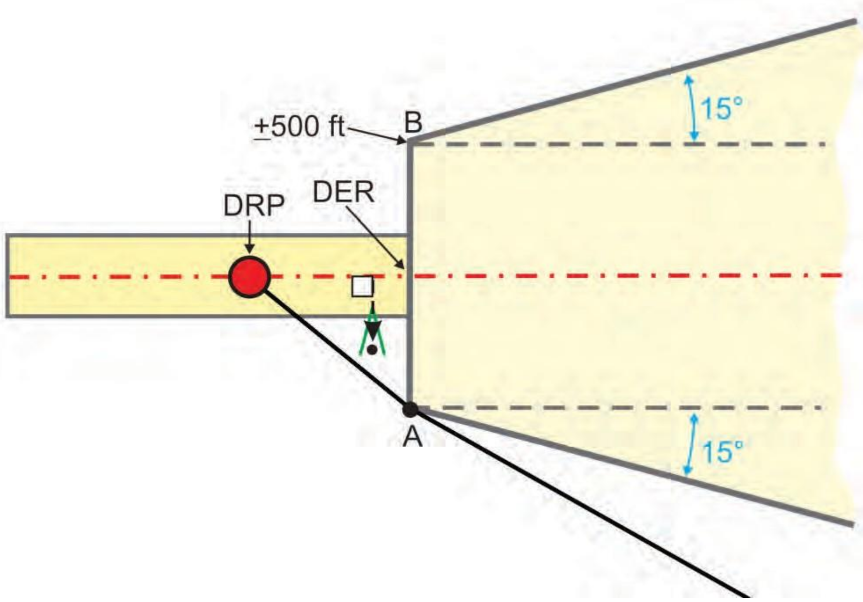


Figure 4-3-10B. VA Leg Construction Alternate Inside Boundary



b. Outside Expansion Area.

i. The outside arc R2 begins at point C; center the arc on the perpendicular line (or an extension of this line) at the end of the VA leg. From the point C arc, draw a tangent line (identify tangent location as point F) to the subsequent leg termination fix. Create a 15-degree splay from this line to establish the outside turn expansion line. The 15-degree splay continues until area width equals full primary and secondary area width dimensions combined, then the boundary parallels the arc tangent line until abeam the subsequent leg termination fix (point T) (see figure 4-3-9).

Note: For turns near 90 degrees, construct a second outside arc from point D as outlined in paragraph 4.3.17c. Where this arc intersects the point F tangent line, it must also be included.

ii. Draw the outside boundary from point C direct to point T where paragraph 4.3.16.b(i) design does not establish the combined primary and secondary full width dimensions at point T.

4.3.17. VA-DF Leg Combinations, Turns 90 degrees or more but less than 180 degrees.

a. **Inside Expansion Area.** Construct the inside turn expansion line to the DRP as specified in paragraph 4.3.16.a.

b. **Outside Expansion Area.** Construct the outside area R2 arc as specified in paragraph 4.3.16.b.

c. Additional Outside Expansion Area.

i. Begin a second arc, with the same calculated Turn Radius, Chapter 7 calculator 1-3c, of the first arc and also centered on the perpendicular line at the end of the segment, from point D to protect aircraft which may begin the turn in this vicinity. Construct a line tangent to both arcs (point F to point G) and construct another tangent line from the second arc (point H) to the DF leg termination fix. Create a 15-degree splay from this line to establish the outside turn expansion line. The 15-degree splay continues until area width equals full primary and secondary area width dimensions combined, then the boundary parallels the arc tangent line until abeam the DF leg termination fix (point T) (see figure 4-3-11).

iii. c. (2) Draw the outside boundary from point G direct to point T where paragraph 4.3.17.c(i) design does not establish the combined primary and secondary full width dimensions at point T.

Note: For turns near 180degrees, construct an early turn protection arc as outlined in paragraph 4.3.18.c. Where this arc intersects the point Htangent line, it must also be included (see figure 4-3-12).

Figure 4-3-11. VA-DF Construction Turn more than 90 degrees

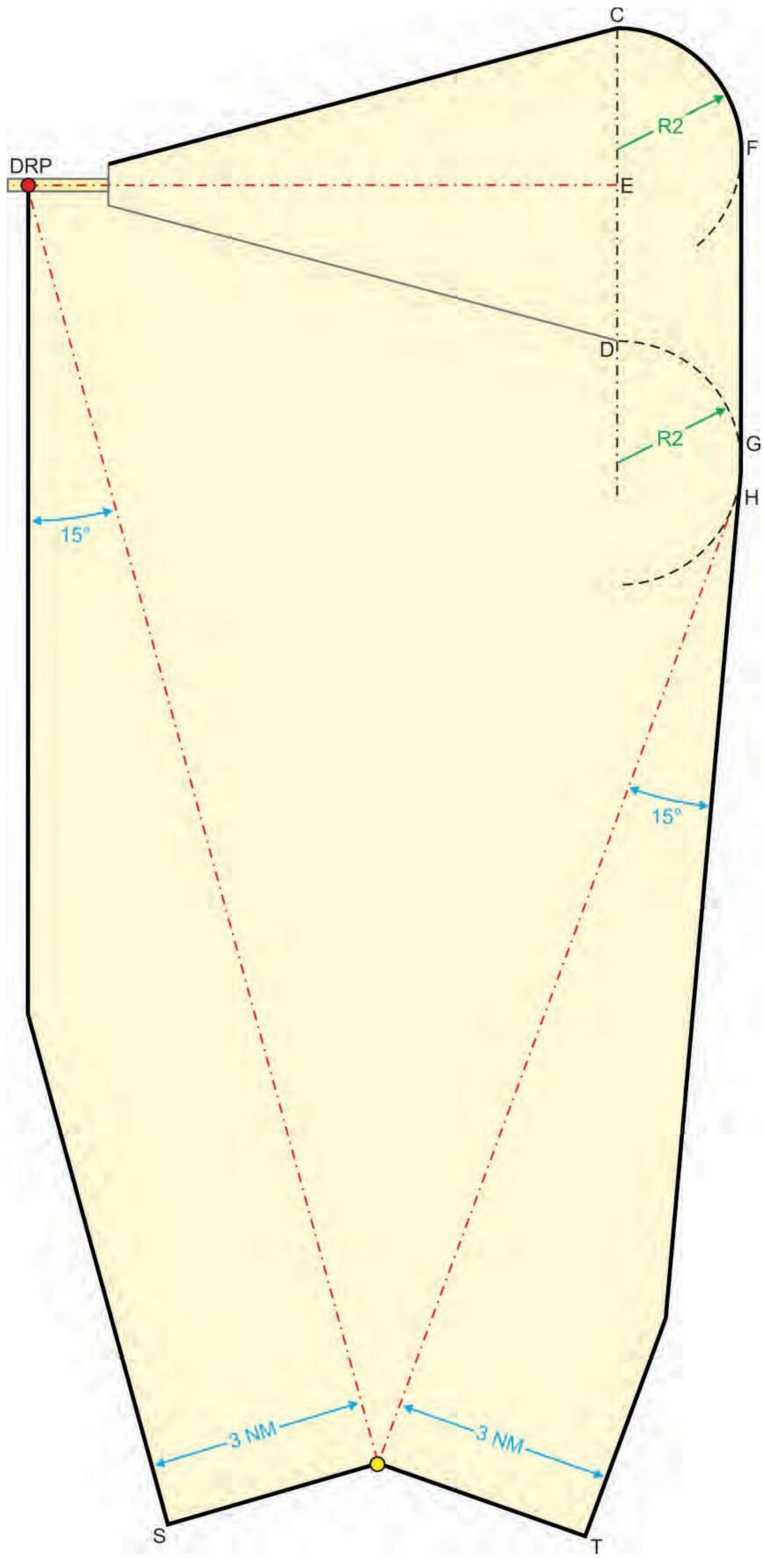
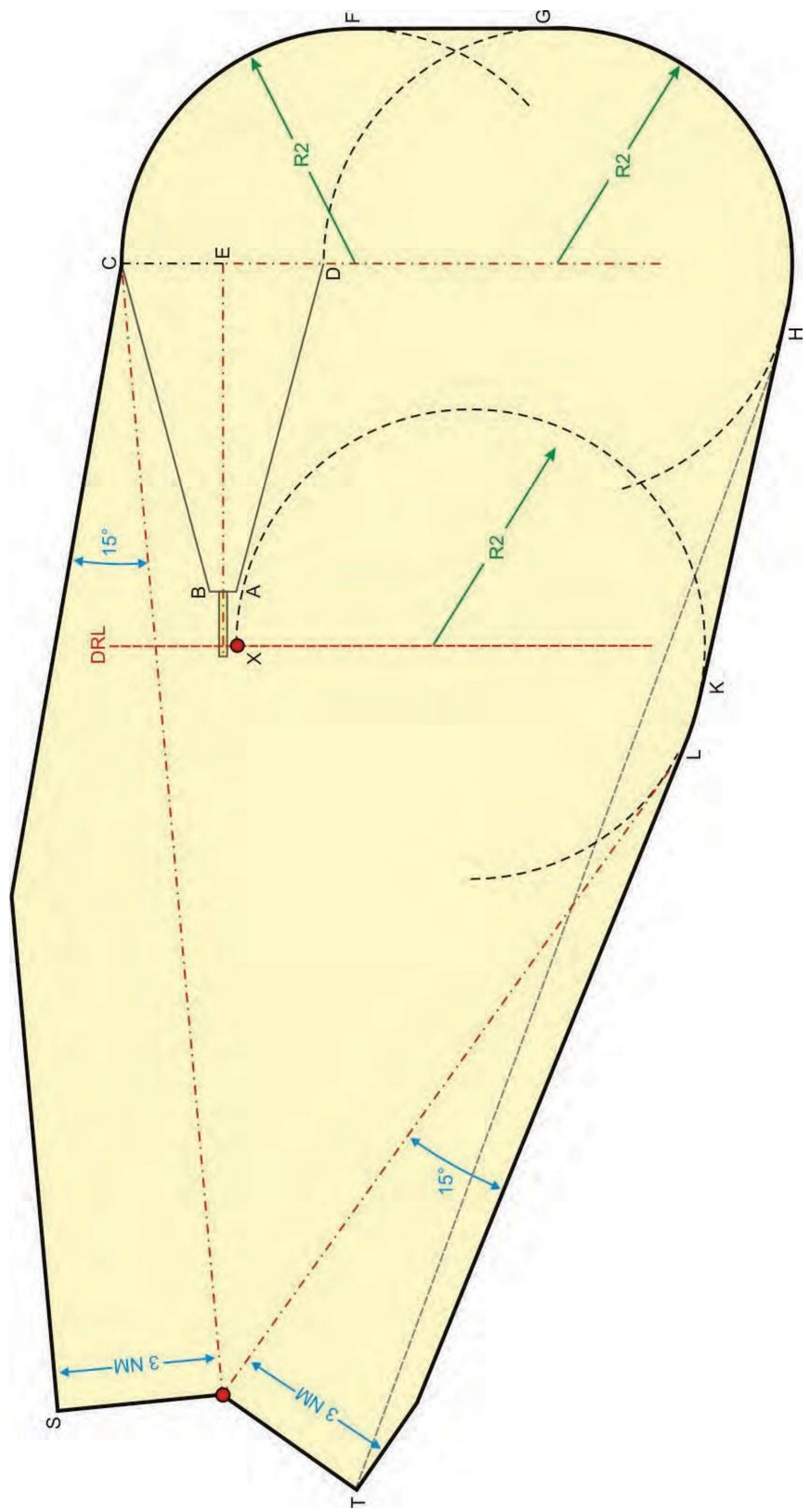


Figure 4-3-12.VA-OF Construction 180 degree Right Turn



4.3.18. VA-DF Leg Combinations, Turns 180 degrees or more.

a. **Inside Expansion Area.** Draw a line from point C to the DF leg termination fix. From this line, splay 15 degrees outward to construct the outer boundary until reaching the combined dimensions of the primary and secondary width. The splay ends at the combined width and the boundary line, then parallels the line to the DF leg termination fix until abeam the fix (point S). Where a 15-degree splay does not reach the combined primary and secondary area width dimensions prior to or at point S, create the boundary with a line drawn from point C to point S (see figure 4-3-12).

b. **Outside Expansion Area.** Construct two outside expansion arcs based on the calculated Turn Radius, Chapter 7 calculator 1-3c, distance as specified in paragraphs 4.3.17.b and 4.3.17.c.

c. **Early Turn Protection Area.** A third arc is included to protect aircraft that may turn prior to the end of the VA leg. Based on the same calculated Turn Radius of the first arc, the arc begins at point X (500 ft from the runway centerline, centered on the DRL and abeam point A). Create the early turn expansion by drawing a tangent line from the second arc (point H) to the third arc (point K). Construct a tangent line from the third arc (point L) to the subsequent leg termination fix. Create a 15- degree splay from this line to establish the outside turn expansion line. The 15- degree splay continues until area width equals full primary and secondary area width dimensions combined, then the boundary parallels the arc tangent line until abeam the subsequent leg termination fix (point T) (see figure 4-3-12). Draw the outside boundary from point K direct to point T where design does not establish the combined primary and secondary full width dimensions at point T.

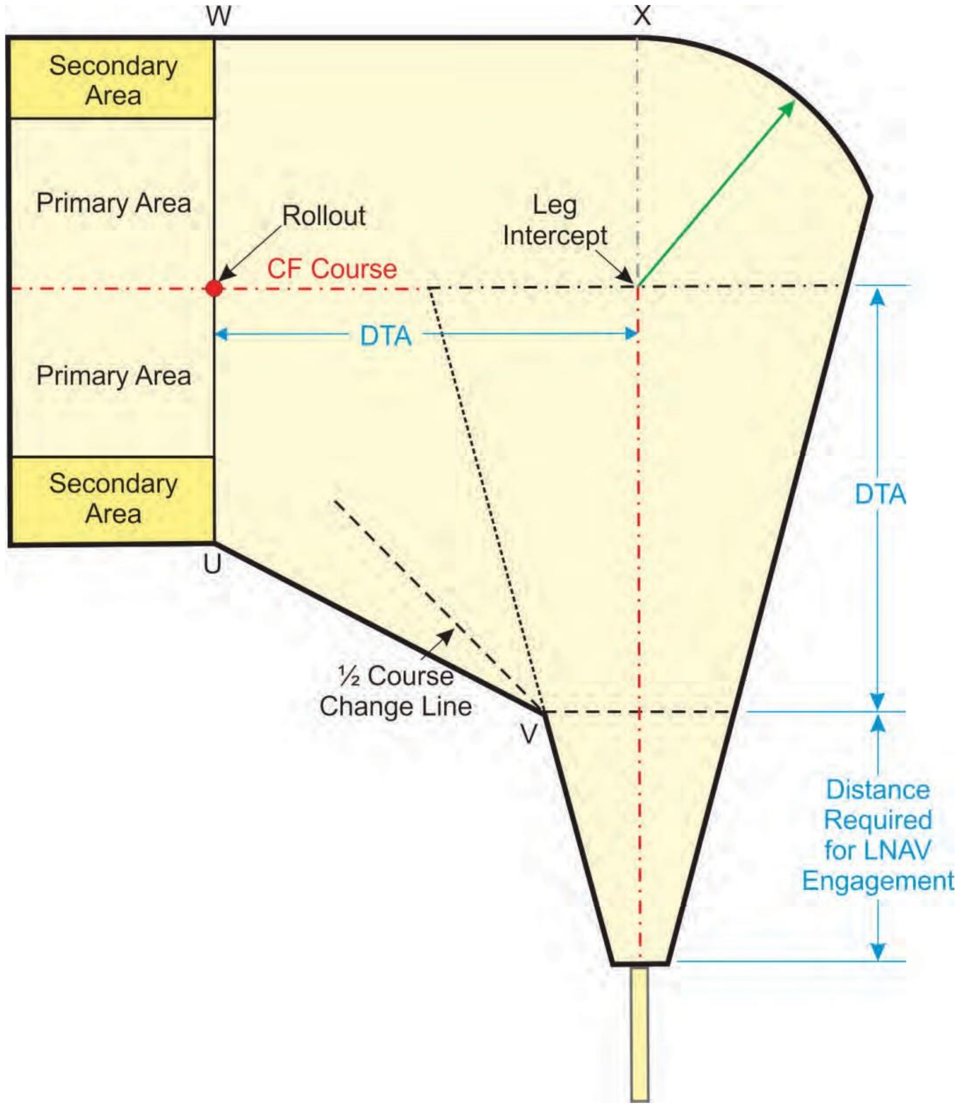
4.3.19. Standard VI-CF Leg Combination Construction, Turns 90 degrees or less (see figure 4-3-13). The VI leg is an all primary area and the CF leg secondary areas begin at the rollout point at full width.

a. **Inside Expansion Area.** Inside expansion starts where the VI DTA area begins (point V) with an angle drawn at one-half of the course change at leg intercept and ends where the angle converges with the CF leg secondary boundary. Where the angle does not converge with the secondary boundary, draw a line from point V to the inside secondary area boundary abeam the rollout (point U) for area completion.

b. **CF Leg Construction.** Along the CF leg course, a rollout point is established from leg intercept at a distance of the calculated DTA, Chapter 7 calculator 1-6, based on the altitude at leg intercept. At the rollout point, the CF leg OEA is the full combined width of the primary and secondary areas.

c. **Outside Expansion Area.** Outside protection is provided by constructing a line parallel to the CFleg course from the outside secondary area boundary abeam the rollout (point W) until intersecting the extended runway centerline (point X). Draw a 3NM arc centered at leg intercept from point X until intersecting an extended outside ICA15-degree splay line drawn beyond leg intercept to complete the area.

Figure 4-3-13. Standard VI-CF Construction, 90 degree Turn



4.3.20. Minimum VI-CF Leg Combination Construction, Turns 90degrees or Less. Where a short initial departure leg must be developed, the VI leg length may be designed to the greater of 1NMfrom DER or the distance required to climb to 500ft above the airport elevation. For this early turn, the OEA is modified to be somewhat like a FB fix turn for inside expansion and additional protection is also provided for outside area expansion built similarly to a FO fix turn.

4.3.21. Inside Expansion Area.

a. **For turns of 30 degrees or less,** splay 15 degrees relative to the CF leg course from point A and continue this line until intersecting the CF leg secondary area boundary (see figure 4-3-14). The secondary area begins where this line crosses the primary area boundary.

b. **For turns of more than 30 degrees,** the inside boundary is from the DRP to the inside secondary area boundary abeam the rollout (point R). From point R, the secondary area tapers 30 degrees inward relative to the CF leg course until the CF leg standard primary area boundary (see figures 4-3-15 thru 4-3-17).

c. CF Leg Construction. Along the CF leg course, a rollout point is established from leg intercept at a distance of the calculated DTA, Chapter 7 calculator 1-6, based on the altitude at leg intercept. Establish a full primary and secondary width OEA at the rollout point; the area may or may not be fully utilized based upon the leg intercept turn.

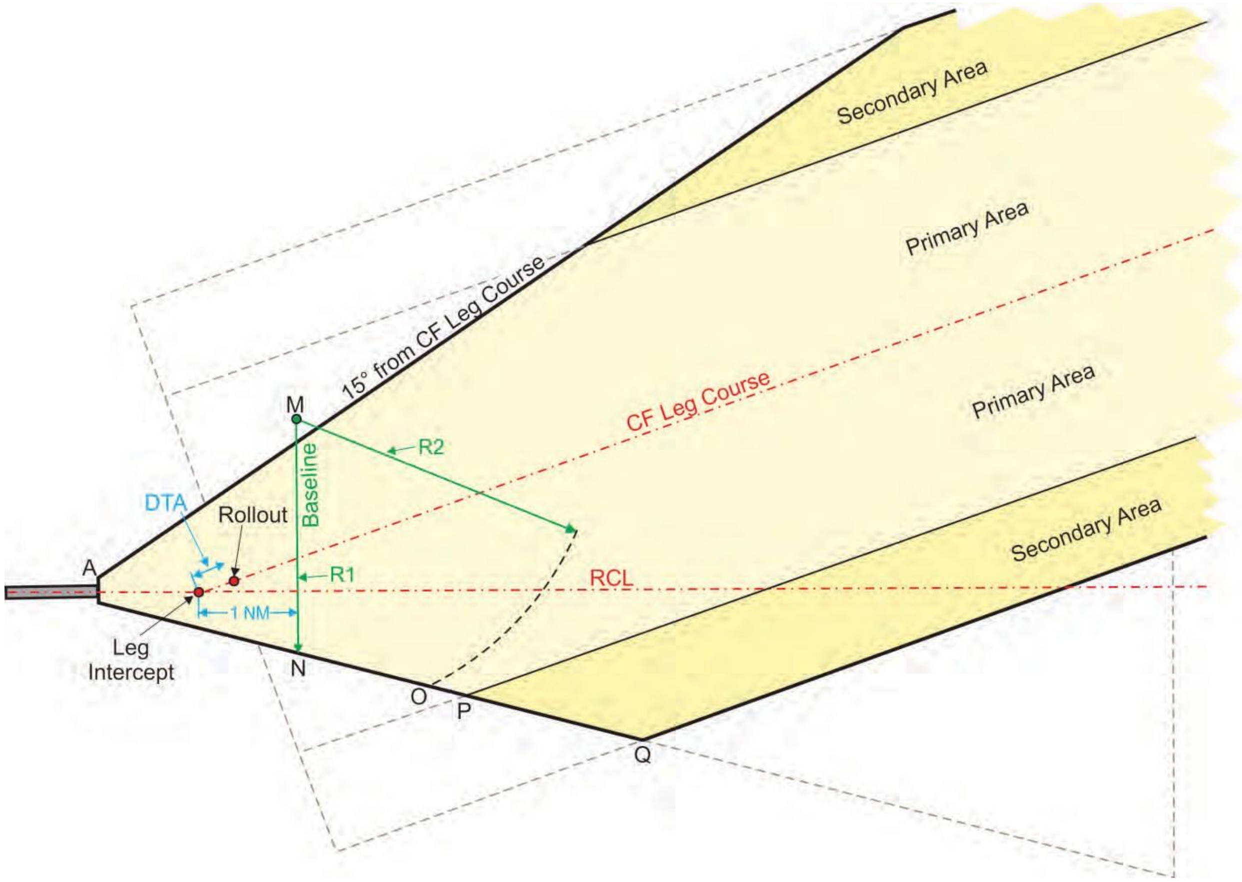
4.3.22. Outside Expansion Area.

a. Establish a baseline 1 NM past leg intercept perpendicular to the extended RCL. Locate point N at the intersection of the baseline and the outside ICA 15-degree splay line. Locate point M on the baseline from point N at a distance based upon the calculated Turn Radius, Chapter 7 calculator 1-3c, determined by the altitude at leg intercept.

b. Centered on point M, the outside R2 arc is the calculated Turn Radius plus 1 NM and begins from the outside ICA 15-degree splay line (point O). Outside construction is based upon the R2 arc in relation to the primary and secondary areas boundaries of the CF leg.

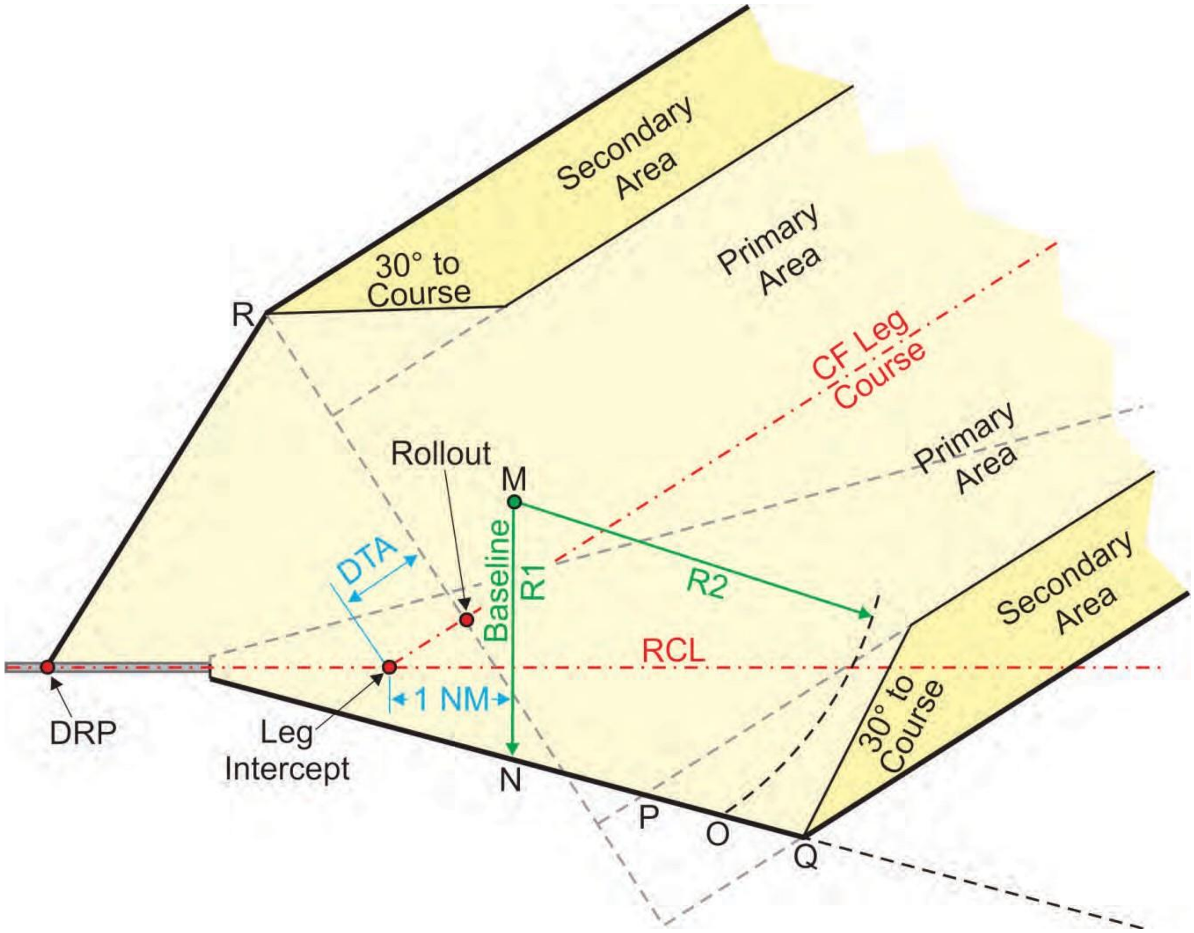
c. **Where the R2 arc is inside** the CF leg primary area, the arc is not necessary. Instead, continue the outside ICA 15-degree splay line until intersecting the CF leg secondary boundary (point Q). The CF leg secondary area begins where the ICA splay crosses the CF leg primary area boundary (point P), see figure 4-3-14.

Figure 4-3-14. Minimum VI-CF Construction, Turn 30 Degrees or Less



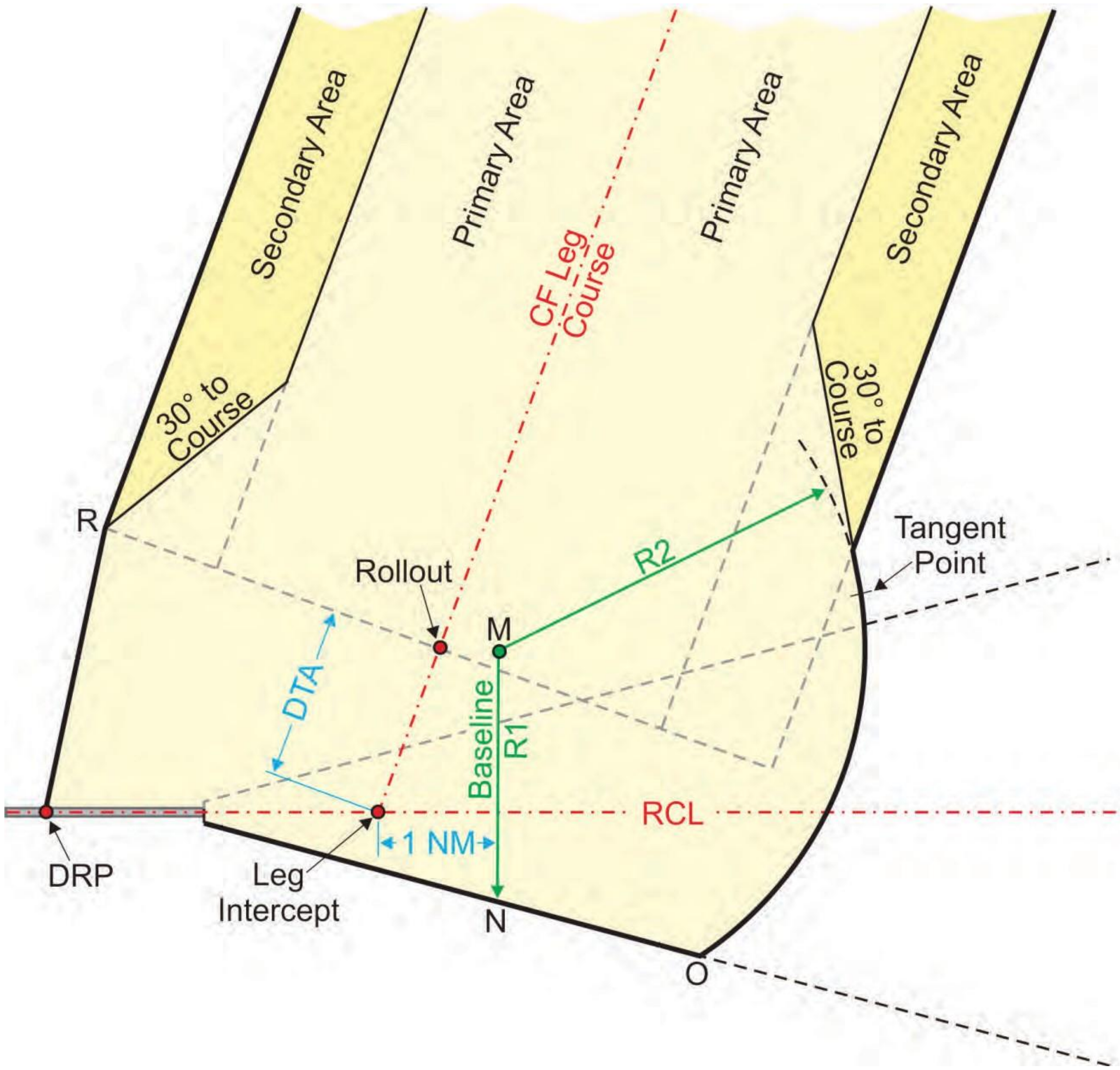
d. **Where the R2 arc extends into** the CF leg secondary area, the arc is also not necessary. Instead, continue the outside ICA 15-degree splay line until intersecting the CF leg secondary boundary (point Q). From the beginning of the secondary area at point Q, taper 30 degrees inward relative to the CF leg course until intersecting the CF leg primary area boundary (see figure 4-3-15).

Figure 4-3-15. Minimum VI-CF Construction, Greater than 30 degree Turn



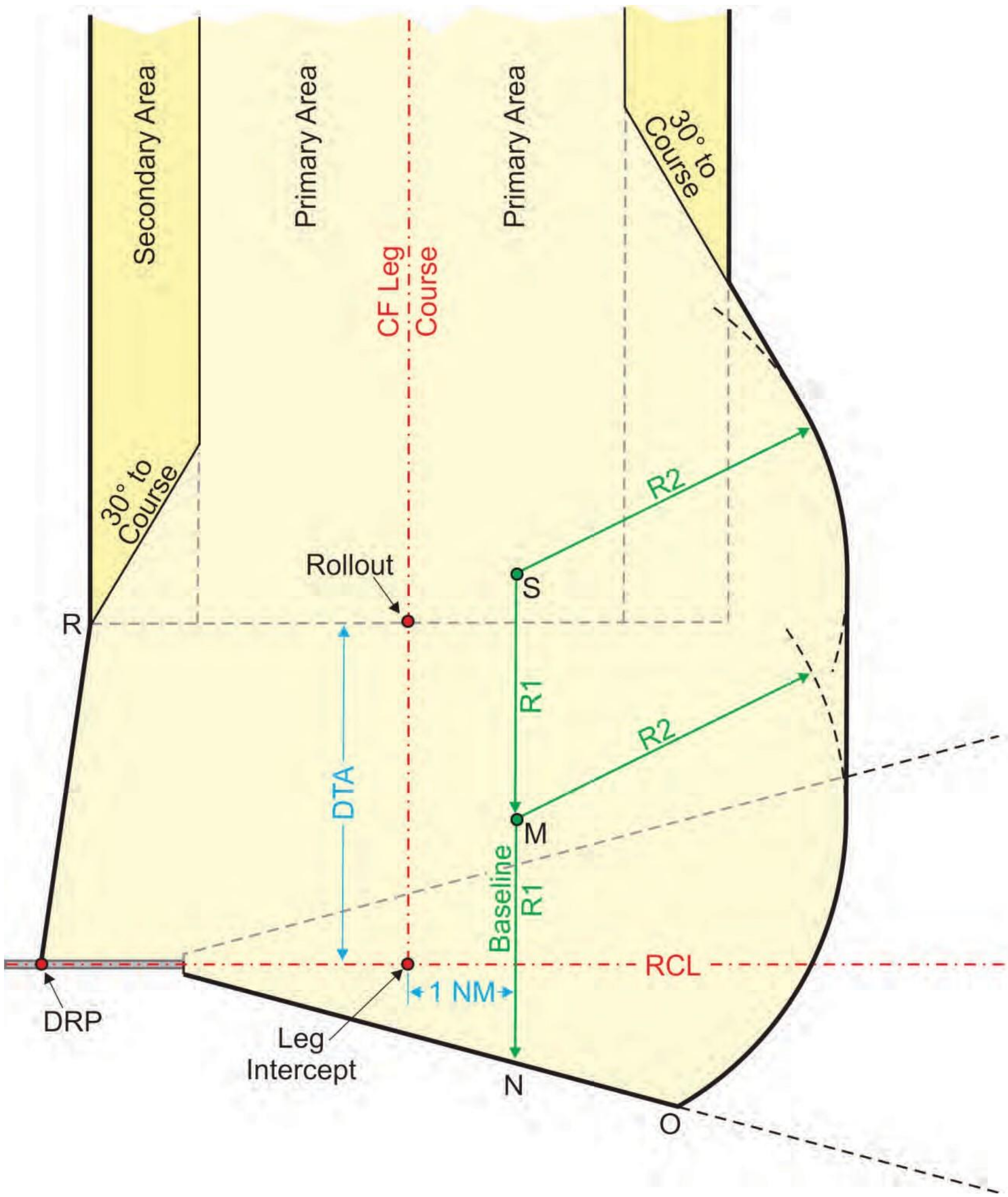
e. **Where the R2 arc continues outside** the CF leg secondary area boundary, the arc continues until reaching a tangent point to a line tapering 30 degrees inward relative to the CF leg course. The CF leg outside secondary area starts where the 30-degree taper line crosses the CF leg secondary boundary (see figure 4-3-16).

Figure 4-3-16. Minimum VI-CF Construction, 75 degree Turn



f. **For 90-degree turns,** locate point S along an extended baseline from point M at a distance based on the same calculated Turn Radius. Construct another outside R2 arc centered on point S based on the calculated Turn Radius plus 1 NM. Connect the two arcs with a tangent line and continue the second arc until reaching a tangent point to a line tapering 30 degrees inward relative to the CF leg course. The CF leg outside secondary area starts where the 30-degree taper line crosses the CF leg secondary boundary (see figure 4-3-17).

Figure 4-3-17. Minimum VI-CF Construction, 90 degree Turn



4.3.23. Departure Area Width Joining En Route Width (crossing 30 NM from ARP) or Airway.

4.3.24. Where the DP area width has reached en route width and a turn is not required, the segment boundaries merge. If a turn is required, construct as specified in paragraph 4.3.3 or 4.3.5.

4.3.25. Where the DP area width is less than en route width:

a. **And a turn is not required,** the DP primary and secondary areas immediately increase to en route width at the fix or NAVAID where the DP joins the airway/en route width.

b. **And a FB turn is established.**

i. When the DTA area begins at or prior to the intersection of the DP/en route width primary and secondary area boundaries expansion is required. On the inside turn expand the DP primary and secondary boundaries at an angle equal to one-half of the course change as specified in paragraph 4.3.3. On the outside turn, increase to en route width adjacent to the intersection of the en route area except when joining an airway. When joining an airway extend the DP outer boundary until it merges with airway boundary.

ii. Where the DTA areas begins at or after the intersection of the DP/airway primary and secondary area boundaries, the segment boundaries merge (no inside or outside expansion is required).

a. And a FO turn is established, no inside expansion is required. The DP outside area is as specified in paragraph 4.3.5.

4.3.26. Departure Altitude. Establish a departure altitude, which is the highest altitude of: the lowest MEAor highest MCAfor the direction of flight, an altitude that will allow random (diverse) IFRflight, an altitude where ATCradar service is provided, or an altitude that provides obstacle clearance with a standard climb gradient.

4.3.27. End of Departure. The departure evaluation terminates at an altitude that will allow random (diverse) IFRflight or at a fix/NAVAIDwhere radar service can be provided or a climb-in-hold evaluation is required.

SECTION 4: OEA ASSESSMENT

4.4. OEA Assement.

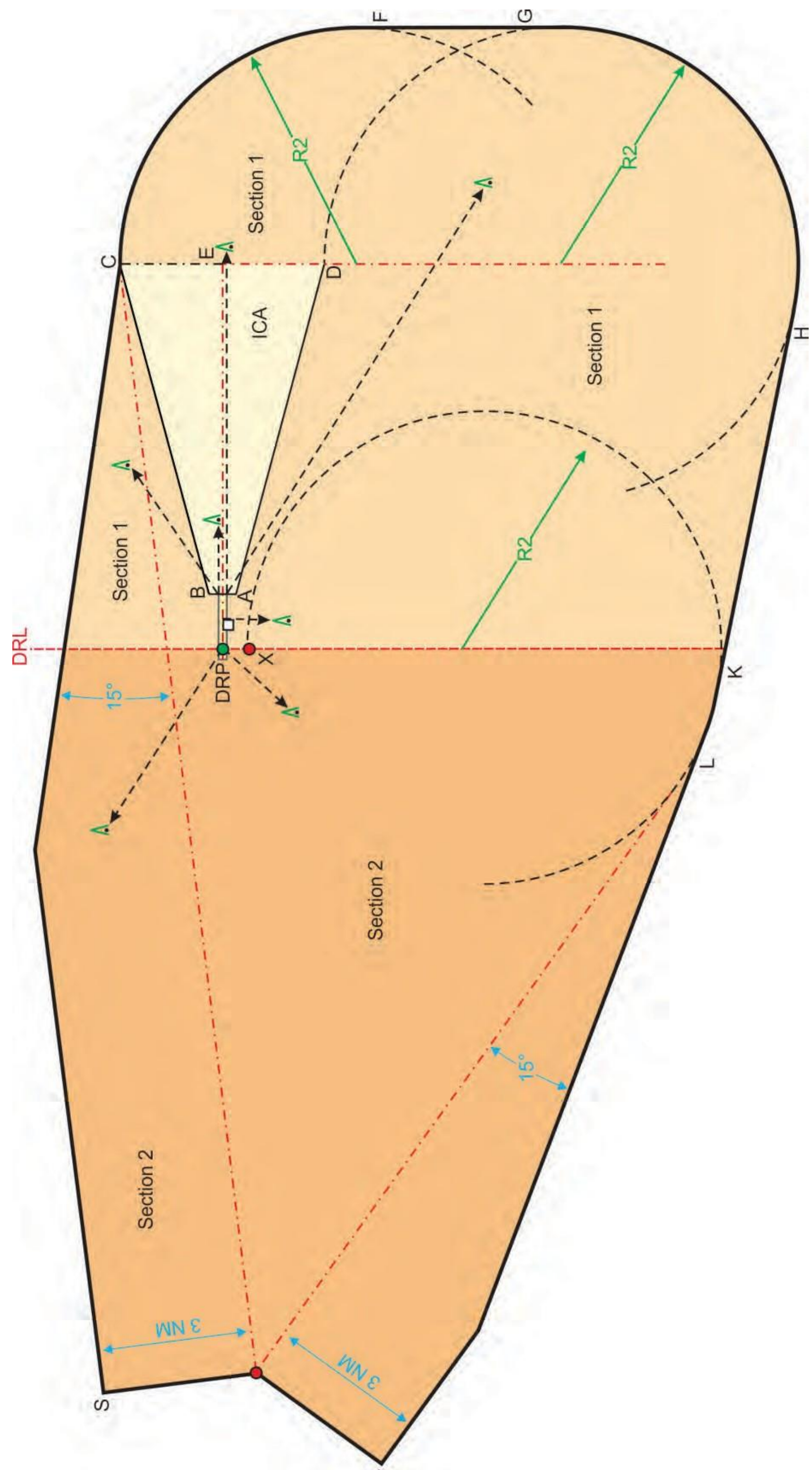
4.4.1. Obstacle Evaluation. ICA obstacles are measured by the shortest distance from the DER to the obstacle beginning at the DER elevation. Measure section 1 obstacles outside of the ICA to the centerline of the runway from DRP to DER and to the closest point on the ICA boundary past DER. The Section 1 OCS begins at the MSL elevation of the OCS at the ICA end line. Where applicable for VA-DF construction, obstacles in section 2 are evaluated utilizing only the shortest primary area distance from the DRP beginning at the VA segment termination MSL altitude (see figure 4-4-1). For all succeeding segments, the primary area is evaluated utilizing the shortest primary area distance to the obstacle (see figure 4-4-2). Where leg OEAs overlap, obstacles are evaluated in each leg.

4.4.2. ROC. All primary area obstacles are evaluated for the minimum climb gradient required to provide ROC (see TP308/GPH209 Vol 1, Chap 2, paragraph 203). In the secondary area, measure the 12:1 secondary OCS perpendicular to the nominal track. In expansion areas (arc, diagonal, corner-cutter, etc.), the slope rises perpendicular to the primary area boundary (see calculator 2-4).

4.4.3. CG. Where the highest required climb gradient value is greater than 200 ft/NM, it will be published as the procedure minimum climb gradient (see calculator 2-4). Do not utilize a climb gradient in excess of 500 ft/NM without approval from Flight Standards (or the appropriate military authority).

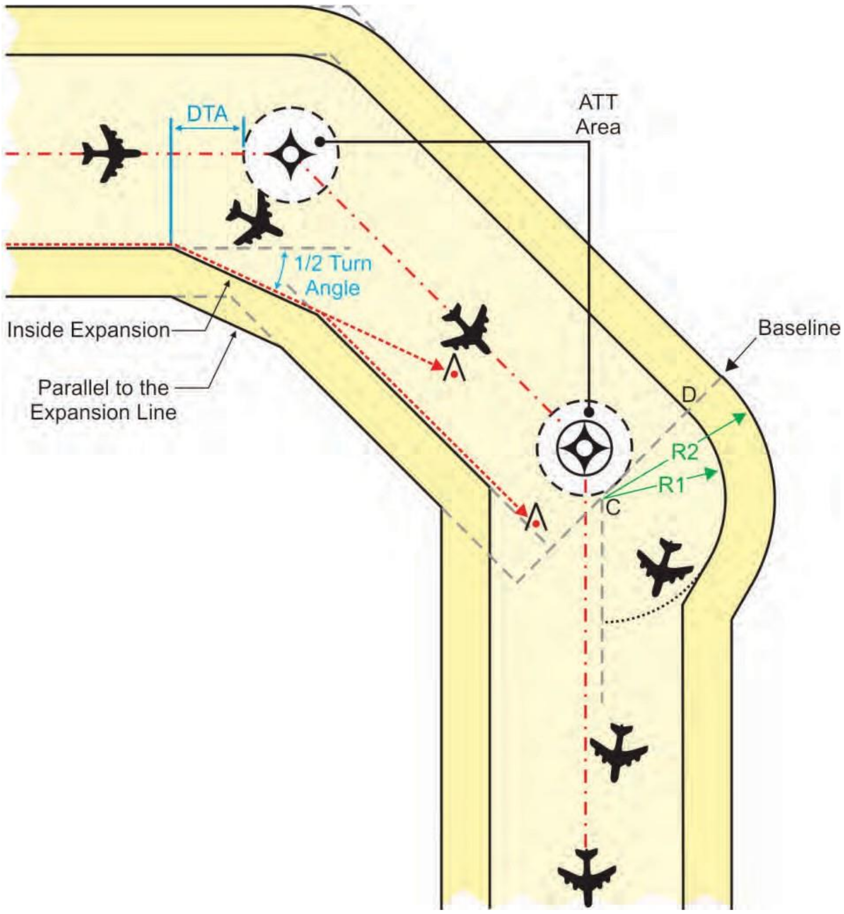
4.4.4. Climb in a Holding Pattern. Where required, apply climb-in-hold criteria contained in TP308/GPH209 Chapter 18 Holding Criteria.

Figure 4-4-1. VA-DF Construction OEA Assessment



Supplementary note: Disregard all illustrations of obstacle measurement in the figure.

Figure 4-4-2. Fix Turn Construction OEA Assessment



SECTION 5: VA-DF LEG LENGTH ANALYSIS

4.5. VA-DF Leg Length Analysis.

4.5.1. Purpose. This analysis is created to provide guidance for evaluating the DF maneuver but does not mirror OEA construction. In this assessment, the VA leg Earliest TP and Latest TP are treated as a FO fix.

4.5.2. Earliest TP. Measure from the DRP at airport elevation with 1100 ft/NM climb gradient, which reaches the earliest climb-to altitude or the DER, whichever occurs first. If the climb-to altitude is not reached by the DER, continue the climb determination starting at the DER using a climb gradient of 500 ft/NM until reaching 10000 ft, then 350 ft/NM.

4.5.3. Latest TP. Commencing at the DER at DER elevation, the latest TP is where an aircraft reaches the climb-to altitude at a climb gradient of 200 ft/NM or the minimum climb gradient required for obstacle clearance whichever is higher.

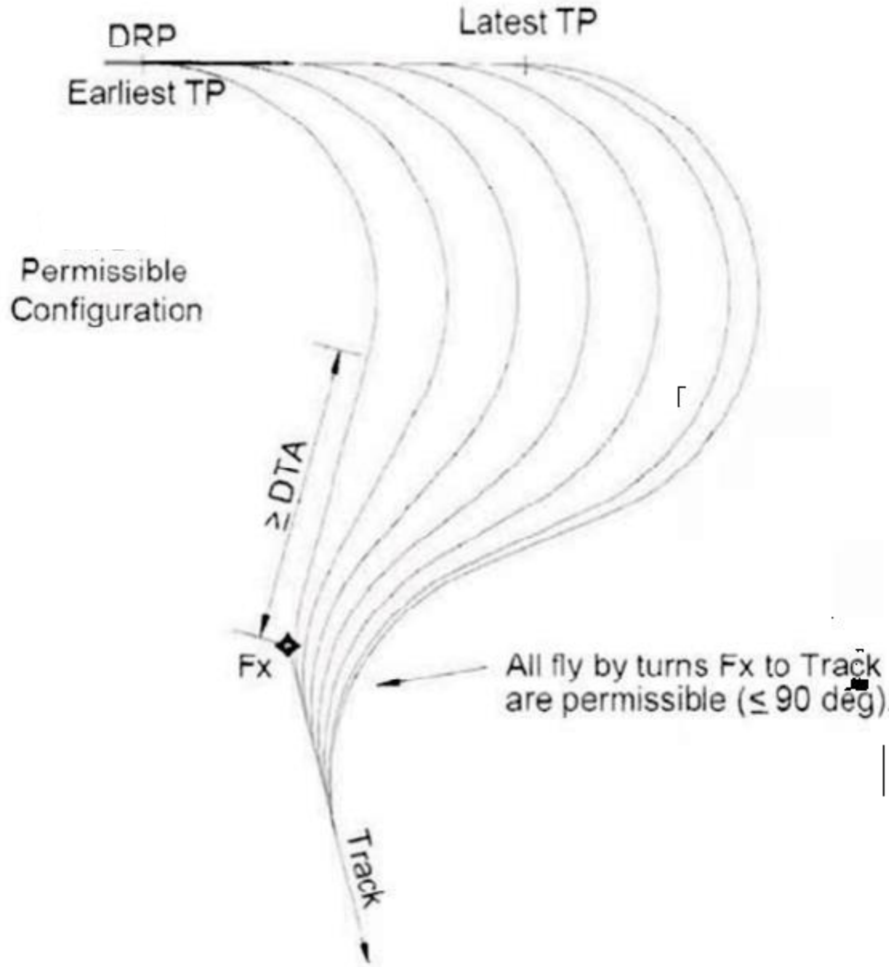
4.5.4. Calculations. Given the location of the DF leg termination fix and the outbound track from this fix, analyze a FO and FB turn at the termination fix from the ETP then every 0.1 NM until the latest TP to verify:

a. if the fix is on or outside all paths scribed from the ETP until the latest TP based on the calculated turn radius;

b. if the turn at the fix is 90 degrees or less; and

c. where the fix is a FB, if the required DTA area is available. If all three conditions are met, the design passes analysis and is acceptable, see also the VA-DF calculator in the "Terminal Instrument Procedures (TERPS) Tools" section of the Flight Procedure Standards Branch web site. There is no course change limitation at the termination of the VA leg to join the DF leg (see figure 4-5-1).

Figure 4-5-1. VA-DF Permissible Configuration



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VOLUME 2: PERFORMANCE BASED NAVIGATION (PBN)

CHAPTER 5: TERMINAL ARRIVAL AREA (TAA) DESIGN

SECTION 1: TAA AND APPROACH SEGMENT CONSTRUCTION

5.1. TAA and Approach Segment Construction.

5.1.1. Minimum Safe/Sector Altitude (MSA).

Do not publish an MSAfor an approach with a TAA.

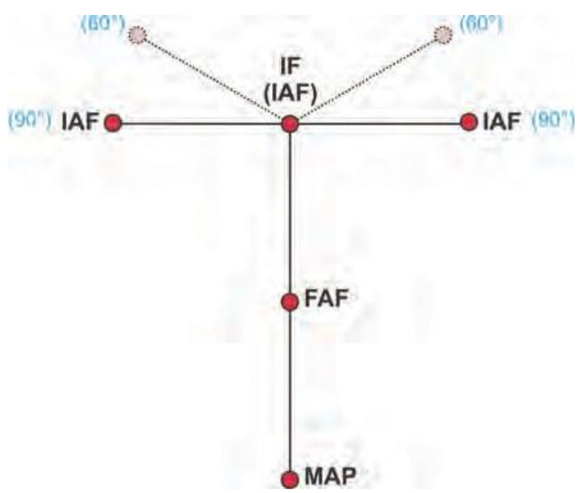
5.1.2. Initial, Intermediate, Final and Missed Approach Segments.

The following application guidelines are specific to the TAA and apply to all PBN procedures. The Basic T approach segment configuration, as described below, is the standard configuration for transition from the en route to the terminal environment. Deviations from the Basic T configuration should be made only when absolutely necessary. The TAA was conceived as a “free flight” concept; i.e., the pilot can maneuver as necessary within the TAA sector. It is assumed the pilot will maneuver to enter at a given IAF at an airspeed and intercept angle to correctly fly the procedure.

5.1.3. Initial Alignment to the Intermediate Segment.

a. The MAXIMUM intercept angle of the initial segment to the intermediate segment is 90 degrees (+/- 0.03 degrees). The MINIMUM intercept angle is 60 degrees (+/- 0.03 degrees)(see figure 5-1-1A).

Figure 5-1-1A. Initial/Intermediate Segment Alignment



b. The minimum length of the T initial segments is the larger of the table 5-1-1 value or the results of the Chapter 7, paragraph 7.1.10 “Fly-By Turn” calculation. Since the TAA is considered a “Free Flight” concept, assume a 45-degree turn at the IAF. Use the value for the highest approach category published on the procedure. Descent gradient considerations may require longer segment lengths. Maximum leg length is 10 NM. If Chapter 7 initial segment descent gradient criteria cannot be met, eliminate the T initial approach fix (IAF). Then, aircraft arriving from the direction of the eliminated T IAF will fly the course reversal holding pattern (see figure 5-1-1B). For parallel runway configurations, construct T IAFs so that they serve all parallel intermediate segments (see figure 5-1-1C).

Figure 5-1-1B. Basic T with an IAF Eliminated Application

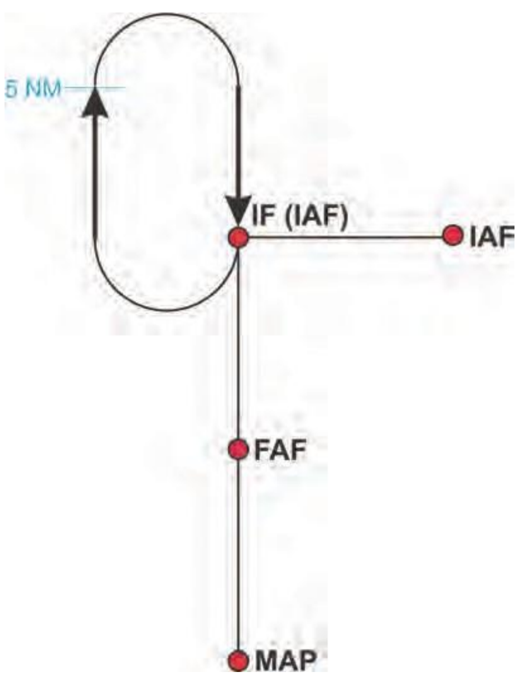


Figure 5-1-1C. Basic T Parallel Runway

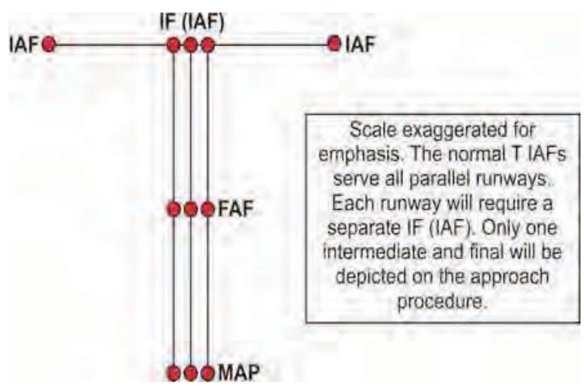


Table 5-1-1. Minimum Initial Segment Length for TAA Construction

Category	Minimum Length (NM)
A	3
B	4
C	5
D	5
E	6

Note: The TAA is a "free flight" area. Pilots are assumed to maneuver so as to enter the initial segment at approximately a 45-degree angle.

5.1.4. Intermediate Alignment to the Final Segment.

Align the intermediate segment with the final segment; i.e., turns over the FAF are not allowed.

5.1.5. Establish a holding pattern at the IF (IAF).

The inbound holding course shall be aligned with the inbound intermediate course (see figure 5-1-1C). Express all RNAV holding patterns in NM leg lengths vice timed holding under TP308/GPH209 Vol 1 Chap 18.

5.1.6. Missed Approach Segments.

OPTIMALLY, construct missed approach segments to allow a "direct entry" into a missed approach holding pattern as illustrated in figure 5-1-2A. If the missed approach routing terminates at a T IAF, OPTIMUM alignment of the missed approach holding pattern is with the initial inbound course, with a direct entry into holding (see figure 5-1-2B).

Figure 5-1-2A. OPTIMUM Missed Approach Holding

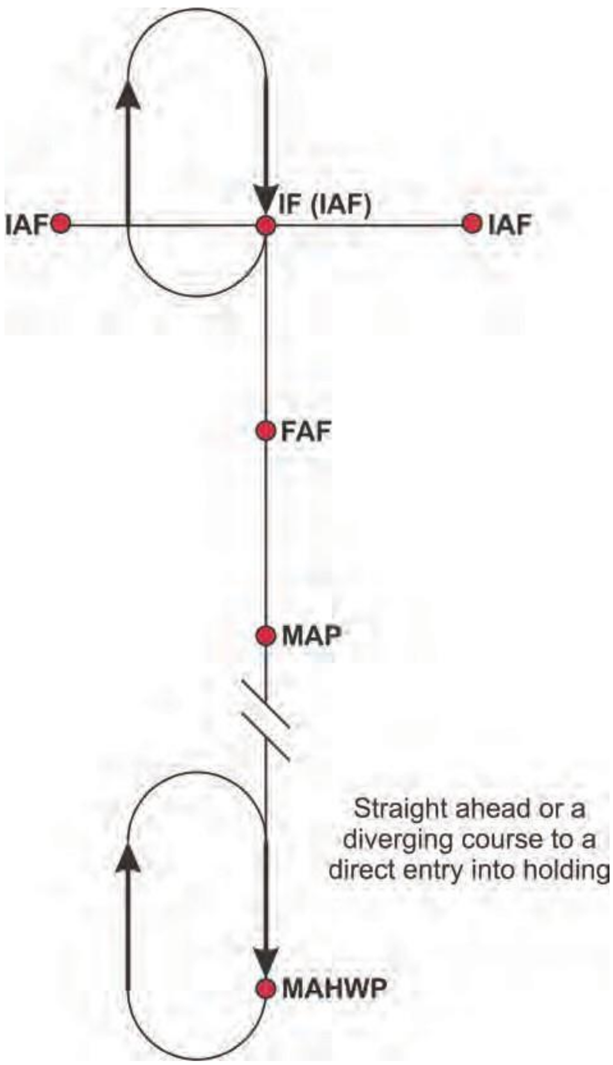
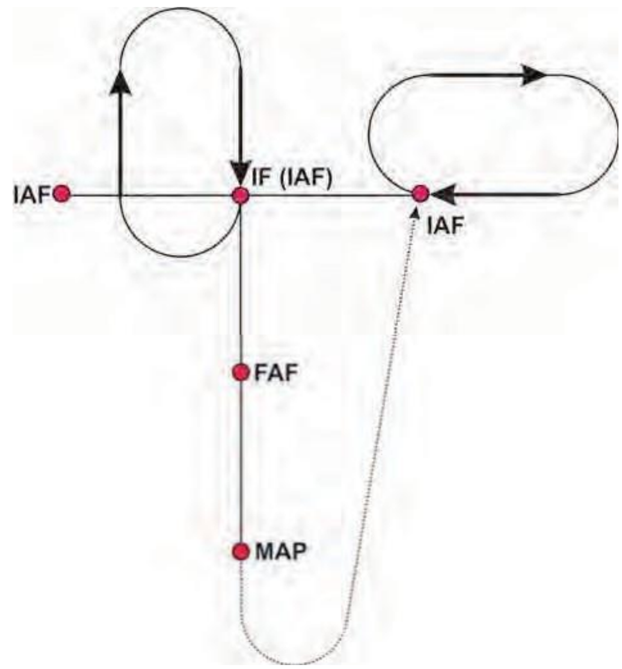


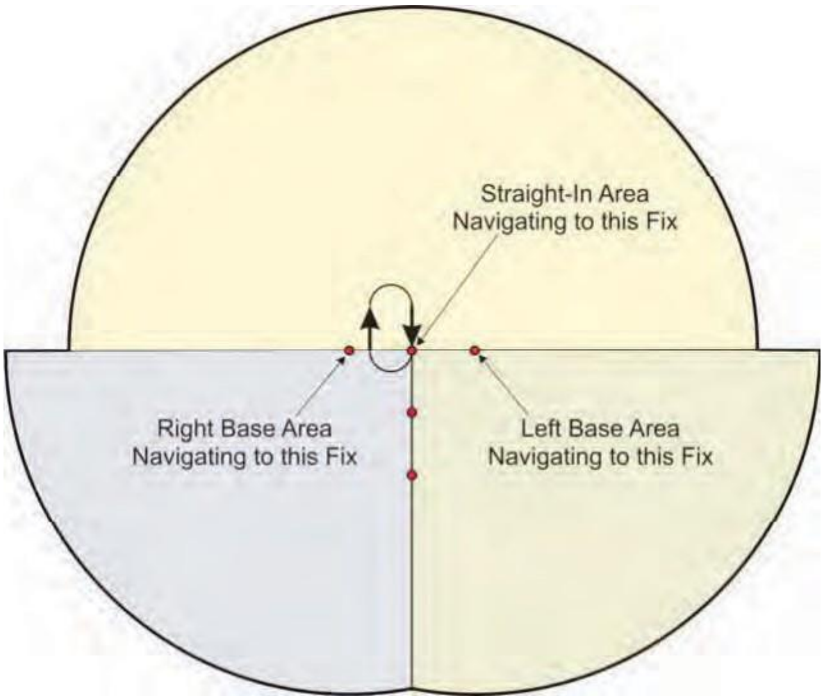
Figure 5-1-2B. Missed Approach Holding at an IA



5.1.7. Standard TAA Areas.

The standard TAA contains three areas defined by the basic T segment centerline extensions: the straight-in area, right base area, and the left base area (see figure 5-1-3A). The TAA boundaries shall coincide with procedure flight tracks; e.g., the boundary between the straight-in area and either base area shall be the initial segment centerline extended; and the boundary between base areas shall be the intermediate segment centerline extended.

Figure 5-1-3A. Standard TAA



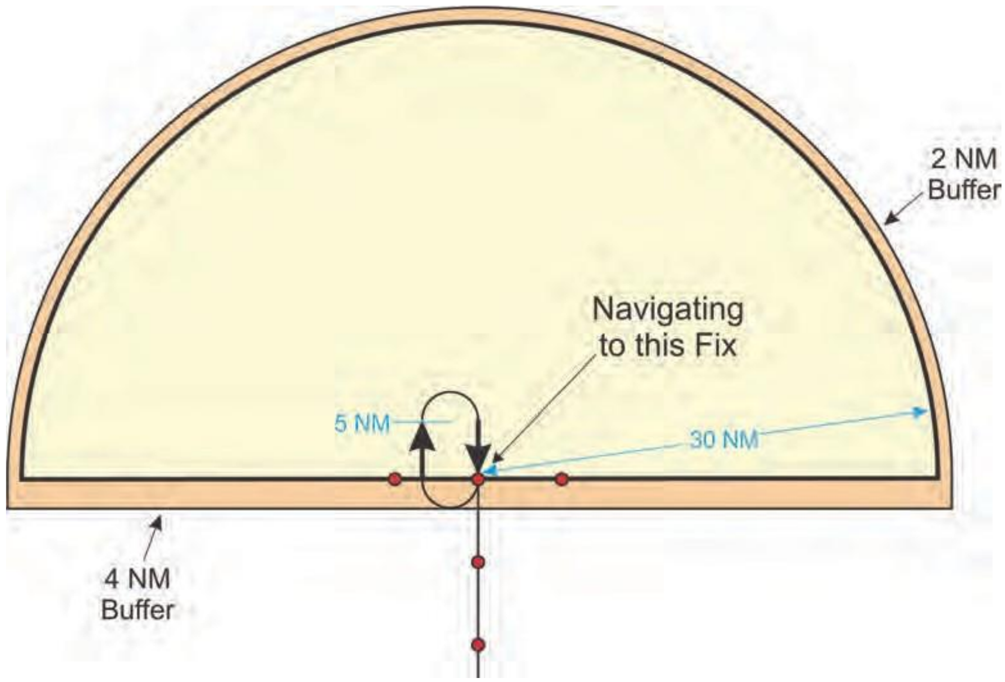
5.1.8. Straight-In Area.

a. The arc boundary of the straight-in area is equivalent to a feeder fix. When crossing the boundary or when released by ATC within the straight-in area, the pilot can maneuver as necessary within the TAA sector to enter at a given IAF at an airspeed and intercept angle to correctly fly the procedure (assume 45 degrees for leg length calculation).

b. **Construction.** Draw a straight line through the T IAFs, extending 30 NM in each direction from the IF. Then, on the side of the line away from the airport, scribe a 30-NM arc centered on the IF connecting the straight-line end points (see figure 5-1-3B).

c. Obstacle Clearance. The area considered for obstacle clearance includes the entire straight-in area and its associated buffer areas (see figure 5-1-3B). TP308/GPH209 Vol 1 Chap 17, Para 1720.

Figure 5-1-3B. Straight-In Area



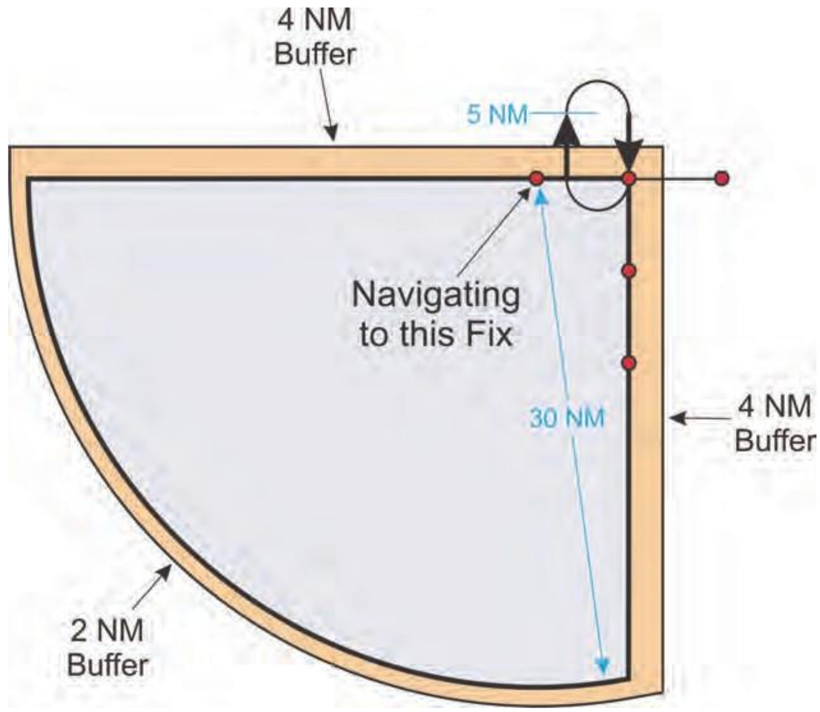
5.1.9. Right Base Area.

a. The arc boundary of the right base area is equivalent to a feeder fix. When crossing the boundary or when released by ATC within the right base area, an aircraft is considered at the feeder fix and is expected to maneuver as necessary within the TAA sector to enter at the IAF at an airspeed and intercept angle to correctly fly the procedure (assume 45 degrees for leg length calculation).

b. **Construction.** To construct the top boundary, extend the line from the IF through the T IAF for 30 NM beyond the T IAF. Draw a 30- NM arc, centered on the T IAF, from the end point of the top boundary counter-clockwise to the point it intersects a straight-line extension of the intermediate course (see figure 5-1-3C).

c. **Obstacle Clearance.** The area considered for obstacle clearance includes the entire right base area and its associated buffer areas. TP308/GPH209 Vol 1 Chap 17, Para 1720.

Figure 5-1-3C. Right Base Area



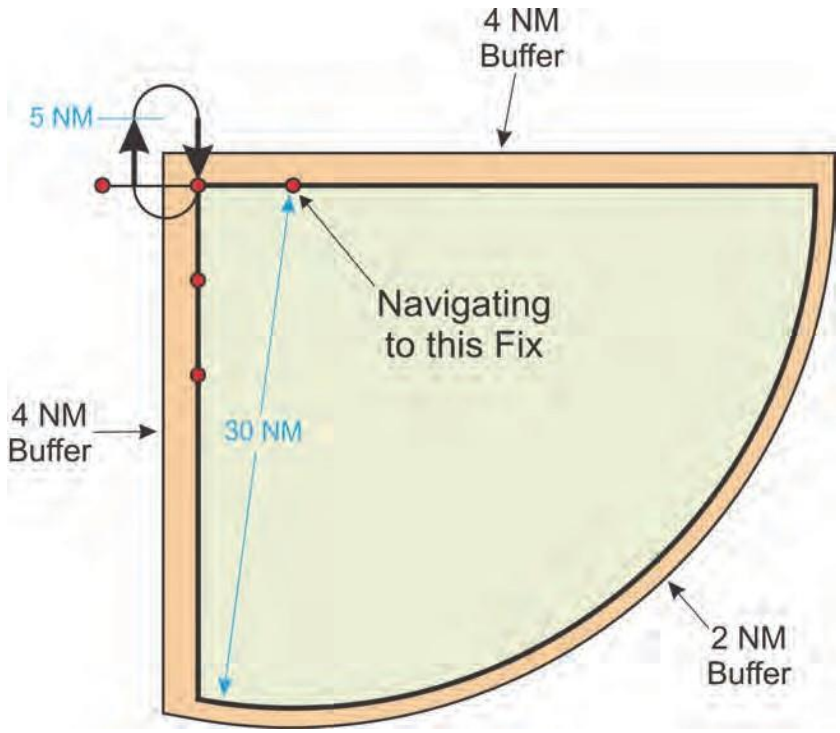
5.1.10. Left Base Area.

a. The arc boundary of the left base area is equivalent to a feeder fix. When crossing the boundary or when released by ATC within the left base area, an aircraft is considered at the feeder fix and is expected to maneuver as necessary within the TAA sector to enter at the IAF at an airspeed and intercept angle to correctly fly the procedure (assume 45 degrees for leg length calculation).

b. **Construction.** To construct the top boundary, extend the line from the IF through the T IAF for 30 NM beyond the T IAF. Draw a 30- NM arc, centered on the T IAF, from the end point of the top boundary clockwise to the point it intersects a straight-line extension of the intermediate course (see figure 5-1-3D).

c. **Obstacle Clearance.** The area considered for obstacle clearance includes the entire left base area and its associated buffer areas. TP308/GPH209 Vol 1 Chap 17, Para 1720.

Figure 5-1-3D. Left Base Area



5.1.11. Altitude Selection Within TAA.

OPTIMALLY, all TAA areas, course reversal holding pattern, and initial segment minimum altitudes should be the same. All NoPT routings shall join the IF(IAF) at a common altitude. When terrain or operational constraints force higher area altitudes that do not allow descent within gradient limits, the course reversal pattern at the IF (IAF) shall allow descent from the highest minimum sector altitude to the common IF(IAF) altitude.

5.1.12. Sectors/Stepdown Arcs.

a. When necessary to accommodate terrain diversity, operational constraints, or excessive descent gradients, the straight-in, left, and right base areas may be subdivided to gain relief, within the limitations noted below. Stepdown arcs, when used, shall be no closer than 4 NM from the WP upon which the arc is based and must be a minimum of 4 NM from the TAA outer boundary.

b. **Straight-in Area.** The straight-in area may be divided into as many as three sectors defined radially by magnetic inbound course to the IF(IAF). Each sector may be further sub-divided by a single stepdown arc centered on the IF(IAF). The minimum sector size shall be 30 degrees; except the minimum sector size shall be 45 degrees when the sector contains a stepdown arc and its radial boundaries terminate at the IF(IAF) (see figures 5-1-4A through 5-1-4D).

c. **The left and right base areas may not be radially sectored.** Only stepdown arcs (centered on the fix that defines the area) may be used, but are limited to one per sector (see figures 5-1-4A through 5-1-4D).

Figure 5-1-4A. A Sectorized TAA with Stepdown Arcs

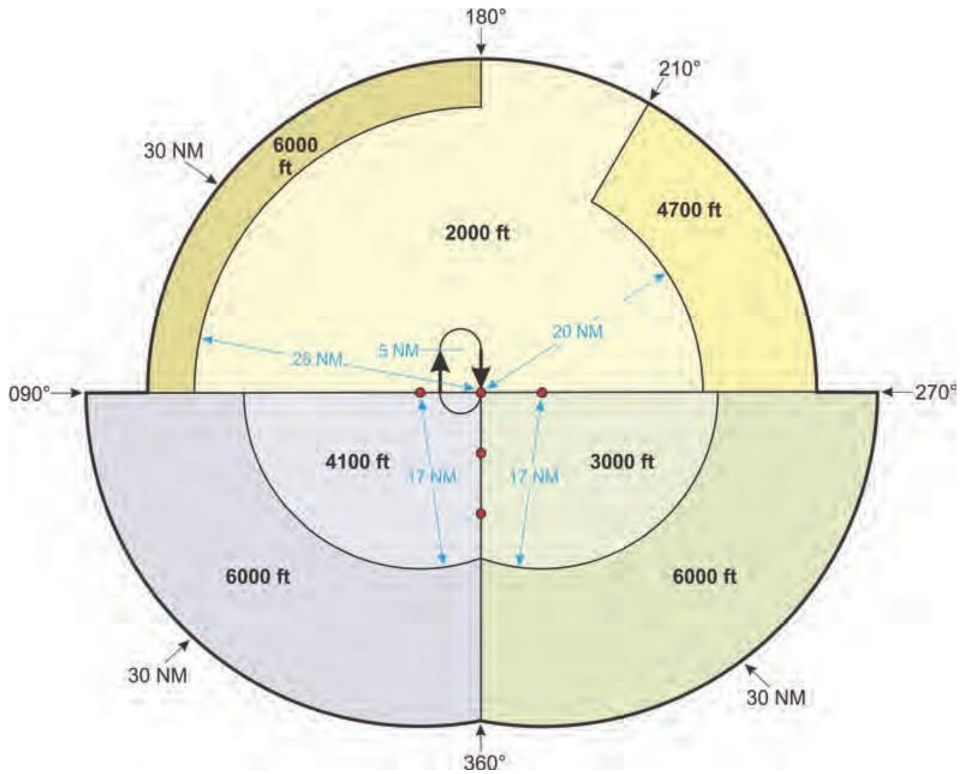


Figure 5-1-4B. TAA Maximum Sectorization with Maximum Stepdown Arcs

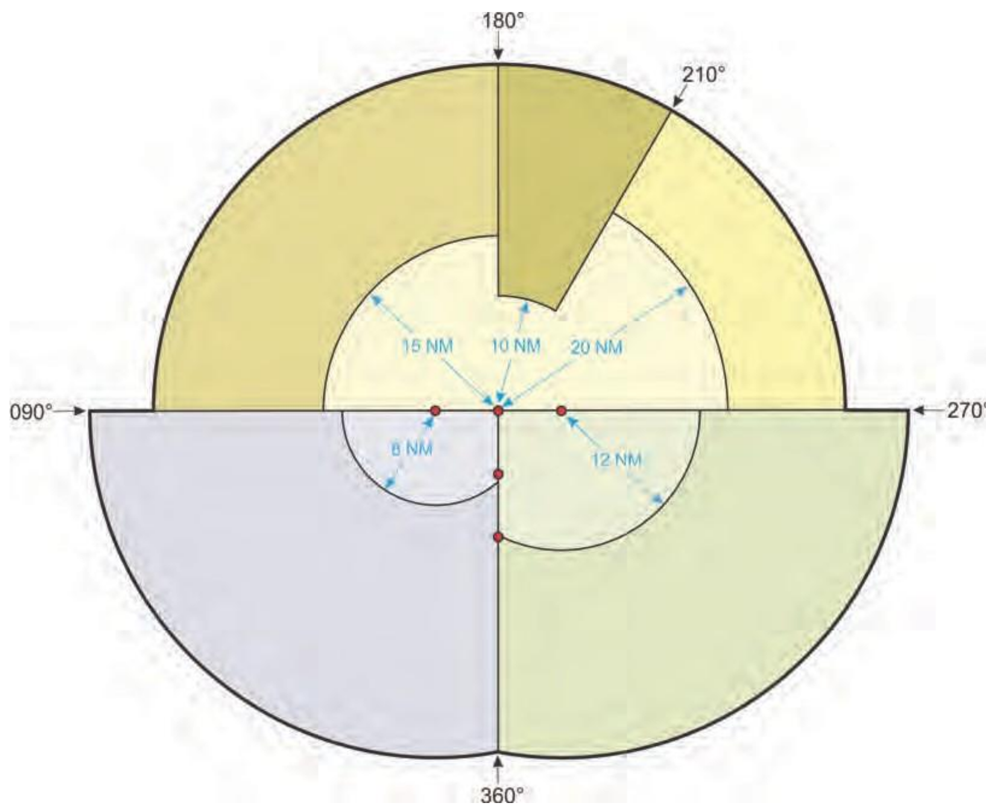


Figure 5-1-4C. TAA Maximum Sectorization with Maximum Stepdown Arcs

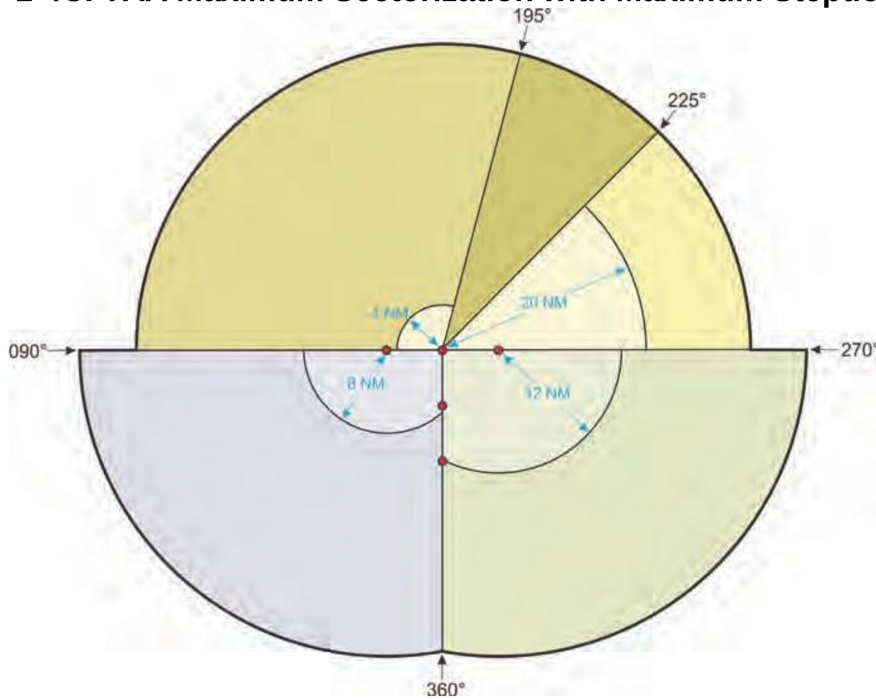
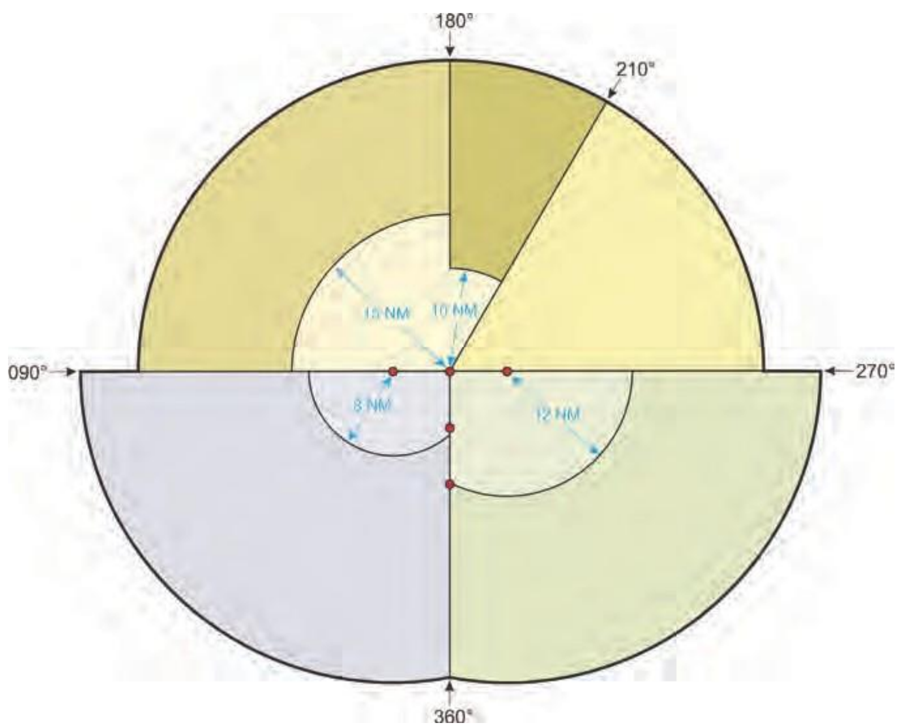


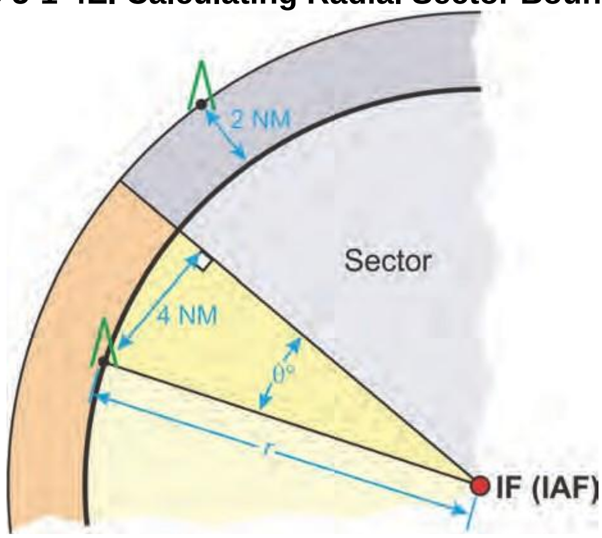
Figure 5-1-4D. TAA Maximum Sectorization with Maximum Stepdown Arcs



5.1.13. Altitude Sectors.

Sectors must provide appropriate required obstacle clearance within the sector boundaries and over all obstacles within a 4-NM buffer area (measured perpendicular to the radial boundary line) and within a 2-NM buffer from the outer boundary and any stepdown arcs. See figure 5-1-4E for a method to calculate the distance from a straight-in boundary line.

Figure 5-1-4E. Calculating Radial Sector Boundaries



$$\theta = ArcSin\left(\frac{4}{r}\right)$$

Where:

$\theta = angle\ in\ degrees$

r $\geq$ 4 NM

e.g., If r = 8 then $\theta = ArcSin\left(\frac{4}{8}\right) = 30^o$

5.1.14. TAA Area Modifications.

Modifications to the standard TAA design may be necessary to accommodate operational requirements. Variations may eliminate one or both base areas, and/or limit or modify the angular size of the straight-in area. If the left or right base area is eliminated, modify the straight-in area by extending its 30-mile radius to join the remaining base area boundary. If the left and right base areas are eliminated, extend the straight-in 30-mile radius to complete 360 degrees of arc. Construct a sector that requires a course reversal in the extended straight-in area to accommodate entry at the IF (IAF) at angles greater than 90 degrees. This sector does not count toward the sectorization limitation stated in paragraph 5.1.12.b (see figures 5-1-5A through 5-1-5E).

Figure 5-1-5A. TAA with Left and Right Base Areas Eliminated

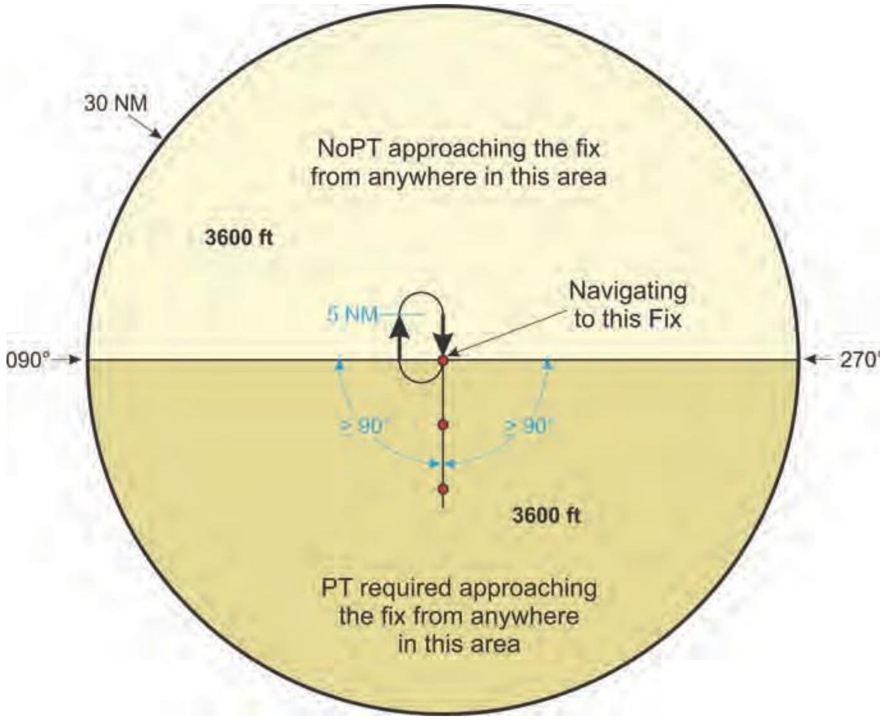


Figure 5-1-5B. TAA with Right Base Eliminated

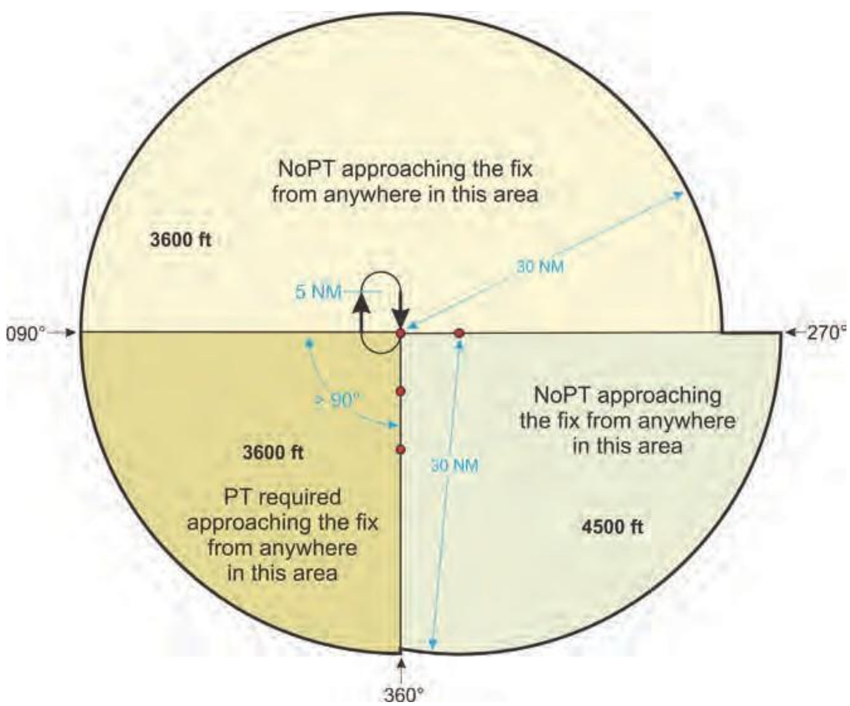


Figure 5-1-5C. TAA with Left Base Eliminated

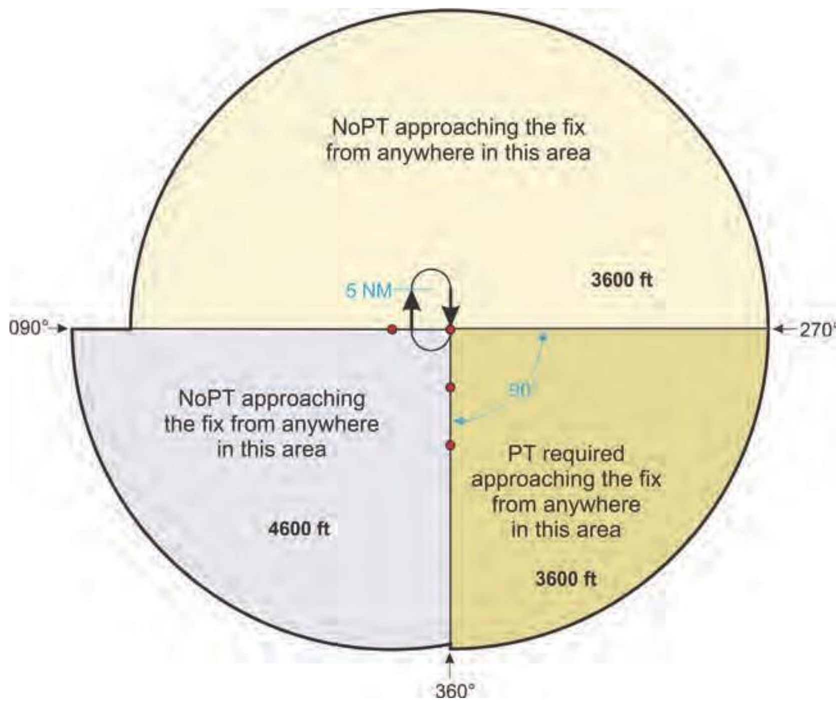


Figure 5-1-5D. TAA with Part of Straight-In Area Eliminated

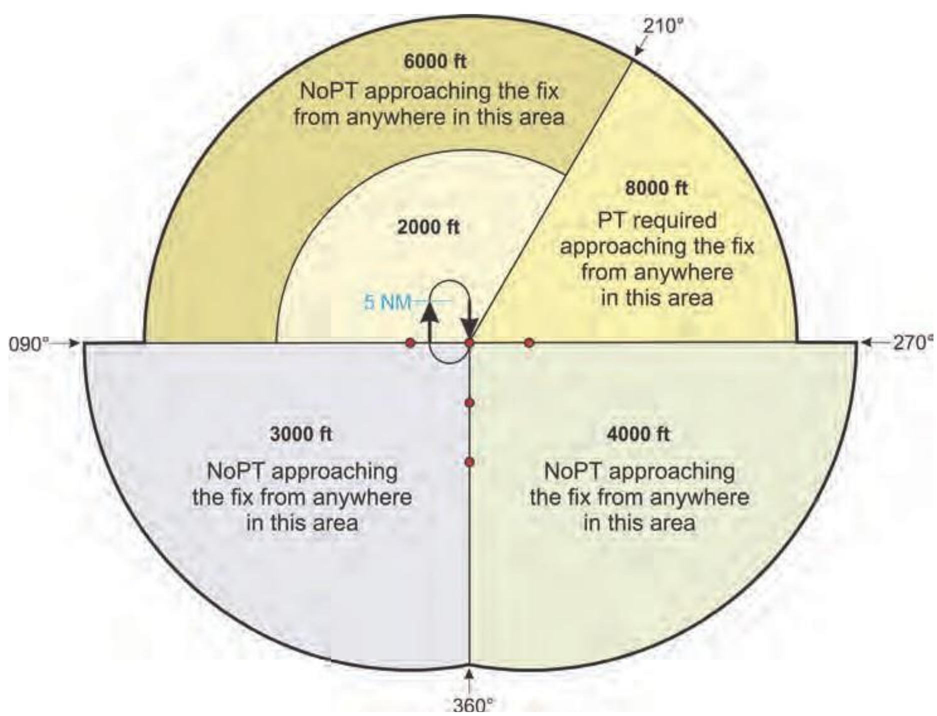
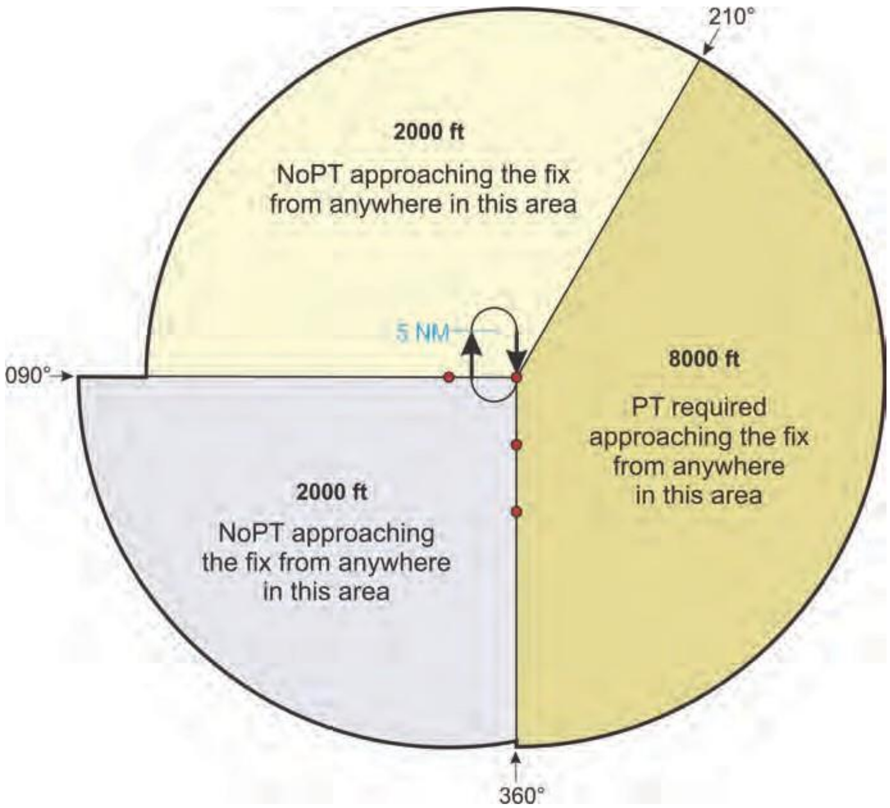


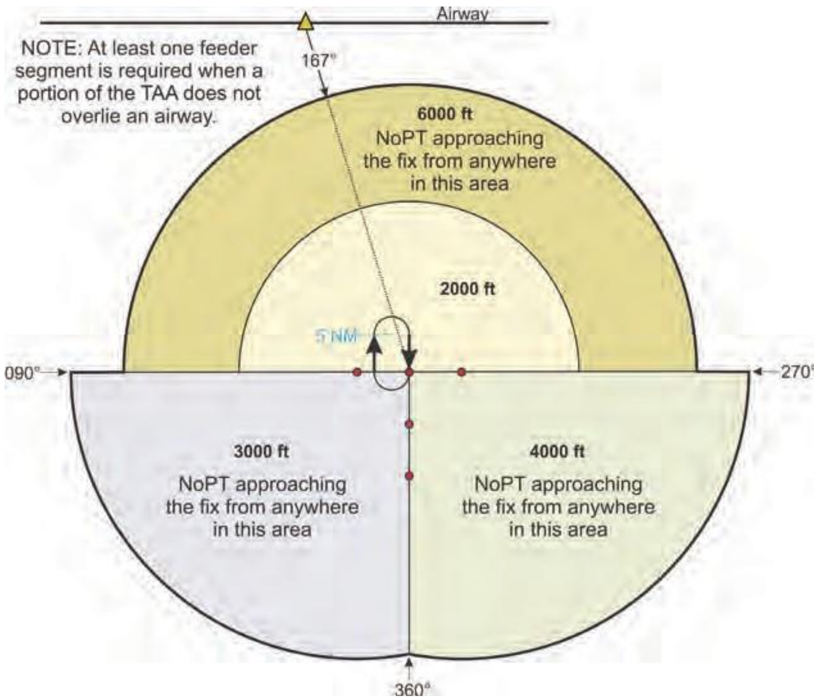
Figure 5-1-5E. TAA Example with Left Base and Part of Straight-In Area Eliminated



5.1.15. Connection to En Route Structure.

Normally, a portion of the TAA will overlie an airway. If this is not the case, construct at least one feeder route from an airway fix or NAVAID to the TAA boundary aligned along a direct course from the en route fix/NAVAID to the appropriate IF (IAF) and/or T IAF(s) (see figure 5-1-5F). Multiple feeder routes may be established if the procedure designer deems necessary.

Figure 5-1-5F. Examples of a TAA with Feeders from an Airway



5.1.16. Airspace Requirements.

a. The TAA should be wholly contained within controlled airspace insofar as possible.

b. **If the TAA overlies Class B, C or D airspace,** in whole or in part, the ATC facility exercising control responsibility for the airspace may recommend minimum TAA sector altitudes. It is the responsibility of the ATC facility providing approach control service for the airport to resolve TAA altitude and overlapping airspace issues with adjoining ATC facilities. Modify the TAA to accommodate controlled/restricted/warning areas as appropriate.

c. In Canada, level of service issues are brought to the attention of NAV CANADA.

SECTION 2: DOCUMENTATION AND PROCESSING

5.2. Documentation and Processing.

All issues concerning documentation and processing should be brought to the attention of NAV CANADA.

VOLUME 2: PERFORMANCE BASED NAVIGATION (PBN)

CHAPTER 6: STANDARD FOR REQUIRED NAVIGATION PERFORMANCE (RNP) APPROACH PROCEDURES WITH AUTHORIZATION REQUIRED (AR)

SECTION 1: BASIC CRITERIA INFORMATION

6.1. Basic Criteria Information.

6.1.1. Design Concept.

a. Use these criteria to develop RNP AR instrument approach procedures. The following basic conditions are considered in the development of obstacle clearance criteria for RNP approach procedures: The aircraft descends and decelerates from the en route environment or a terminal transition route through the initial/intermediate approach segments to the PFAF. The aircraft arrives at the DA and continues with visual reference to a landing on the runway or initiates a missed approach. The design of the instrument procedure defines the boundaries of the airspace within which the instrument operation will be conducted. This is the airspace that will "contain" (account for) all of the major factors influencing RNP: System accuracy, flight technical error, navigation system error, and error values that provide an acceptable level of continuity, availability, and integrity.

b. For obstacle clearance purposes, the boundaries are specified as a nautical mile measurement perpendicular to the designed flight path. This measurement is specified as an RNP value or level. The primary OEA of RNP instrument procedures is defined as $\pm 2 \times RNP$. Table 6-1-1 lists RNP values applicable to specific instrument procedure segments.

Table 6-1-1. RNP Values

SEGMENT	RNP VALUES		
	MAXIMUM	STANDARD	MINIMUM
Feeder	2	2	1.0
Initial	1	1	0.1
Intermediate	1	1	0.1
Final	0.5	0.3	0.1
Missed Approach	1	1	0.1

Note: Prior to the PFAF, RNP values may decrease only. RNP values may not change in the FAS. After crossing the LTP/FTP, RNP values may increase only. See Chapter 6 paragraph 6.4.4 for limitations of missed approach segment minimum values.

6.1.2. Applicability.

Approach procedures developed under these criteria are published under the authority of CARs 803.02 and identified as "Authorization Required." General criteria contained in the latest editions of TP308/ GPH209 and RNAV and RNP specific criteria contained in TP308/GPH209 Annex C apply unless modified by these criteria.

6.1.3. Procedure Identification.

Use TP308/GPH 209 Volume 1 Chapter 1 Para 161.

6.1.4. Published Minimums.

The lowest usable visibility minimum/advisory is 1 SM.

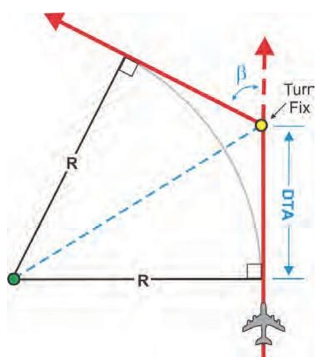
6.1.5. Calculating True Airspeed, Turn Radius, and Bank Angle.

See Chapter 7, paragraph 7.1.5, 7.1.1 and 7.1.7.

6.1.6. DTA Application.

DTA is a calculated value for use in determining minimum straight segment length where a TF-TF turn is required at the beginning or ending fix (see figure 6-1-1). See paragraph 6.2.4 for determination of minimum segment length. Use calculator 1-1 to determine DTA for any given turn.

Figure 6-1-1. DTA



Calculator 1-1. DTA

$$DTA_{NM} = round\left[R \times tan\left(\frac{\beta^{o}}{2} \times \frac{\pi}{180^{o}}\right), 2\right]$$

$$DTA_{feet} = round\left[R \times tan\left(\frac{\beta^{o}}{2} \times \frac{\pi}{180^{o}}\right) \times \mathrm{fpnm}, 0\right]$$

6.1.7. Visibility Minimums.

See TP308/GPH 209, Volume 1, chapter 3.

SECTION 2: TERMINAL SEGMENTS

6.2. Terminal Segments.

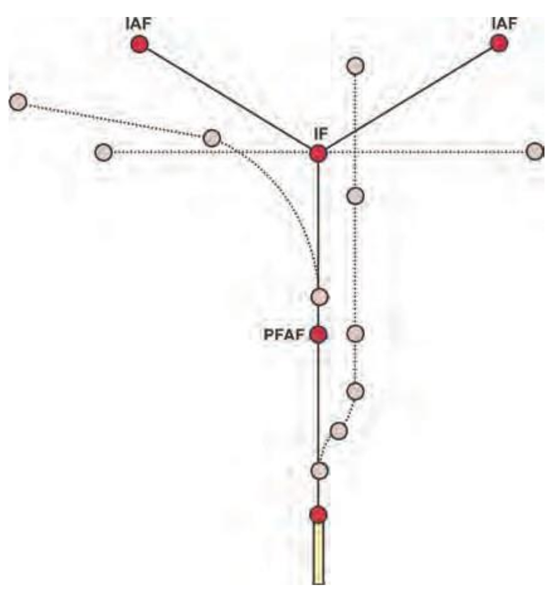
6.2.1. General.

Feeder, initial, and intermediate segments provide a smooth transition from the en route environment to the FAS. Descent to glidepath intercept and configuring the aircraft for final approach must be accomplished in these segments. Design RNP segments using the most appropriate leg type (TF or RF) to satisfy obstruction and operational requirements in feeder, initial, intermediate, final, and missed approach segments. Generally, designs with TF legs are preferred but RF legs may be used in lieu of TF-TF turns for turn path control, procedure simplification, or improved flyability.

6.2.2. Configuration.

RNP navigation enables the geometry of approach procedure design to be very flexible, especially when it incorporates a Terminal Arrival Area as described in Chapter 5. The “Y” segment configuration is preferred where obstructions and air traffic flow allow. The approach design should provide the least complex configuration possible to achieve the desired minimums (see figure 6-2-1 for examples). FB turns at the PFAF are limited to a maximum of 15 degrees.

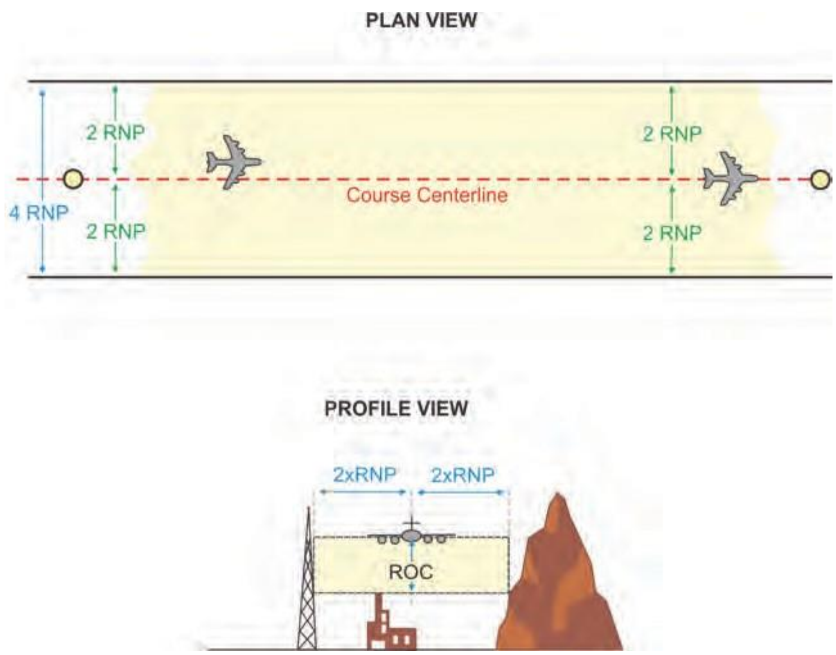
Figure 6-2-1. Optimum Configuration



6.2.3. RNP Segment Width.

a. 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 6-2-2). Standard RNP values for instrument procedures are listed in table 6-1-1.

Figure 6-2-2. RNP Segment Width



b. Apply the standard RNP values listed in table 6-1-1 unless a lower value is required to achieve the desired ground track or lowest minimums. The lowest RNP values are listed in the "MINIMUM" column of table 6-1-1.

6.2.4. RNP Segment Length.

a. Design segments with sufficient length to accommodate the required descent as close to the OPTIMUM gradient as possible and DTA (see paragraph 6.1.6) where fly-by turns are required. Minimum TF segment length is the greater of:

i. DTA (does not apply to turns ≤ 10 degrees)
ii. The lesser of 2×RNP or 1 NM where RNP is less than 0.5.

b. Minimum RF segment length is 2×RNP. Paragraph 6.2.12 applies where RNP changes occur (RNP value changes 1RNP prior to fix).

6.2.5. RNP Segment Descent Gradient.

Design instrument approach procedure segments to provide descent at the standard gradient to the extent possible. Table 6-2-1 lists the standard and maximum allowable descent gradients.

Table 6-2-1. Descent Gradient Constraints

SEGMENT	DESCENT GRADIENT (FT/NM)	
	STANDARD	MAXIMUM
Feeder	250	500
Initial	250 800[1]	500 1000[1]
Intermediate	≤ 150	Equal to Final Segment Gradient[2]
Final	318 (3°)	See Chap 7, table 1-4

Note: DND Only

6.2.6. Descent Gradient Calculation.

a. Determine total altitude lost between the plotted positions of the fixes. Determine the along-track distance in NM. For RF legs, determine the distance using Chapter 7, calculator 1-9. Determine descent gradient using Chapter 7, calculator 1-11.

Calculator 2-1. RESERVED

b. Deceleration Segment requirement is only applicable to the intermediate segment (see Chap 7, Para 7.1.19)

6.2.7. RNP Segment ROC.

Minimum ROC requirements are listed by segment type in table 6-2-2.

Table 6-2-2. Minimum ROC Value

Segment	ROC Value
Feeder	2000/1000
Initial	1000
Intermediate	500 or VEB Value
Final	VEB

6.2.8. TF Leg Segment.

A TF leg is a geodesic flight path between two fixes. The first fix is either the previous leg termination fix or the initial (first) fix of a TF leg (see figure 6-2-3).

Figure 6-2-3. TF Leg

6.2.9. OEA Construction of Turns at FB Waypoints that Join Two TF Legs.

a. This construction is the standard for FB turn construction. Limit turns at a FB fix to a maximum of 70 degrees (+/- 0.03 degrees) where aircraft are expected to cross (FB) the fix at altitudes above FL 195, 90 degrees (+/- 0.03 degrees) at and below FL 195. Where TF-FB-TF construction is not feasible, use RF leg construction to accomplish the course change (see paragraph 6.2.11). Construct FB turning OEAs using the following steps:

STEP 1: Construct the turning flight path. Determine the R as described in Chapter 7, paragraph 7.1.5 (calculator 1-3c). Placing the origin on the angle bisector line, scribe an arc of radius R tangent to the inbound and outbound legs (see figure 6-2-4A).

STEP 2: Construct the outer OEA boundary line. Using the turn fix as the origin, scribe an arc of radius 2×RNP tangent to the inbound (or preceding) and outbound (or succeeding) TF legs.

STEP 3: Construct inner turn expansion boundary line. Placing the origin on the angle bisector line, scribe an arc of radius R+1×RNP from the tangent point on the inbound (or preceding) leg inner boundary to the tangent point on the outbound (or succeeding) leg inner boundary.

b. The evaluation for the succeeding segment begins 1 RNP from the turn fix (example in figure 6-2-4A) or the angle bisector line (example in figure 6-2-4B), whichever is encountered first.

Figure 6-2-4A. Small Turn at a Fly-by Fix

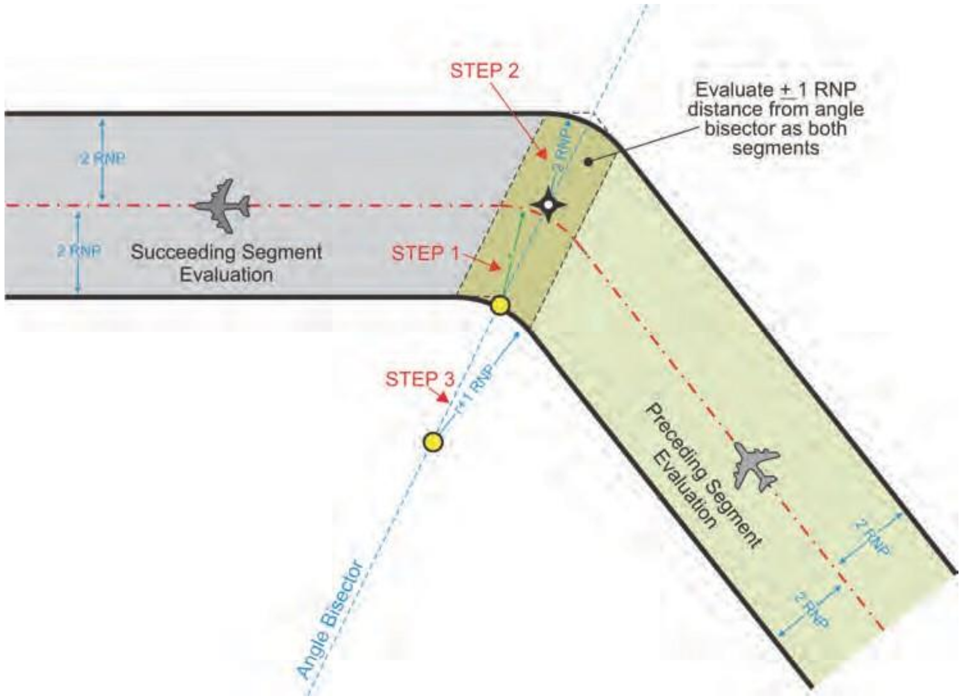
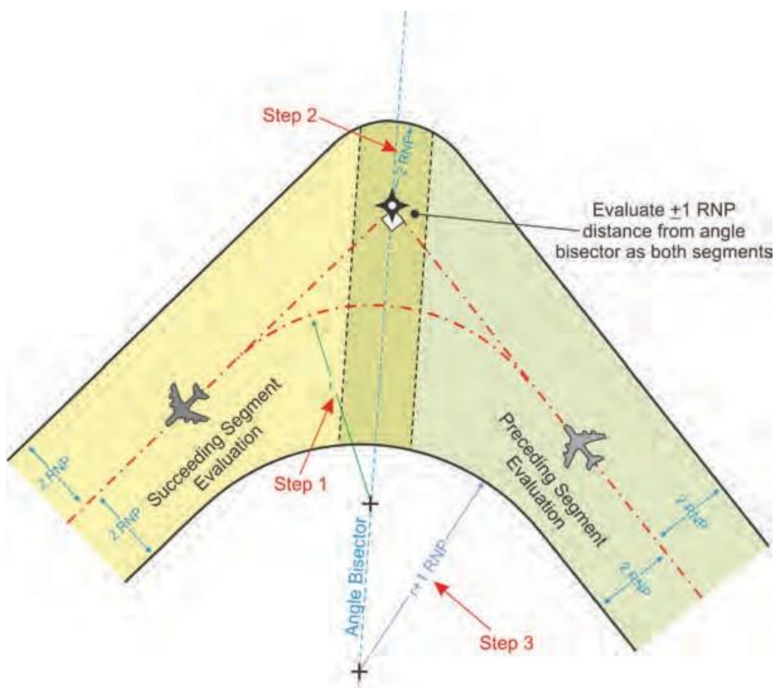


Figure 6-2-4B. Large Turn at a Fly-by Fix



6.2.10. RF Leg Segment.

See Chapter 7, paragraph 7.1.11 Steps 5 and 7 do not apply.

Figure 6-2-5. Reserved

6.2.11. Changing Segment Width (RNP Values).

Changes in RNP values must occur at a fix. The aircraft avionics transition to the new RNP value no later than reaching the fix marking the value change. Therefore, the area within $\pm$ 1 RNP of the fix must be evaluated for both segments. RNP reduction is illustrated in figure 6-2-6A, RNP increase is illustrated in figure 6-2-6B, and RNP changes involving RF legs are illustrated in figure 6-2-6C.

Figure 6-2-6A. RNP Reduction (Prior to PFAF only)

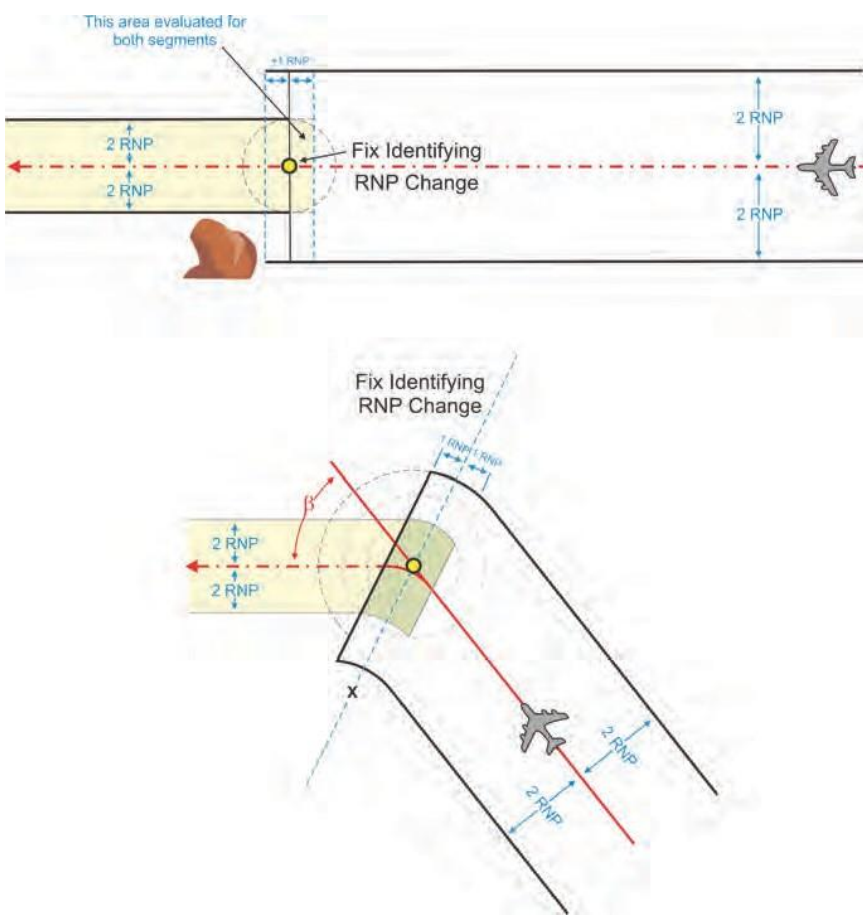


Figure 6-2-6B. RNP Increase (After Crossing the LTP/FTP)

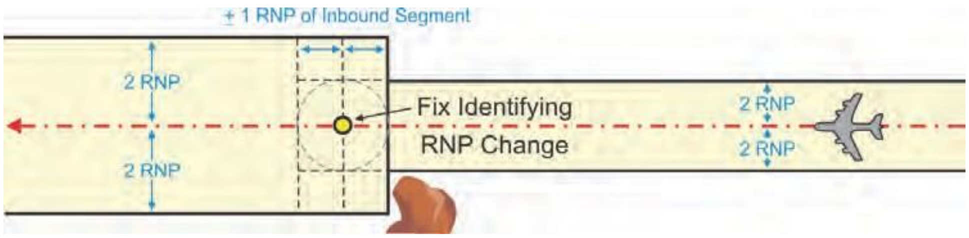
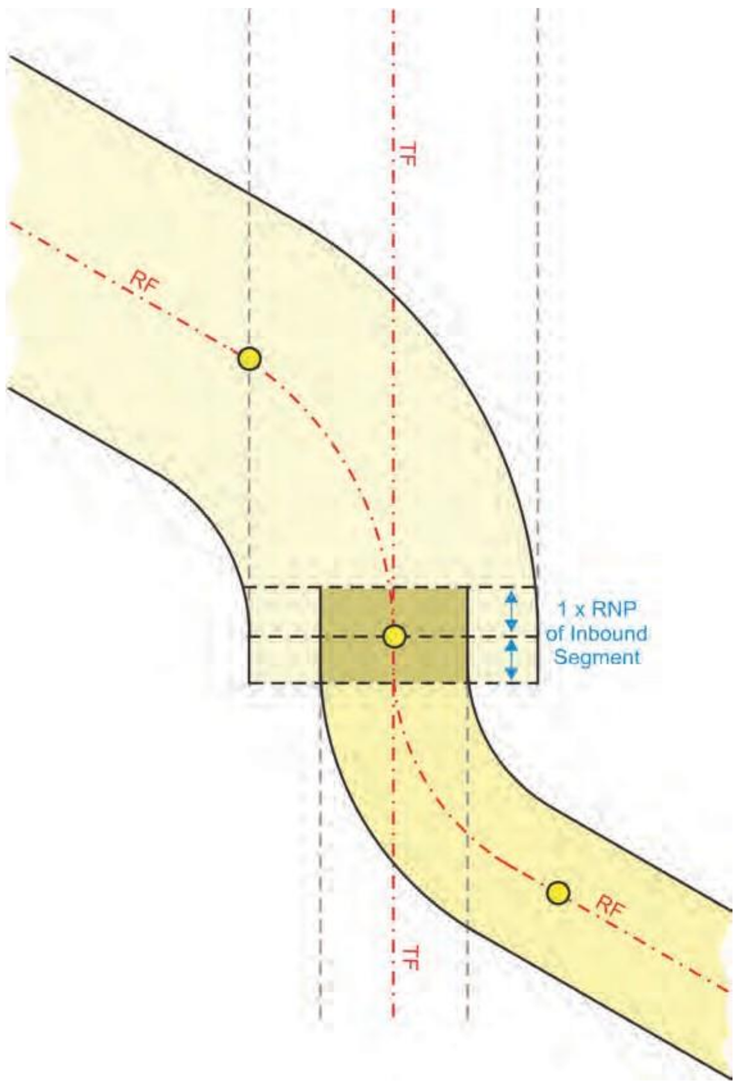


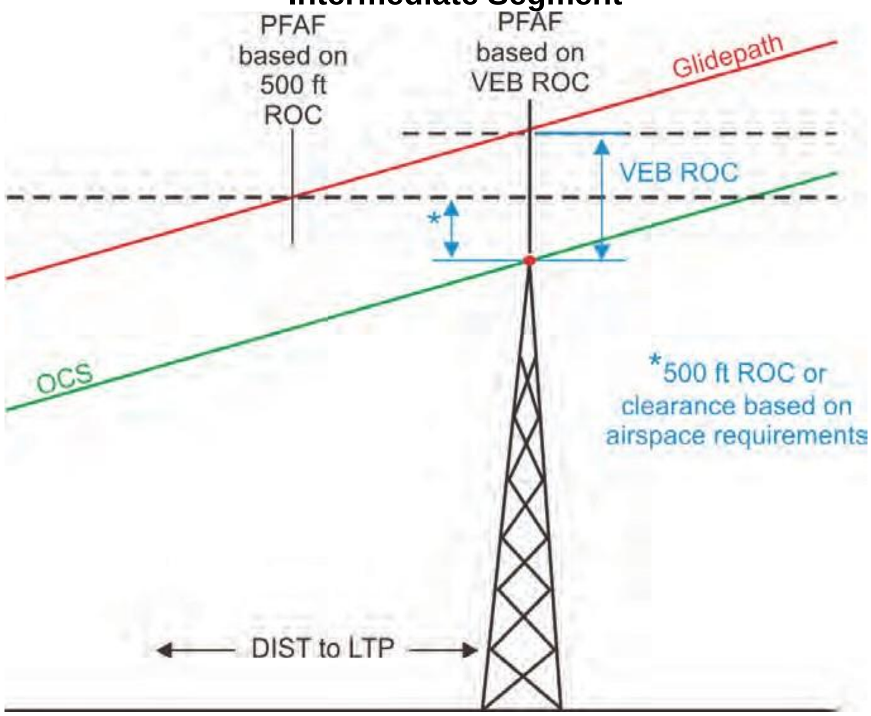
Figure 6-2-6C. RNP Change Involving RF Legs (increase and decrease)



6.2.12. Effects of Cold Temperature on ROC in the Intermediate Segment.

When establishing the intermediate segment minimum altitude (glidepath intercept altitude), compare the difference between the 500-ft intermediate ROC value and the ROC value provided by the VEB OCS at the elevation of the intermediate segment controlling obstacle. If the VEB ROC value exceeds 500, apply this ROC value in lieu of 500 ft in the intermediate segment (see figure 6-2-7). Applying VEB ROC may raise the intermediate segment altitude.

Figure 6-2-7. Application of VEB in Lieu of ROC in Intermediate Segment



SECTION 3: FINAL APPROACH SEGMENT (FAS)

6.3. Final Approach Segment (FAS)

6.3.1. General.

RNP approaches are 3D procedures; the final segment provides the pilot with final segment vertical and lateral path deviation information based on BaroVNAV systems. Therefore, RNP procedures may not be developed for locations where the primary altimeter is a remote altimeter or where the final segment overlies precipitous terrain. The GQS described in TP308/GPH 209, Volume 3, Chapter 2, paragraph 2.11 must be clear in order to publish a 3D procedure to the runway (for procedures with an RF turn in the final segment, the GQS terminates at the DA or FROP, whichever is closer to the LTP/FTP). The FAS OCS is based on limiting the vertical error performance of BaroVNAV avionic systems to stated limits. Minimum and maximum temperature limitations are specified on the approach chart for aircraft that do not have temperature-compensating systems. The minimum HATh value is 250 ft.

6.3.2. Reserved.

6.3.3. GPA and TCH Requirements.

The OPTIMUM (design standard) GPA is 3 degrees. GPAs greater than 3 degrees but not more than the maximum (Chapter 7, table 7-1-4) are authorized without approval when needed to provide obstacle clearance, minimum temperature limitations restrict approach availability when the approach is operationally needed, or to meet simultaneous parallel approach standards. Other cases and/or GPAs less than 3 degrees require Transport Canada Flight Standards (AARTAC) or Canadian Department of National Defence (DND) authority approval. Chapter 7 table 7-1-4b lists the highest allowable GPA by aircraft category. If the required GPA is greater than the maximum for an aircraft category, do not publish minimums for that category. Chapter 7 table 7-1-4b lists standard TCH values and recommended ranges of values appropriate for cockpit-to-wheel height groups 1 through 4. Three-dimensional procedures serving the same runway should share common TCH and GPA values. If an ILS serves the runway, use the ILS TCH and GPA values. If there is no ILS but a VGSI system with a suitable TCH and GPA serves the runway, use the VGSI TCH and GPA. Otherwise, select an appropriate TCH value from Chapter 7 table 7-1--5, and 3-degree GPA.

6.3.4. High Temperature Limitation.

Publish a high temperature limit based on a maximum angle for the fastest published category. See Chapter 7 paragraph 7.3.9 to determine the high temperature limit.

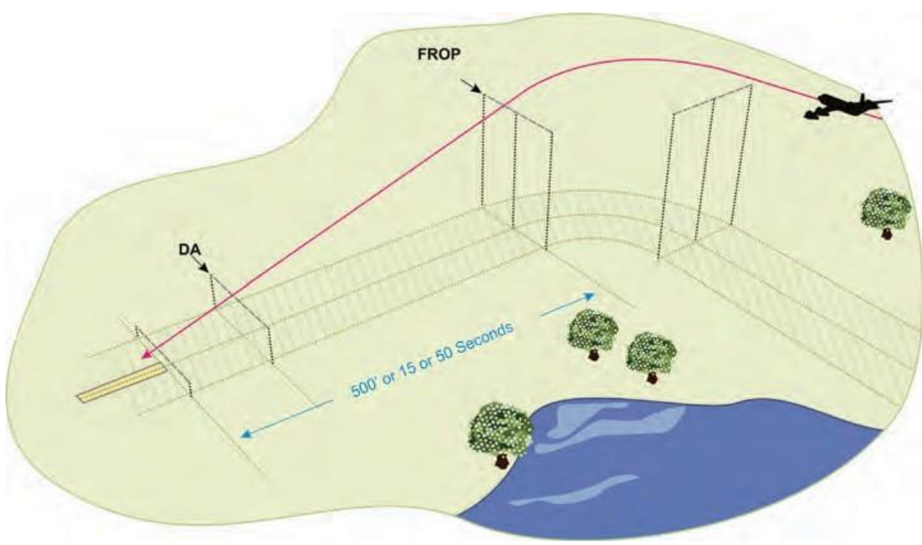
6.3.5. Low Temperature Limitation.

Publish a low temperature limit for the procedure. See Chapter 7 paragraph 7.3.8 to determine the low temperature limit and its value below airport ISA (ΔISA_{LOW}).

6.3.6. Turns in the FAS.

FB turns are not allowed in the FAS. Where turns are necessary, use an RF leg. Design procedures that incorporate an RF turn leading to or in the final segment (RF termination fix at or inside the PFAF) to establish the aircraft on a straight segment aligned with the runway centerline prior to reaching DA. The FROP is the initial fix of the straight segment (see figure 6-3-1). Locate the FROP at a minimum distance (DFROP) the greater of either 500 ft above LTP/FTP elevation or a distance appropriate for 15 or 50 seconds of flight depending on the initial missed approach RNP value ($\mathrm{RNP_{IMAS}}$) using calculator 3-1.

Figure 6-3-1. FROP



Note: Where the PFAF is also the termination fix of an RF leg, the PFAF must meet FROP requirements.

Calculator 3-1. Distance to FROP

1) $D_{500} = \frac{500-TCH}{tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)}$

2) $D_{15sec} = \frac{HATh-TCH}{tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)} + (V_{KTAS} + 15) \times 25.32$

3) $D_{50sec} = \frac{HATh-TCH}{tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)} + (V_{KTAS} + 15) \times 84.39$

4) Case $RNP_{IMAS} = 1.0$: $D_{IMASvalue} = D_{15sec}$
Case $RNP_{IMAS} < 1.0$: $D_{IMASvalue} = D_{50sec}$

5) $D_{FROP} = \max[D_{500}, D_{IMASvalue}]$

Where $RNP_{IMAS} = Initial\ MAS\ RNP\ value$

6.3.7. Determining PFAF Location. (In all cases, the PFAF will be identified as a named fix.)

The OPTIMUM alignment is a TF segment straight in from PFAF to LTP on runway centerline extended (± 0.03° tolerance). If necessary, the TF course may be offset by up to 3 degrees. Where the course is offset, it must cross runway centerline extended at least 1500 ft out from LTP. A final segment may be designed using an RF leg segment when obstacles or operational requirements prevent a straight-in approach from PFAF to LTP. Determine the along-track distance from the LTP (FTP if offset) to the point where the glidepath intercepts the intermediate segment minimum altitude (D_{PFAF}). Calculate D_{PFAF} using Chapter 7 calculator 1-15b.

6.3.8. PFAF Located on TF Leg.

Geodetically calculate the latitude and longitude of the PFAF using the reverse true course of the TF leg (true course – 180 degrees) and D_{PFAF} measured along- track from the LTP (FTP if offset). Where the FAS consist of a single TF leg, HTML Calculators are provided on the AFS-420 web site to calculate D_{PFAF} and the WGS-84 latitude and longitude of the PFAF.

Figure 6-3-2. Reserved

Calculator 3-2. Reserved

6.3.9. PFAF Located on RF Leg.

a. The PFAF must be located at the initial fix of a TF or RF segment. The length in feet of the RF leg from the FROP to PFAF can be calculated by calculator 3-3.

Calculator 3-3. RF Leg Length

$$Length_{RF} = D_{PFAF} - D_{FROP}$$

Where $D_{PFAF = results\ of\ chapter\ 7\ , calculator\ 1-15b}$

$D_{FROP = results\ of\ calculator\ 3-1}$

b. The number of degrees of arc given a specific arc length may be calculated using calculator 3-4.

Calculator 3-4. Degrees of an Arc

$$\boldsymbol{Degrees\ of\ Arc\ [\alpha^o]:}\quad \boldsymbol{\alpha^o = \frac{180^o \times L}{\pi \times R}}$$

Where $L = arc\ Length$

$R = arc\ radius$

c. Conversely, the length of an arc given a specific number of degrees of arc may be calculated using calculator 3-5.

Calculator 3-5. Length of an Arc

$$\boldsymbol{Length\ of\ Arc\ [L]:}\quad \boldsymbol{L = \frac{\alpha^o \times \pi \times R}{180^o}}$$

Where $\boldsymbol{\alpha^o} = degrees\ of\ arc$

$R = arc\ radius$

6.3.10. Determining RF PFAF Location Relative to LTP/FTP.

a. This method may be used for calculating WGS-84 latitude and longitude (see figure 6-3-3). Several software packages will calculate a geographical coordinate derived from Cartesian measurements from the LTP/FTP. Use calculators 3-6 and 3-7 to obtain the Cartesian values.

STEP 1: Determine the flight track distance (D_{PFAF}) from LTP/FTP to PFAF under Chapter 7 calculator 1-15b.

STEP 2: Determine the distance (D_{FROP}) from LTP/FTP to the FROP (see paragraph 6.3.6).

STEP 3: Subtract D_{FROP} from D_{PFAF} to calculate the distance around the arc to the PFAFfrom the FROP. Use calculator 3-4 to determine number of degrees of arc; conversely, use calculator 3-5 to convert degrees of arc to length.

b. If the PFAF is in the RF segment, determine its X, Y coordinates using calculators 3-6 and 3-7:

Calculator 3-6. X Coordinate PFAF in an RF Segment

$$\boldsymbol{X = D_{FROP} + R \times sin\left(\alpha^o \times \frac{\pi}{180^o}\right)}$$

Where $\boldsymbol{D_{FROP}} = result\ of\ formula\ 3-1$

$R = arc\ radius$

$\boldsymbol{\alpha^o} = degrees\ of\ arc$

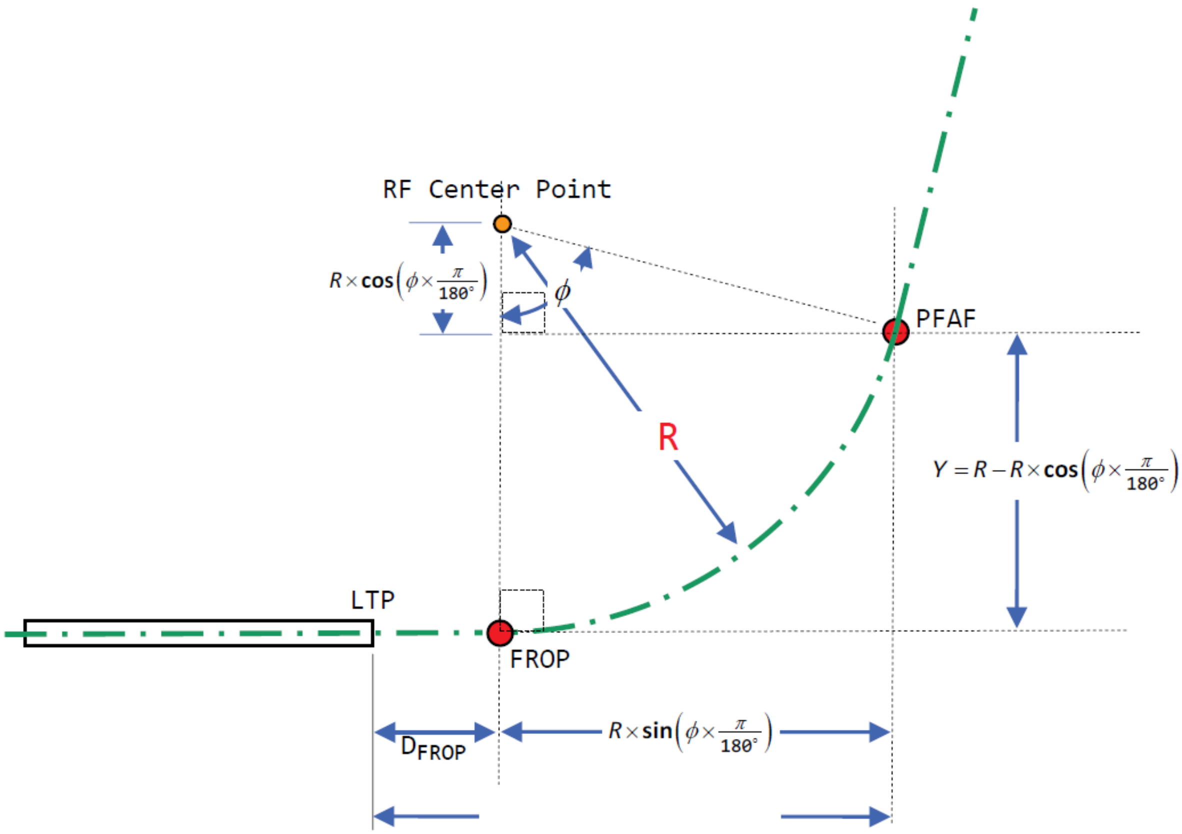
Calculator 3-7. Y Coordinate PFAF in an RF Segment

$$\boldsymbol{Y = R - \left[R \times cos\ \left(\alpha^o \times \frac{\pi}{180^o}\right)\right]}$$

Where $R = arc\ radius$

$\boldsymbol{\alpha^o} = degrees\ of\ arc$

Figure 6-3-3. Determining PFAF Position (X, Y) Relative to LTP



6.3.11. Final Segment OEA.

a. The final segment OEA begins 1×RNP prior to the PFAF and extends to the LTP/FTP. The final segment OEA contains the evaluation surfaces for final approach and landing: VEB OCS which is evaluated to establish the DA point; the visual segment OIS to identify noteworthy obstructions between the DA point and the LTP/FTP; and the GQS which limits the height of obstructions in the vicinity of centerline between the DA point and the LTP/FTP. The OEA area between the DA and LTP/FTP is also evaluated for missed approach as described in chapter 4. The OCS origin distance from LTP/FTP (D_{VEB}) and its slope are determined through application of the VEB. The VEB provides origin and slope values for both TF and RF based final segments. Origin values are further divided into two categories: aircraft with wingspans ≤ 262 ft, and aircraft with wingspans ≤ 136 ft. Develop procedures using the value for wingspans ≤ 262 ft. (this is the nominal design value). Where the DA can be reduced by at least 50 ft or visibility reduced by ¼ mile, the approach may be developed using the value for wingspans ≤ 136 ft; however, the procedure must be restricted for use by aircraft with wingspans ≤ 136 ft only. The VEB calculations require input of values for two variables: final segment RNP value and temperature (°C) deviation ($\Delta\ ISA_{LOW}$)below the airport ISA temperature.

Calculate D_{VEB} and the OCS slope using Calculator 3-8

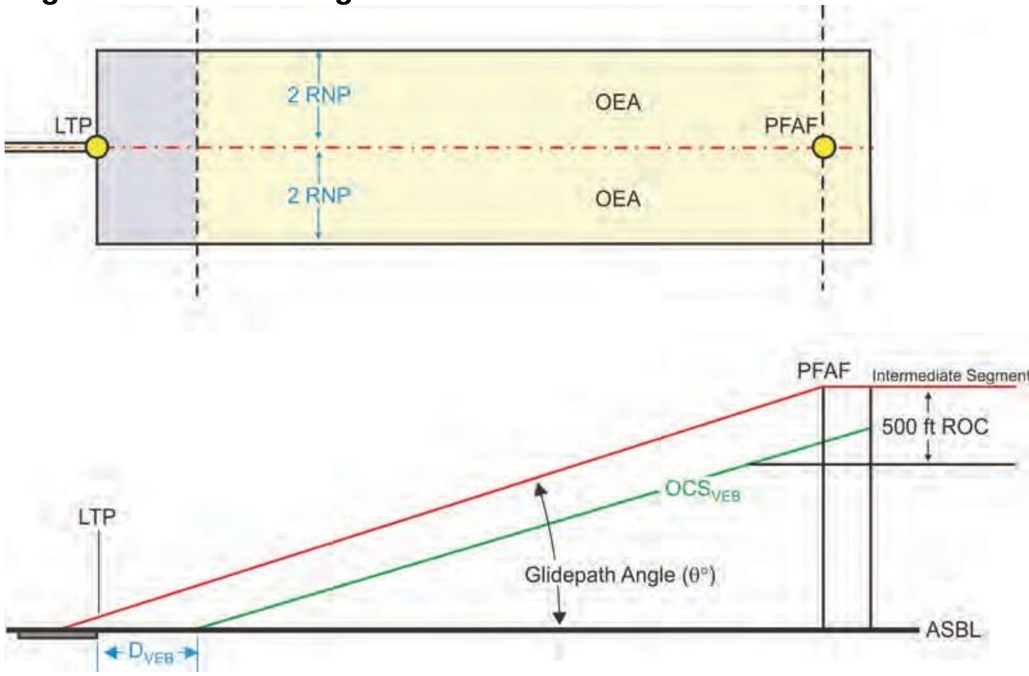
Calculator 3-8. VEB OCS Origin/Slope Calculator (see chapter 4, section 5 for formulas)

Calculator 3 8			
Intermediate Segment Altitude (ft):			Calculate
LTP/FTP MSL Elevation (ft):			
TCH (ft):			
GPA:			
ACT(°C):			
RNP Value (NM):			
Bank Angle (RF Only):			
OCS Slope Ratio :	():1		
D_{VEB}:	Straight-in	RF turn	
Wingspan <= 262			
Wingspan <= 136			
VEB Variables			
	Straight-in	RF turn	Clear
Airport ISA			
Delta ISA			
ASE PFAF			
ASE 250			
VAE PFAF			
VAE 250			
ISAD PFAF			
ISAD 250			
ROC PFAF Wingspan < = 262			
Wingspan < = 136			
ROC 250 Wingspan <= 262			
Wingspan <= 136			
BG Wingspan <= 262			
Wingspan <= 136			

Supplementary note: Calculator 3-8 requires input of the variable ACT(°C), which must be interpreted to be the "NA_{below} (°C)" output form Calculator 3-4.

b. Calculate the MSL elevation of the OCS at any distance 'd' from LTP/FTP using calculator 3-9.

Figure 6-3-4. Final Segment OEA and OCS



Calculator 3-9. OCS MSL Elevation

$$VEB_{\ MSL} = LTP_{elev} + \frac{d - \ D_{VEB}}{OCS_{sLope}}$$

Where $d \ = \ distance \ along \ course \ centerline \ from \ RWT$

$D_{VEB} = distance \ of \ OCS \ origin \ from \ LTP \ deried \ from \ VEB \ Calculations$

$OCS_{sLope} = OCS \ spole \ derived \ from \ VEB \ Calculations$

6.3.12. Obstacle Evaluation.

a. If the FAS OCS is not penetrated, the MINIMUM HATh value of 250 ft applies. Limitation: Determine the DA and D_{DA} using calculator 3-10.

Supplementary note: D_{DA} must be interpreted to be the minimum distance from LTP/FTP to DA.

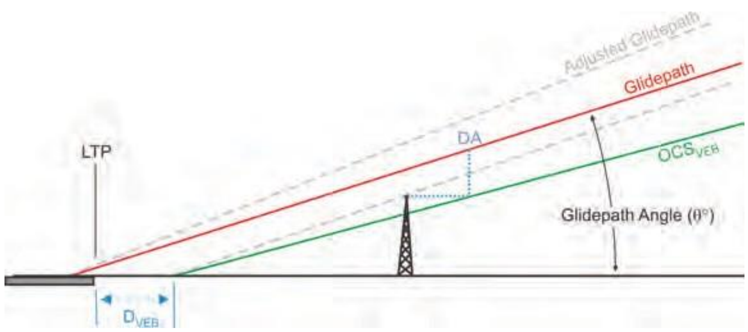
Calculator 3-10. DA

$$DA = HATh + LTP_{elev}$$

$$D_{DA} = ceiling\left[max\left(DEV + \frac{50}{tan\left(\theta^o \times \frac{\pi}{180^o}\right)}, r \times \left(\frac{\pi}{2} - \theta^o \frac{\pi}{180^o} - asin\left(\frac{cos\left(\theta^o \times \frac{\pi}{180^o}\right) \times (r + LTP_{elev} + TCH)}{r + DA}\right)\right)\right)\right]$$

b. Obstacles that penetrate an OCS may be mitigated by one of the following actions: remove or lower obstacle, lower the RNP value for the segment (if appropriate), adjust the lateral path, raise GPA, raise TCH (within Chapter 7 table 7-1-5 limits), or adjust HATh (see figure 6-3-5 and calculator 3-11).

Figure 6-3-5. VEB Adjustment of DA or GPA



Note: D_{VEB} decreases slightly when GPA is increased. Therefore, if the angle is increased to accommodate a penetration, the VEB must be recalculated and the OCS re-evaluated.

Calculator 3-11. HATh Adjustment

$$HATh_{adjusted} = tan\left(\theta^o \times \frac{\pi}{180^o}\right) \times (\mathrm{d} + \mathrm{p} \times \mathrm{OCS_{VEB}}) + \mathrm{TCH} - \mathrm{LTP_{elev}}$$

$$DA_{adjested} = ceiling\left[LTP_{elev} + HATh_{adjusted}\right]$$

$$D_{DA} = ceiling\left[r \times \left(\left(\frac{\pi}{2} - \theta^o \frac{\pi}{180^o} - asin\left(\frac{cos\left(\theta^o \times \frac{\pi}{180^o}\right) \times (r + LTP_{elev} + TCH)}{r + DA_{adjusted}}\right)\right)\right)\right]$$

Where $d = distance\ (ft)\ LTP\ to\ obstacle$

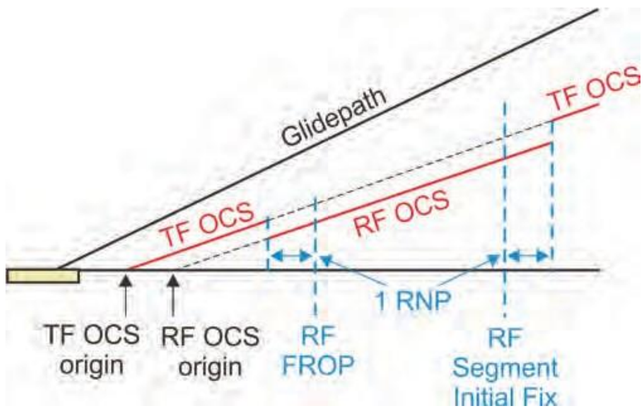
$p = amount\ of\ penetration\ (ft)$

$OCS_{VEB} = SLope\ of\ VEB\ OCS$

6.3.13. Applying VEB OCS to RF Final Segments.

Where RF legs are incorporated in the final segment, the OCS slope ratio will be consistent for the straight and curved path portions; however, the OCS origin will be different because the variables for aircraft body geometry are different for straight and curved path legs. The OCS elevation at any point is equal to the surface elevation of the course centerline abeam it (see figure 6-3-6).

Figure 6-3-6. RF Final Segment OCS Evaluation



SECTION 4: MISSED APPROACH SEGMENT (MAS)

6.4. Missed Approach Segment (MAS).

6.4.1. General.

a. These criteria are based on the following assumptions:

   i. Aircraft climb at a rate of at least 200 ft/NM (3.29%) in the missed approach segment.

   ii. The OEA expansion where FAS RNP levels less than RNP-1 are continued into the MAS is based on IRU drift rates of 8 NM per hour.

   iii. For RNP levels less than 1, turns are not allowed below 500 ft measured AGL.

   iv. A 50-ft height loss is inherent in MA initiation.

b. Construct the missed approach segment using one of the following methods in order of precedence:

   i. RNP AR standard missed segment (required in paragraph 6.1.4). The construction is a continuation of the FAC. The OEA expands at a 15-degree splay relative to course from the width of the FAS RNP value to an RNP value of 1.0. (This construction accommodates single thread equipage – serves broad scope.)

   ii. RNAV missed segment. Where turns are required before the RNP AR standard MAS would reach full width, construct the MAS under Chapter 7 paragraph 7.3.16 (This construction accommodates single thread equipage – serves broad scope.)

   iii. RNP AR missed segment with RNP<1.0. Construct straight or turning (using RF legs) missed approach under Chapter 7, paragraph 7.1.11. Steps 5 and 7 do not apply. (This construction accommodates dual thread equipage – serves narrower scope.)

6.4.2. MAS Leg Types.

a. AR.

i. The MA route is a series of segments. The following leg types are authorized for MA procedure design:

1. TF
2. RF

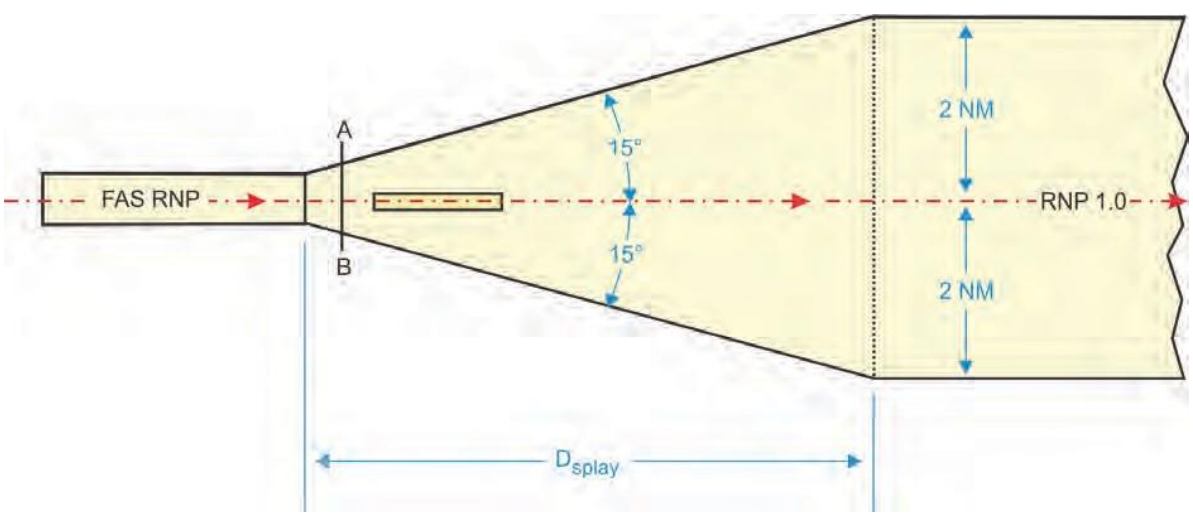
ii. Additionally, if the RF leg RNP value is <1.0, the RF leg length must comply with paragraph 6.4.4.

b. RNAV. See Chapter 7, paragraph 7.3.16.

6.4.3. MAS RNP Level.

a. The standard MA segment splays from the FAS width at DA; 15 degrees relative to course centerline, to a width of $\pm$2 NM (RNP 1.0) (see figure 6-4-1A).

Figure 6-4-1A. Transition from FAS to MAS RNP Levels



b. The along-track distance (NM) required to complete the splay may be calculated using calculator 4-1.

Calculator 4-1. Along-Track Distance To Complete Splay

$$D_{splay} = 7.464 \times (1 - RNP_{FAS})$$

Where $RNP_{FASS} = RNP\ value\ of\ final\ segment$

c. Turns are not allowed until the splay is complete. If turns are required before $\mathrm{D_{splay}}$, consider another construction technique; e.g., applying paragraph 6.4.4.

6.4.4. RNP Values < 1.

a. Where turns are necessary, the turn initiation must occur after passing 500 ft AGL and at least $\mathrm{D_{MASturn}}$ feet from DA. When possible, the turn should not occur until after DER. Calculate $\mathrm{D_{MASturn}}$ using calculator 4-2.

Calculator 4-2. Distance MA Turn

$$D_{MASturn} = \frac{10}{3600} \times fpnm \times (V_{KTAS} - 10)$$

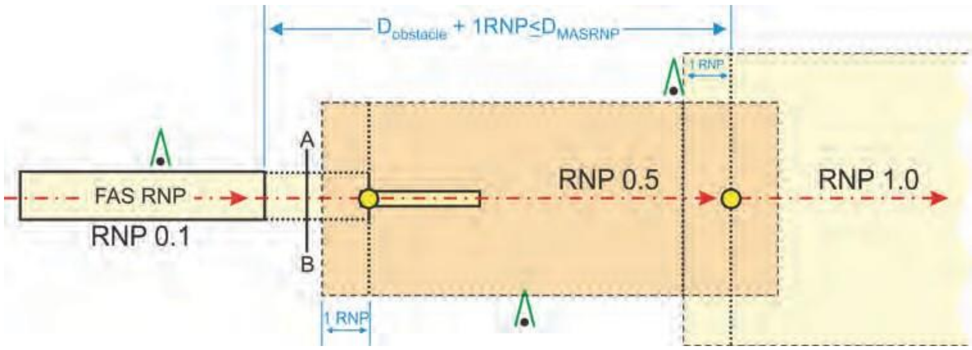
Where $V_{KTAS}\ is\ based\ on\ final\ approach\ speed\ at\ DA$

b. Where the 40:1 OCS is penetrated and the resulting HAT or visibility can be reduced by at least 50 ft or ¼ SM respectively, consider limiting the MAS RNP value until clearing the obstruction.

c. Use the largest RNP value (FAS RNP ≤ MAS RNP ≤ 1.0) that clears the obstruction. The maximum distance (NM) (DMASRNP) that the < 1.0RNP value may be extended into the MAS is calculated using calculator 4-3 (see figure 6-4-1B)

Note: Use of MAS RNP values < 1.0 requires track guidance (TF or RF leg segments). Paragraph 6.2.12 applies to RNPincreases.

Figure 6-4-1B. RNP Value <1.0



Calculator 4-3. Max Distance RNP 1.0 Can Extend into MAS

$$D = (RNP_{MAS} - 0.05) \times \frac{V_{KTAS} - 10}{8}$$

Where $RNP_{\ MAS} = Missed\ approach\ RNP\ Value\ < 1.0$

d. VKTAS is based on slowest published category final approach airspeed at DA.

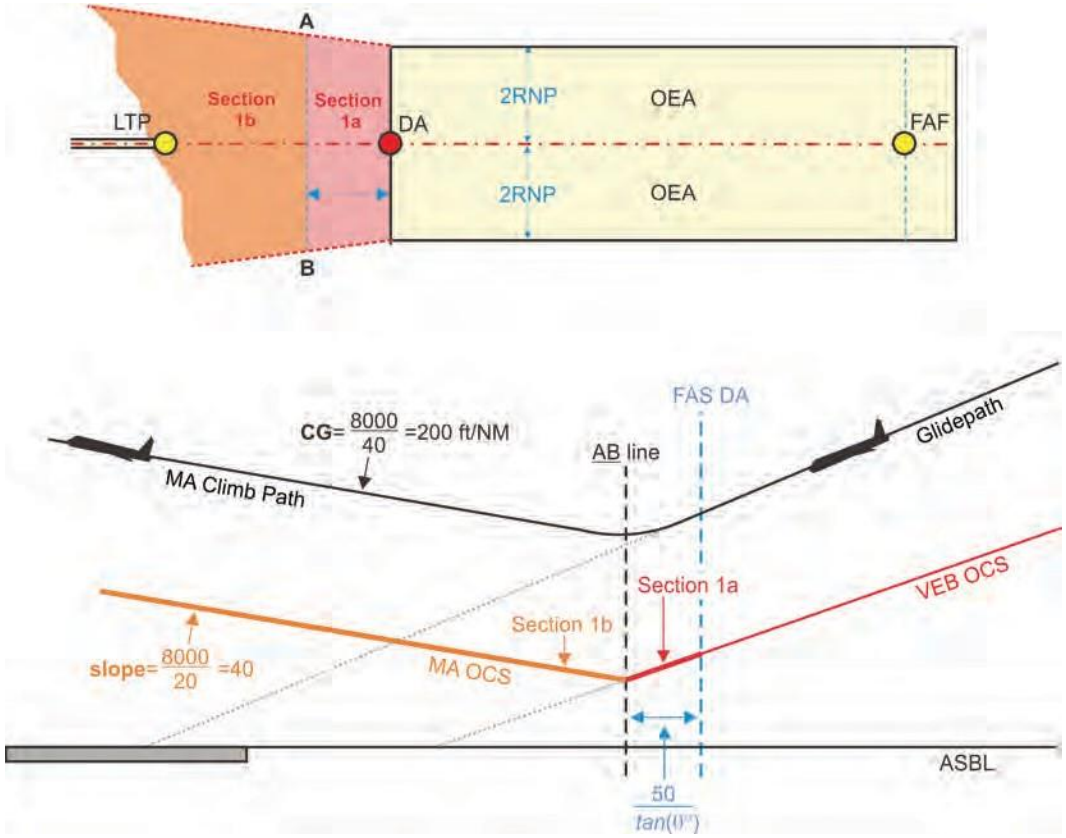
6.4.5. MA Segment OCS Evaluation.

a. The MAS is composed of OCS sections 1a and 1b (see figure 6-4-2). Sections 1a and 1b are separated by the AB line. Section 1a OCS extends from the DA point downward at the VEBOCS slope ratio for a distance of Dheightloss (calculated using calculator 4-4) measured along the final course track to the AB line. From the AB line, section 1b OCS rises at a 40:1 slope. Obstacles must not penetrate the OCS.

Calculator 4-4. Height Loss Distance

$$\boldsymbol{D_{heightLoss}} = \frac{50}{\tan\left(\theta^{o} \times \frac{\pi}{180^{0}}\right)}$$

Figure 6-4-2. MAS OEA/OCS



b. Calculate the MSL HMAS at the AB line (HMASab) using calculator 4-5.

Calculator 4-5. HMAS at the AB line

$$D_{DA} - D_{OCSorigin} - \frac{50}{tan\left(\theta^{o} \times \frac{\pi}{180^{0}}\right)}$$

$$HMAS_{AB} = LTP_{elev} + \frac{D_{DA} - D_{OCSorigin} - \frac{50}{tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)}}{VEB_{OCSsLope}}$$

Where $D_{DA} = Distance\ from\ LTP\ to\ DA$

$D_{OCSorigin} = Distance\ from\ LTP\ to\ OCS\ origin$

$VEB_{OCSsLope} = \ Final\ segment\ OCS\ slope$

c. The MSL height of the section 1b surface ($\mathrm{H_{section1b}}$) at any obstruction can be calculated using calculator 4-6 after determining distance ($\mathrm{D_{section1b}}$) by measuring the along-track centerline distance from the AB line to a point abeam the obstruction.

Calculator 4-6. Height of Section 1b Surface

$$H_{section1b} = HMAS_{AB} + \frac{D_{section1b}}{MA_{OCSsLope}}$$

Where $MA_{AB} = result\ of\ calculator\ 4-5$

$D_{section1b} = atrk\ distcance\ from\ AB\ Line\ to\ abeam\ obstacle$

$MA_{OCSsLope} = \ Normally\ 40{:}\,1\ (calculator\ entry\ 40)$

6.4.6. OCS Penetrations.

a. Where obstructions penetrate the OCS, take one or more of the following actions to achieve the lowest possible DA:

i. Remove or lower the obstruction.

ii. Use RNP level < 1.0 to place obstacle outside the OEA.

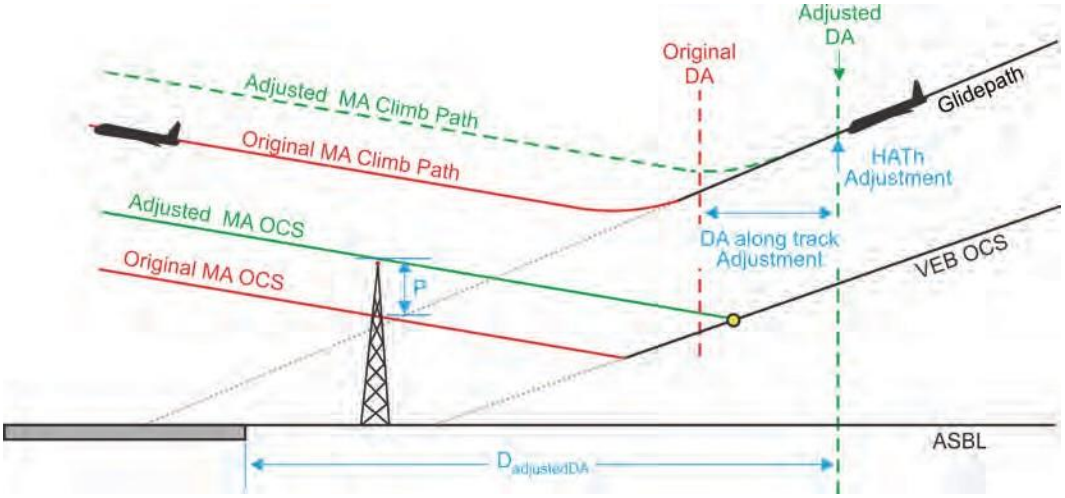
iii. Alter MA track.

iv. Adjust DA.

v. Require MA climb gradient.

b. DA Adjustment. See figure 6-4-3. To determine the DA required to mitigate a MA OCS penetration, determine the amount of increase required in the HATh value using calculator 4-7.

Figure 6-4-3. DA Adjustment



Calculator 4-7. HATh Adjustment

$$HATh_{adjustment} = \frac{\rho \times tan\left(\theta^o \times \frac{\pi}{180^o}\right) \times MA_{OCSsLope} \times VEB_{OCSsLope}}{MA_{OCSsLope} \times VEB_{OCSsLope}}$$

Where $\rho = amount\ of\ penetration\ (ft)$

$MA_{OCSsLope} = normally\ 40{:}1$

$VEB_{OCSsLope} = results\ of\ VEB\ calculations$

c. Calculate the adjusted distance from LTP/FTP to DA using calculator 4-8.

Calculator 4-8. Adjusted LTP/FTP to DA Distance

$$D_{adjustment} = \frac{HATh_{FAS} + HATh_{adjustment} - TCH}{tan\left(\theta^o \times \frac{\pi}{180^o}\right)}$$

Where $HATh_{FAS} = HATh\ value\ for\ DA\ based\ on\ finel\ segment\ eval$

$HATh_{adjustment} = results\ of\ calculator\ 4-7$

d. Finally, calculate the adjusted DA value using calculator 4-9.

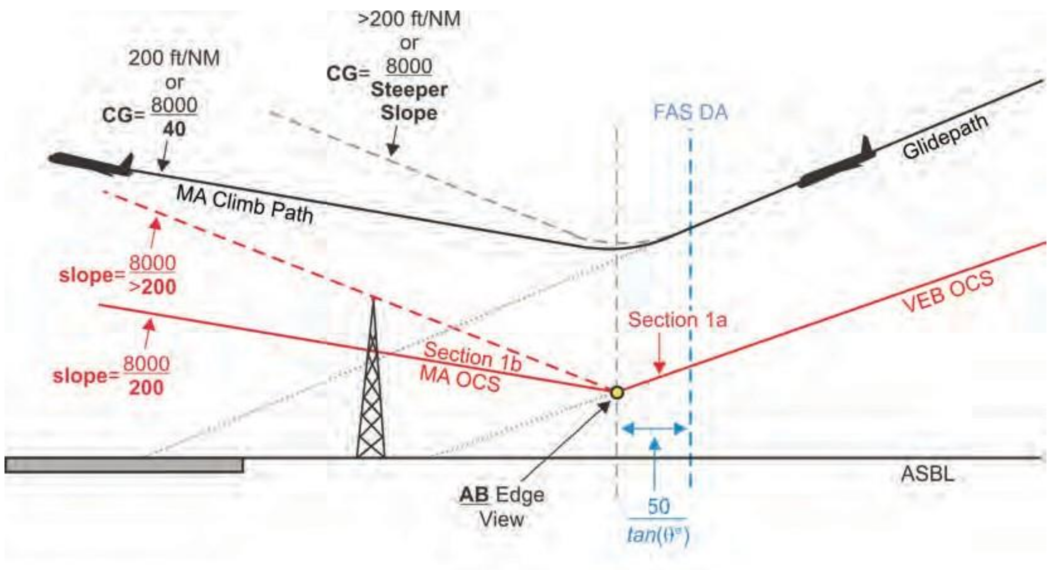
Calculator 4-9. Adjusted DA

$$DA_{adjustment} = tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right) \times D_{adjustedDA} + (\mathrm{LTP_{elev}} + \mathrm{TCH})$$

Where $D_{adjustedDA} = results\ of\ calculator\ 4-8$

e. Calculating MA climb gradient. See figure 6-4-4. Where the section 1b OCS is penetrated and resulting HAT or visibility can be reduced by at least 50 ft or ¼ SM respectively, consider avoiding the obstruction by requiring an MA climb gradient.

Figure 6-4-4. MA Climb Gradient



f. To determine the climb gradient required to clear a section 1b obstacle, apply calculator 4-10.

Calculator 4-10. MA CG

$$MA_{CG} = ceiling\left[\frac{8000 \times (Obs_{elev} - HMAS_{AB})}{5 \times D_{ABobs}}\right] \times 5$$

Where $HMAS_{AB} = results\ of\ calculator\ 4-5$

$D_{ABobs} = ATD\ distance\ (ft) from\ AB\ Line\ to\ Obstacle$

Note: If the climb gradient exceeds 425 ft/NM, evaluate the MAS using the OCS slope appropriate for 425 ft/NM (18.82:1) and adjust DA for the remaining penetration per paragraph 6.4.6b.

g. Calculating CG termination altitude. Calculate the altitude above which the climb gradient is no longer required using calculator 4-11. Round the result to the next higher 100 ft increment.

Calculator 4-11. CG Termination altitude

$$TA_{CG} = ceiling\left[\frac{(DA - 50) + \left(CG - \frac{D_{ABobs}}{fpnm}\right)}{100}\right] \times 100$$

Where $CG = climb\ gradient$

$D_{ABobs} = atrk\ ATD\ distance\ (ft) from\ AB\ Line\ to\ Obstacle$

SECTION 5: VERTICAL ERROR BUDGET (VEB)

6.5. Vertical Error Budget (VEB).

6.5.1. The ROC 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 ROC.

6.5.2. VEB variables.

a. The sources of variation included in the ROC for the VEB are:

i. Actual navigation performance error (anpe)

ii. Waypoint precision error (wpr)

iii. Flight technical error (fte) fixed at 75 ft Altimetry system error (ase)

iv. Vertical angle error (vae)

v. Automatic terminal information system (atis) fixed at 20 ft

b. The bias errors for the ROC are:

i. Body geometry error (bg)

ii. International standard atmosphere temperature deviation (isad)

iii. Semi-span for narrow body fixed at 68

iv. Semi-span for wide body fixed at 131

c. The ROC equation which combines these is:

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

d. Three Standard Deviation Formulas for Root-Sum of Squares Computations:

The anpe: $\text{anpe} = 1.225 \times \text{rnp} \times \text{fpnm} \times \tan\left(\theta^o \times \frac{\pi}{180^o}\right)$

The wpr: $\text{wpr} = 60 \times \tan\left(\theta^o \times \frac{\pi}{180^o}\right)$

The fte: *fte =75*

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

The vae: $vae = \left(\frac{elev - Ltp_{elev}}{tan\left(\theta^o \times \frac{\pi}{180^o}\right)}\right) \times \left(tan\left(\theta^o \times \frac{\pi}{180^o}\right) - tan\left((\theta^o - 0.01^o) \times \frac{\pi}{180^o}\right)\right)$

The atis: $atis = 20$

6.5.3. Bias Error Computations.

a. The isad: $isad = \frac{(elev - Ltp_{elev}) \times \Delta ISA}{288 + \Delta ISA - 0.5 \times 0.00198 \times elev}$

b. The bg bias:

c. Straight segments fixed values:

i. narrow body $bg = 15 \; semi\text{-}span = 68$

ii. wide body $bg = 25 \; semi\text{-}span = 131$

d. RF segments:

i. narrow body $bg = max\left(15{,}68 \times sin\left(\emptyset^{o} \times \frac{\pi}{180^{o}}\right)\right)$

ii. wide body $bg = max\left(25{,}131 \times sin\left(\emptyset^{o} \times \frac{\pi}{180^{o}}\right)\right)$

6.5.4. Sample Calculations.

a. Design Variables

Applicable facility temperature minimum is 20° C below standard: $(\Delta ISA = -20)$

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

Wing semispan of 68ft: $(semispan = 68)$

RF segment.

b. Aircraft and Aircrew Authorization Required (AR) Fixed Values

Vertical flight technical error (FTE) of two standard deviations is assumed to be 75ft: $(fte = 75)$

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

The maximum assumed bank angle is 18degrees: $(\phi^{\circ} = 18^{\circ})$

c. Glidepath Variables

Precision Final Approach Fix Altitude (PFAF) is 4500ft: $(4{,}500 ft)$

Landing Threshold Point Elevation (ltpelev): $(Ltp_{elev} = 1200)$

Threshold Crossing Height (TCH): $(tch = 55)$

Glide Path Angle (θ): $\theta° = 3$

d. Calculations:

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

The anpe:
$$\begin{aligned} \text{anpe} &= 1.225 \times \text{rnp} \times \frac{1852}{0.3048} \times \tan\left(\theta^o \times \frac{\pi}{180^o}\right) \\ &= 1.225 \times 0.14 \times \frac{1852}{0.3048} \times \tan\left(3^o \times \frac{\pi}{180^o}\right) \\ &= 54.6117 \end{aligned}$$

The wpr:
$$\begin{aligned} \text{wpr} &= 60 \times \tan\left(\theta^o \times \frac{\pi}{180^o}\right) \\ &= 60 \times \tan\left(3^o \times \frac{\pi}{180^o}\right) \\ &= 3.1445 \end{aligned}$$

The fte: =75

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

$$\begin{aligned} ASE250 &= -8.8 \times 10^{-8} \times (\text{Ltp}_{\text{elev}} + 250)^2 + 6.5 \times 10^{-3} \times (\text{Ltp}_{\text{elev}} + \text{elev}) + 50 \\ &= -8.8 \times 10^{-8} \times (1200 + 250)^2 + 6.5 \times 10^{-3} \times (1200 + 250) + 50 \\ &= 59.2400 \end{aligned}$$

$$\begin{aligned} ASEpfaf &= -8.8 \times 10^{-8} \times (\text{PFAF})^2 + 6.5 \times 10^{-3} \times (\text{PFAF}) + 50 \\ &= -8.8 \times 10^{-8} \times (4500)^2 + 6.5 \times 10^{-3} \times (4500) + 50 \\ &= 77.4680 \end{aligned}$$

The vae:
$$vae = \left(\frac{elev - Ltp_{elev}}{tan\left(\theta^o \times \frac{\pi}{180^o}\right)}\right) \times \left(tan\left(\theta^o \times \frac{\pi}{180^o}\right) - tan\left((\theta^o - 0.01^o) \times \frac{\pi}{180^o}\right)\right)$$

$$\begin{aligned} VAE_{pfaf} &= \left(\frac{PFAF - Ltp_{elev}}{tan\left(\theta^o \times \frac{\pi}{180^o}\right)}\right) \times \left(tan\left(\theta^o \times \frac{\pi}{180^o}\right) - tan\left((\theta^o - 0.01^o) \times \frac{\pi}{180^o}\right)\right) \\ &= \left(\frac{4500 - 1200}{tan\left(3^o \times \frac{\pi}{180^o}\right)}\right) \times \left(tan\left(3^o \times \frac{\pi}{180^o}\right) - tan\left((\theta 3^o - 0.01^o) \times \frac{\pi}{180^o}\right)\right) \\ &= 11.0200 \end{aligned}$$

$$VAE_{250} = \left(\frac{250}{tan\left(\theta^o \times \frac{\pi}{180^o}\right)}\right) \times \left(tan\left(\theta^o \times \frac{\pi}{180^o}\right) - tan\left((\theta^o - 0.01^o) \times \frac{\pi}{180^o}\right)\right)$$

$$= \left(\frac{250}{tan\left(3^o \times \frac{\pi}{180^o}\right)}\right) \times \left(tan\left(3^o \times \frac{\pi}{180^o}\right) - tan\left((\theta 3^o - 0.01^o) \times \frac{\pi}{180^o}\right)\right)$$

= 0.8349

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

$$ISAD_{pfaf} = \frac{(PFAF - Ltp_{elev}) \times \Delta ISA}{288 + \Delta ISA - 0.5 \times 0.00198 \times (PFAF)}$$

$$isad = \frac{(4500 - 1200) \times (-20)}{288 - 20 - 0.5 \times 0.00198 \times (4500)}$$

= -250.4316

$$ISAD_{250} = \frac{250 \times \Delta ISA}{288 + \Delta ISA - 0.5 \times 0.00198 \times (Ltp_{elev} + 250)}$$

$$isad = \frac{(250) \times (-20)}{288 - 20 - 0.5 \times 0.00198 \times (1200 + 250)}$$

= -18.7572

The bg: $bg = semispan \times sin\left(\emptyset^o \times \frac{\pi}{180^o}\right)$

$$= 68 \times sin\left(\emptyset^o \times \frac{\pi}{180^o}\right)$$

= 21.0132

$$ROC_{250} = bg - ISAD_{250} + \frac{3}{4}\sqrt{anpe^2 + wpr^2 + fte^2 + ase^2 + vae^2 + atis^2}$$

$$= 21.0132 + 18.7572 + \frac{3}{4}\sqrt{54.6117^2 + 3.1445^2 + 75^2 + 59.2400^2 + 0.8349^2 + 20^2}$$

= 189.0049

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

$$= 21.0132 + 250.4316 + \frac{3}{4}\sqrt{54.6117^2 + 3.1445^2 + 75^2 + 59.2400^2 + 0.8349^2 + 20^2}$$

= 435.5047

6.5.5. Calculating the Obstacle Clearance Surface (OCS) Slope Ratio.

The OCS slope is calculated by taking the difference in heights of the OCS surface at ROC_{pfaf} and ROC_{250}:

$$OCS_{sLope} = \frac{\left(\frac{pfaf - Ltp_{elev} - 250}{tan\left(\emptyset^{o} \times \frac{\pi}{180^{o}}\right)}\right)}{\left((pfaf - Ltp_{elev}) - ROC_{pfaf}\right) - (250 - ROC_{250})}$$

6.5.6. Calculating the OCS LTP/FTP to Origin Distance.

The OCS origin is calculated by taking the distance from threshold of the 250 ft point of the designed glidepath and subtracting the distance along the OCS slope from zero to the ROC250 point.

$$OCS_{origin} = \left(\frac{250 - tch}{tan\left(\emptyset^{o} \times \frac{\pi}{180^{o}}\right)}\right) - (250 - ROC_{250}) \times OCS_{sLope}$$

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VOLUME 2: PERFORMANCE BASED NAVIGATION (PBN)

CHAPTER 7: AREA NAVIGATION (RNAV)

SECTION 1: GENERAL CRITERIA

7.1. Basic Criteria Information.

7.1.1. Published Lines of Minimums.

a. Airplanes.

i. Straight -In Aligned Procedures.

Rule #1: Publish LNAV/VNAV and *LPV minimums. If the GQS is penetrated, this rule does not apply.

Rule #2: Publish LNAV minimums.

Rule #3: *Publish LP minimums if...

1) Neither LNAV/VNAV nor LPV minima are published, and
2) The LP MDA is at least 20 ft lower than the LNAV MDA.

Rule #4: Publish circling minimums if desired.

ii. Non Straight-In Aligned Procedures (Circling Only)

Rule #1: Evaluate an LNAV final segment.

Rule #2: The circling MDA must not be lower than the result of the LNAV final segment evaluation.

b. Helicopters.

i. Public Helicopter Procedures To Heliports

Rule #1: Publish LNAV minimums.

Rule #2: *Publish LP minimums if the LP MDA is at least 20 ft lower than the LNAV MDA.

NOTE: *N/A if airport is not within WAAS coverage.

7.1.2. Segment OEA Width (General).

a. Table 7-1-2 lists primary and secondary width values for all segments of an RNAV procedure. Except for departures, where segments cross a point 30 NM from ARP, segment primary area width increases (expansion) or decreases (taper) at a rate of 30 degrees relative to course to the appropriate width (see figure 7-1-2A). Secondary area expansion/taper is a straight-line connection from the point the primary area begins expansion/taper to the point the primary area expansion/taper ends. Reference to route width values is often specified as NM values measured from secondary area edge across the primary area to the secondary edge at the other side. For example, en route segment width is "2-4-4-2."

b. Feeder, "Q" and "T" routes segment width is 2-4-4-2. STARs and approach/departure procedure segment width is 2-4-4-2 at all distances greater than 30 NM from ARP (see paragraph 7.1.3 and 7.1.4 for width distances ≤ 30 NM). For these procedures, a segment designed to cross within 30 NM of the ARP more than once does not change to en route width until the 30 NM limit is crossed for approach and landing; i.e., crosses the limit for the last time before landing. A departure or missed approach segment designed to cross a point 30 NM from the ARP more than once changes when it crosses the boundary the first time and remains expanded.

Note: Q-routes supporting /E, /F, or /R aircraft may not be established if one or more critical DME facilities are identified.

Table 7-1-1. Reserved

Table 7-1-2. RNAV Linear Segment

Segment		**Primary Area Half-Width (P)**	**Secondary Area (S)**
STARs, Feeder, Initial, Missed Approach & Departures	> 30 **NM** from **ARP**	± 4.00	2.00
		2-4-4-2	
STARs, Feeder, Initial, Missed Approach & Departures	≤ 30 **NM** from **ARP**	± 2.00	1.00
		1-2-2-1	
Intermediate		Continues initial segment width until 2 **NM** prior to **PFAF**. Then tapers uniformly to final segment width.	Continues initial segment width until 2 **NM** prior to **PFAF**. Then it tapers to final segment width.

Supplementary note: Width in NM Values (see figure 7-1-1).

Figure 7-1-1. Segment Width Variables

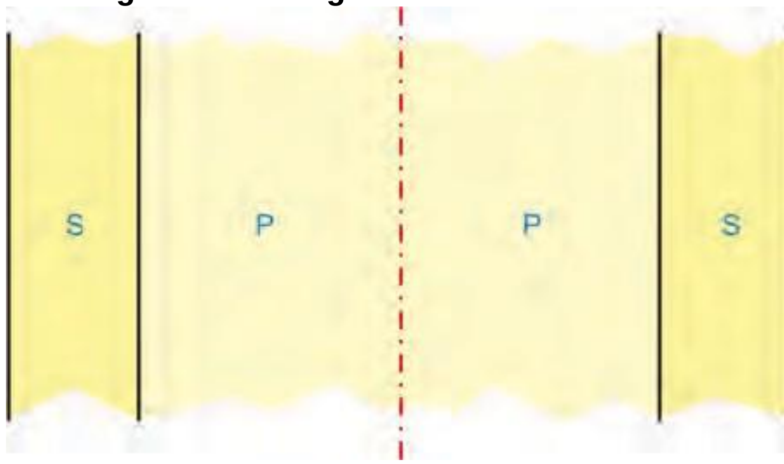
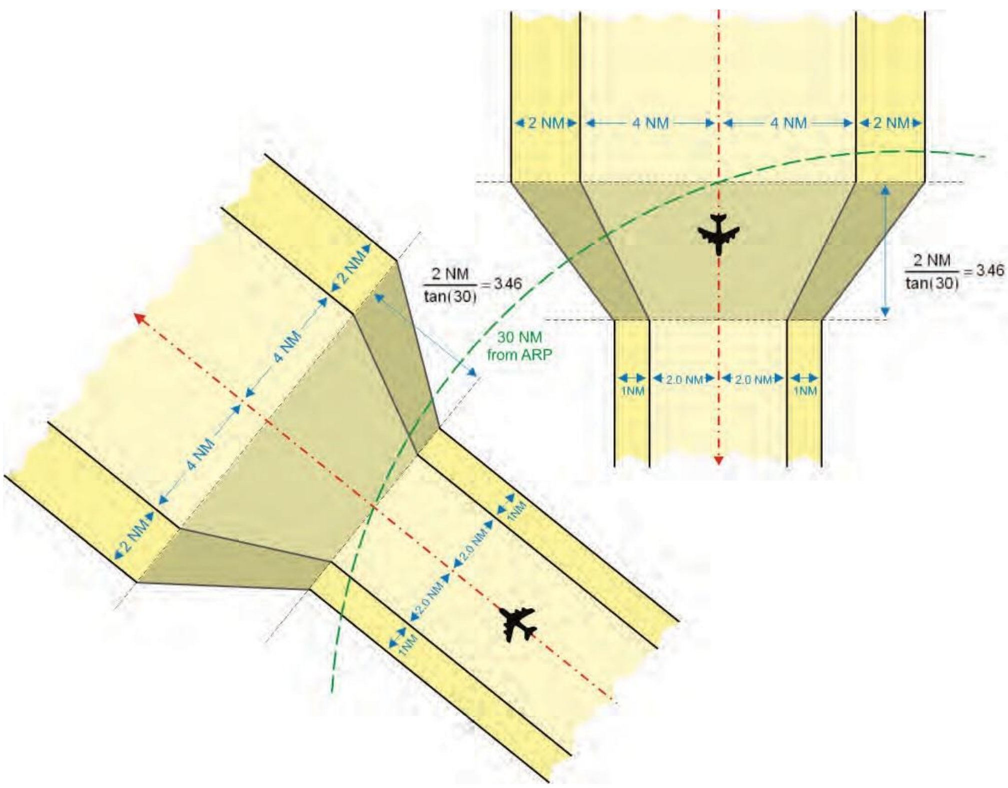


Figure 7-1-2A. Segment Width Changes at 30 NM



7.1.3. Width Changes at 30 NM from ARP (non-RF).

Receiver sensitivity changes at 30 NM from ARP. From the point the designed course crosses 30 NM from ARP, the primary OEA can taper inward at a rate of 30 degrees relative to course from $\pm$4 NM to $\pm$2 NM. The secondary area tapers from a 2 NM width when the 30 NM point is crossed to a 1 NM width abeam the point the primary area reaches the $\pm$2 NM width. The total along-track distance required to complete the taper is approximately 3.46 NM (21048.28 ft). Segment width tapers regardless of fix location within the tapering section unless a turn is associated with the fix. Delay OEA taper until the turn is complete and normal OEA turn construction is possible. EXCEPTION: The taper may occur in an RF turn segment if the taper begins at least 3.46 NM (along-track distance) from the RF leg termination fix; i.e., if it is fully contained in the RF leg.

7.1.4. Width Changes at 30 NM from ARP (RF).

When the approach segment crosses the point 30 NM from ARP in an RF leg, construct the leg beginning at a width of 2-4-4-2 prior to the 30 NM point and taper to 1-2-2-1 width after the 30 NM point. Calculate the perpendicular distance ($B_{primary}$, $B_{secondary}$) from the RF segment track centerline to primary and secondary boundaries at any along-track distance (specified as degrees of RF arc "α") from the point the track crosses the 30 NM point using calculator 1-1 (see figure 7-1-2B).

Calculator 1-1. RF Segment Taper Width

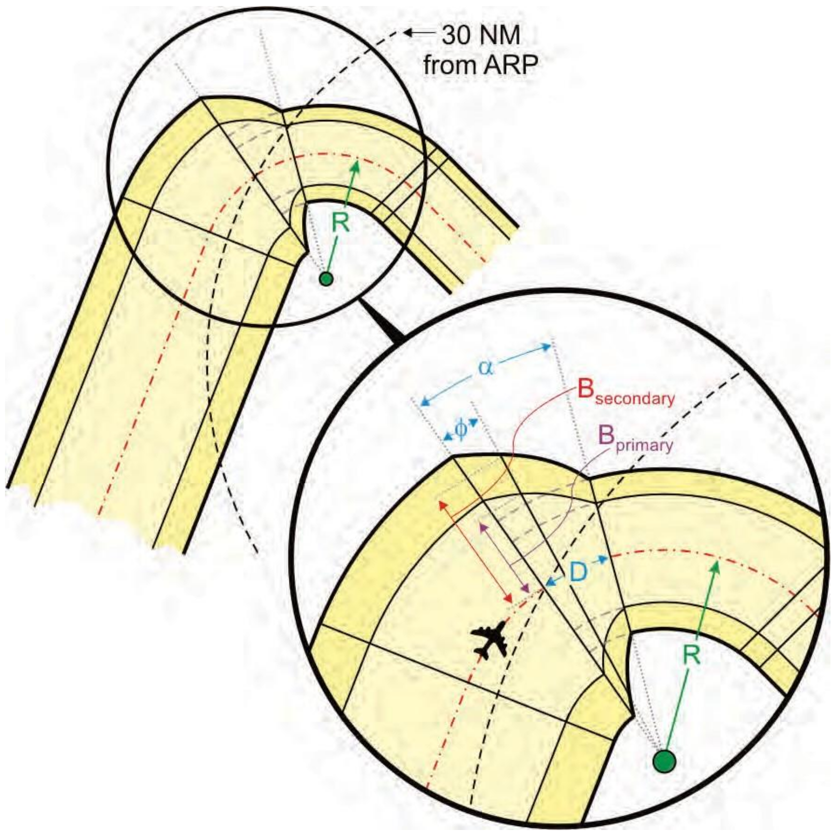
1) $$D = \frac{4-2}{\tan\left(30^o \times \frac{\pi}{180^o}\right)} \qquad \alpha^o = \frac{180^o \times D}{\pi \times R}$$

2) $$B_{primary} = 4 - 2 \times \frac{\phi^o \times \pi \times R}{180^o \times D}$$

3) $$B_{secondary} = 6 - 3 \times \frac{\phi^o \times \pi \times R}{180^o \times D}$$

where R = RF leg radius
$\phi°$ = number of degrees from start (distance on arc specified in degrees)
$\alpha°$ = degrees of arc (RF track)
Note: *"D" will be in the same units as "R"*

Figure 7-1-2B. Segment Width Changes in RF Leg (advanced avionics required)



7.1.5. Turns.

Where the inbound track to a fix differs from the outbound track by more than 0.03 degrees, a turn is indicated for construction purposes. For segment length considerations, turns of 10 degrees or less are considered straight.

7.1.6. Basic information.

a. Except as limited by the rules below, the standard design bank angle is assumed to be 18 degrees. The maximum bank angle is:

i. Fly-by turn rule: One-half the magnitude of track change for turns less than 50 degrees; 25 degrees for turns equal to or greater than 50 degrees (20 for RNP/ATT less than 1.0). Maximum bank angle below 500 ft above airport is 3 degrees.

ii. Fly-over turn rule: Determine the OEA outer boundary radius based on standard bank angle. For segment length calculation, maximum bank angle is 25 degrees. Maximum bank angle below 500 ft above airport is 3 degrees.

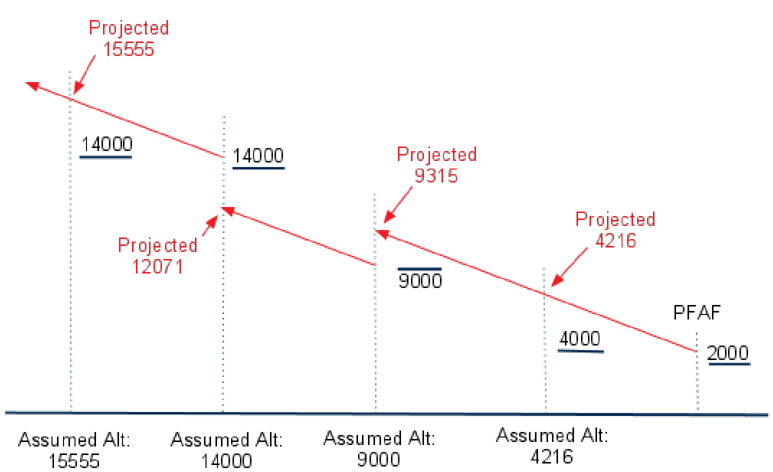
EXCEPTION: Where minimum segment length is necessary and application of the above is not operationally acceptable, it may be ignored if the succeeding segment is compliant with minimum segment length and bank angle rules.

iii. RF turn rule: Calculated RF bank angle based on the design radius is not to exceed 25 degrees (20 for RNP/ATT values less than 1.0). Maximum bank angle below 500 ft above airport is 3 degrees.

b. Determine the highest altitude within a turn by:

i. For approach: Altitude is determined by projecting either a 250 ft/NM (airplane) or 400 ft/NM (helicopter) vertical path from the PFAF to the fix along the fix-fix flight track. The turn altitude is the higher of the altitude of the slope at the fix or the minimum fix altitude, or an altitude cap if applicable (see figure 7-1-3). Exception: If an altitude cap lower than the projected slope is specified at a fix, the slope continues upward from fix starting at the cap altitude.

Figure 7-1-3. Estimating Fix altitude



Calculator 1-2. Reserved

ii. For missed approach – project a vertical path along the nominal flight track from the SOC point and altitude to the turn fix, that rises at a rate of 250 ft/NM (CAT A/B), 500 ft/NM (CAT C/D) or at a higher rate if a steeper climb gradient is specified. For turn-at-altitude and turn-at-fix construction, determine the altitude to calculate VKTAS based on the climb-to altitude plus an additive based on a continuous climb of 250 (CAT A/B) or 500 (CAT C/D) feet per 12 degrees of turn [ϕ*250/12 or ϕ*500/12]. CAT D example: segment length, 1125 ft would be added for a turn of 27 degrees, 958 ft would be added for 23 degrees, 417 ft for 10 degrees of turn. Compare the vertical path altitude at the fix to the published missed approach altitude. The altitude to use is the lower of the two. For missed approach, the turn altitude must not be higher than the published missed approach altitude.

STEP 1: Determine the KTAS for the turn using calculator 1-3a. Locate and use the appropriate KIAS from table 7-1-3. Use the highest altitude within the turn.

Table 7-1-3. Indicated Airspeeds (KIAS)

Segment		Indicated Airspeed by Aircraft Category (CAT)				
		A	B	C	D	E
At and Above 10000 ft						
RNAV and RNP Routes (e.g., Q - and T-Routes), Feeder, Initial, Intermediate, Missed, Departure		180	250	300	300	350
Below 10000						
T-Routes, Feeder, Initial, Intermediate		150	250		250[1]	310
Final		90	120	140	165	250
Missed Approach (MA), Departure		110	150	240	265	310
Minimum Airspeed Restriction[2]						
Minimum Airspeed Restriction[2]	Feeder, Initial, Departure	110	140	200[3]	210[3]	310
	Intermediate	110	140	180	180	310
	Missed Approach	100	130	165	185	310
	Final	Not Authorized				

NOTE:

1) Consider using 265 KIAS where heavy aircraft routinely exceed 250 KIAS under CAR 603.32.
2) Minimum airspeed restrictions are used to reduce turn radius and should be supported by an analysis of performance characteristics of representative aircraft. Only one speed restriction per approach segment is allowed based on fastest published CAT. Missed approach airspeed restrictions should not be used for other than obstacle/terrain avoidance requirements.
3) For Feeder and Departure, use 250 KIAS above 10000 ft.

7.1.7. Calculating the Turn Radius (R).

a. The design turn radius value is based on four variables: indicated airspeed, assumed tailwind, altitude, and bank angle. Apply the indicated airspeed from table 7-1-3 for the highest speed aircraft category that will be published on the approach procedure. Apply the highest expected turn altitude value.

Calculator 1-3a. True Airspeed

$$V_{KTAS} = round\left[\frac{V_{KIAS} \times 171233 \times \sqrt{303 - 0.00198 \times alt}}{(288 - 0.00198 \times alt)^{2.628}}, 0\right]$$

Where alt = the aircraft's MSL elevation
V_{KIAS} = indicated airspeed

STEP 2: Calculate the appropriate tailwind component (VKTW) using calculator 1-3b for the highest altitude within the turn. **EXCEPTION:** If the MSL altitude is 2000 ft or less above airport elevation, use 30 kts.

Calculator 1-3b. Tailwind

$$\textbf{case}(alt\text{-}apt_{elev} \leq 2000): \quad V_{KTW} = 30$$

$$\textbf{case}(alt\text{-}apt_{elev} > 2000): \quad V_{KTW} = \textbf{round}[0.00198 \times alt + 47, 0]$$

where alt = the highest turn altitude
apt_{elev} = airport MSL elevation

NOTE: *If the calculator 1-3b value is considered excessive at a specific location, the 99th percentile wind speed values determined from analysis of a five-year locally measured database may be substituted.

STEP 3: Calculate R using calculator 1-3c.

Calculator 1-3c. Turn Radius

Case (aLt > 19500): $V_{ground} = round\left[min\left[570, \frac{0.9941 \times aLt}{100} + 287\right], 0\right]$

Case (aLt≤ 19500): $V_{ground} = min[500, V_{KTAS} + V_{KTW}]$

where $\phi°$ = the assumed bank angle
(18° for CATs B-D) alt = turn altitude in feet

Note 1: (see calculator 1-3c) For FB and FO turns where the highest altitude in the turn is between 10000 ft and flight level 195, where the sum of “VKTAS+VKTW” is greater than 500 kts, use 500 kts.

Note 2: (calculate or 1-3c) For FB and FO turns, where the highest altitude in the turn is greater than flight level 195, use 570 kts as the value for "VKTAS+VKTW" and 5 degrees of bank rather than 18 degrees. If the resulting DTA is greater than then $R = \frac{20}{\tan\left(\frac{\phi^{o}}{2} \times \frac{\pi}{180^{o}}\right)}$ where ϕ is the amount of turn (heading change).

b. Use calculator 1-8 to verify the required bank angle does not exceed 18 degrees.

7.1.8. Turn Construction.

7.1.9. Turns at FO Fixes (see figures 7-1-4 and 7-1-5).

a. **Extension for Turn Delay.** Turn construction incorporates a delay in start of turn to account for pilot reaction time and roll-in time (rr). Calculate the extension distance in feet using calculator 1-4.

Calculator 1-4. Reaction & Roll Dist

$$\boldsymbol{rr = 6 \times \frac{fpnm}{3600} \times V_{KTAS}}$$

STEP 1: Determine R based on standard bank angle (see calculator 1-3c).

STEP 2: Determine rr (see calculator 1-4).

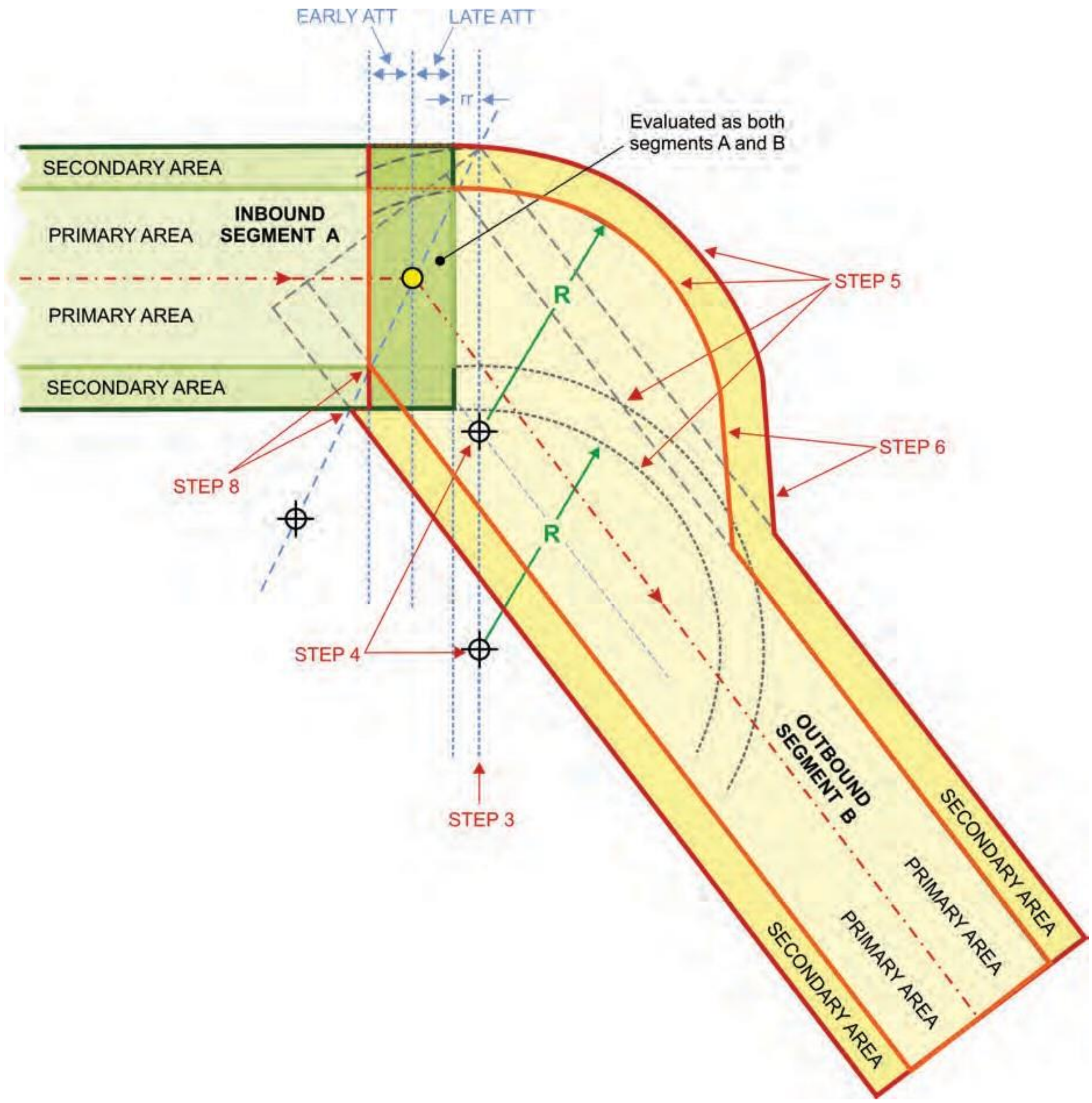
STEP 3: Establish the baseline for construction of the turn expansion area as the line perpendicular to the inbound track at a distance past the turn fix equal to (ATT+rr).

STEP 4: On the baseline, locate the center points for the primary and secondary turn boundaries. The first is located at a distance R from the non-turning side primary boundary. The second is located at a distance R from the turning side secondary boundary (see figures 7-1-4 and 7-1-5).

STEP 5: From these center points construct arcs for the primary boundary of radius R. Complete the secondary boundary by constructing additional arcs of radius ($R+W_S$) from the same center points. (W_S=width of the secondary). This is shown in figures 7-1-4 and 7-1-5.

STEP 6: The arcs constructed in step 5 are tangent to the outer boundary lines of the inbound segment. Construct lines tangent to the arcs based on the first turn point tapering inward at an angle of 30 degrees relative to the outbound track that joins the arc primary and secondary boundaries with the outbound segment primary and secondary boundaries. If the arcs from the second turn point are inside the tapering lines as shown in figure 7-1-4, then they are disregarded and the expanded area construction is completed. If not, proceed to step 7.

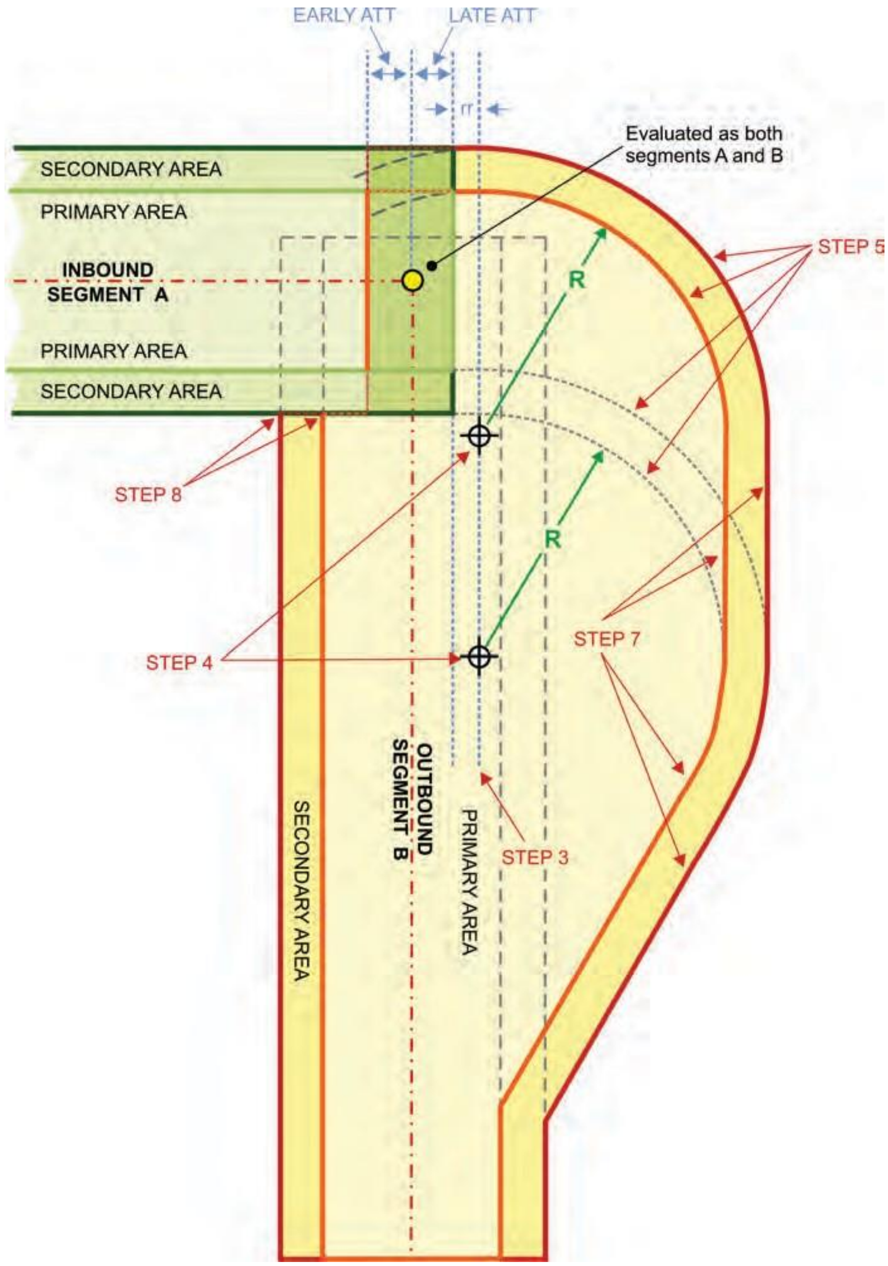
Figure 7-1-4. Fly-Over with No Second Arc Expansion



STEP 7: If both the inner and outer arcs lie outside the tapering lines constructed in step 6, connect the respective inner and outer arcs with tangent lines and then construct the tapering lines from the arcs centered on the second center point as shown in figure 7-1-5.

STEP 8: The inside turn boundaries are the simple intersection of the preceding and succeeding segment primary and secondary boundaries.

Figure 7-1-5. FO with Second Arc Expansion



NOTE: The inbound OEA end (± ATT) is evaluated for both inbound and outbound segments.

b. **Minimum length of TF leg following a FO turn.** The leg length of a TF leg following a FO turn must be sufficient to allow the aircraft to return to course centerline. Determine the minimum leg length (L) using calculator 1-5.

Calculator 1-5. TF Leg Minimum Length Following FO Turn

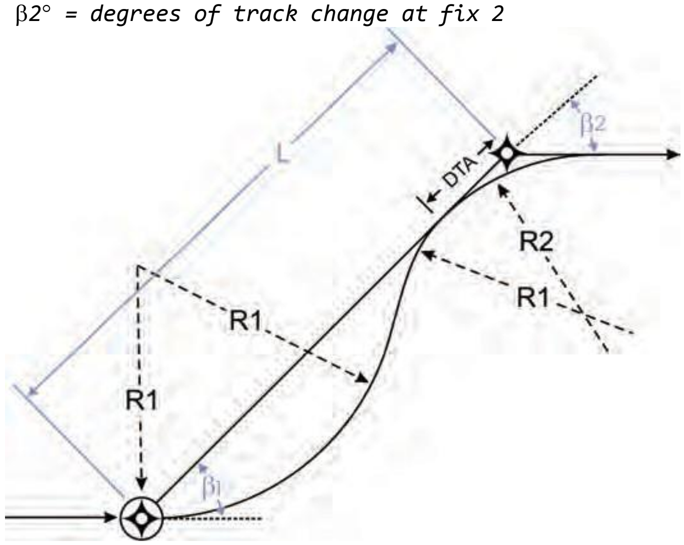
$$\boldsymbol{Case}\ \left(\beta 1^o < acos\left(\sqrt{3}-1\right) \times \frac{180^o}{\pi}\right)$$

$$L = max\left[1, round\left[R1 \times \left(sin\left(\beta 1^o \times \frac{\pi}{180^o}\right) + 2 \times sin\left(acos\left(\frac{1+cos\left(\beta 1^o \times \frac{\pi}{180^o}\right)}{2}\right)\right)\right) + R2 \times tan\left(\frac{\beta 2^o}{2} \times \frac{\pi}{180^o}\right), 2\right]\right]$$

$$\boldsymbol{Case}\ \left(\beta 1^o \geq acos\left(\sqrt{3}-1\right) \times \frac{180^o}{\pi}\right)$$

$$L = max\left[1, round\left[R1 \times \left(sin\left(\beta 1^o \times \frac{\pi}{180^o}\right) + 4 - \sqrt{3} - \sqrt{3} \times cos\left(\beta 1^o \times \frac{\pi}{180^o}\right)\right) + R2 \times tan\left(\frac{\beta 2^o}{2} \times \frac{\pi}{180^o}\right), 2\right]\right]$$

where *R1 = turn radius (NM) from calculator 1-3c at first fix*
R2 = turn radius (NM) from calculator 1-3c at second fix
$\beta 1°$ *= degrees of track change at fix 1*
$\beta 2°$ *= degrees of track change at fix 2*



7.1.10. FB Turn. See figure 7-1-6.

STEP 1: Establish a line through the turn fix that bisects the turn angle. Determine R3 (see calculator 1-3c). Scribe an arc (with origin on bisector line) of radius R3 tangent to inbound and outbound courses. This is the designed turning flight path.

STEP 2: Scribe an arc (with origin on bisector line) that is tangent to the inner primary boundaries of the two segment legs with a radius (R4) equal to

$$R4 = R3 + \frac{Primary\ Area\ Half{-}width}{2}$$

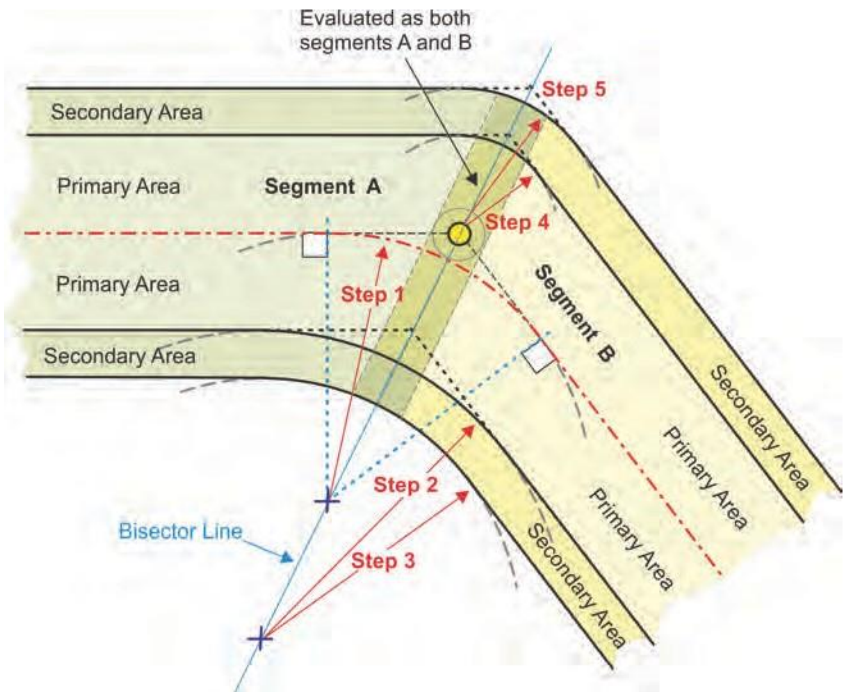
(example: half width of 2 NM, the radius would be R3 +1.0 NM).

STEP 3: Scribe an arc that is tangent to the inner secondary boundaries of the two segment legs using the origin and radius from step 2 minus the secondary width.

STEP 4: Scribe the primary area outer turning boundary with an arc with a radius equal to the segment half width centered on the turn fix.

STEP 5: Scribe the secondary area outer turning boundary with the arc radius from step 4 plus the secondary area width centered on the turn fix.

Figure 7-1-6. FB Turn Construction



Step 1 line is R3

Step 2 line is R4

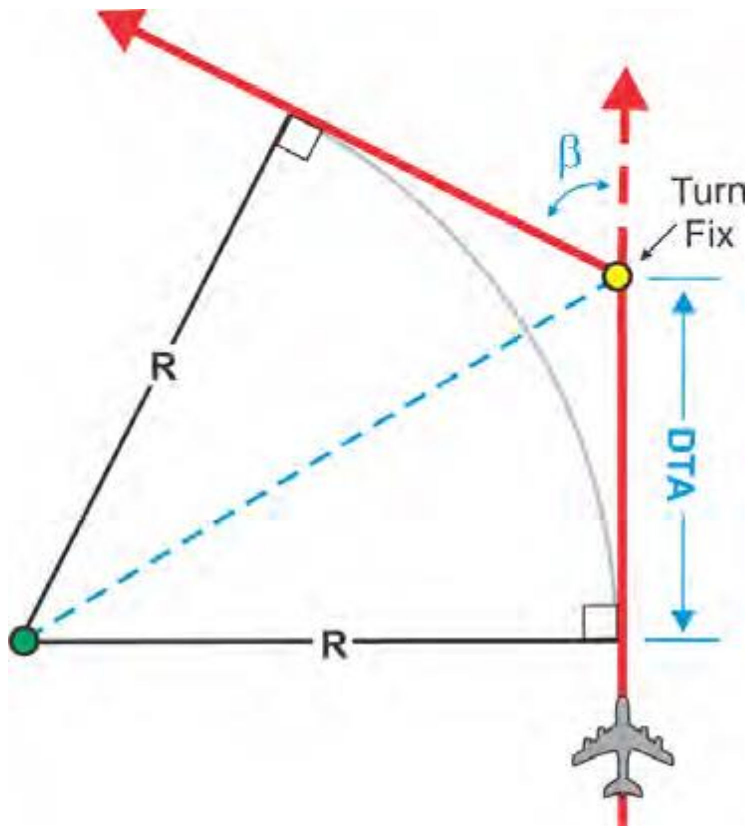
a. The minimum length must not be less than the total of DTAs for the leg. Calculate DTA using calculator 1-6.

Calculator 1-6. Distance of Turn Anticipation

$$DTA_{NM} = round\left[R \times tan\left(\frac{\beta^o}{2} \times \frac{\pi}{180^o}\right), 2\right]$$

$$DTA_{feet} = round\left[R \times tan\left(\frac{\beta^o}{2} \times \frac{\pi}{180^o}\right) \times fpnm, 0\right]$$

where R=turn radius (NM)
β°=degrees of heading change



b. Calculate the minimum length for a TF leg following a FB turn using calculators 1-7a and 1-7b.

Calculator 1-7. TF Leg Minimum Length Following FB Turn

(1) If (RNP AR)

$$\lambda = min(1{,}2 \times RNP)$$

Else

$$\lambda = 1$$

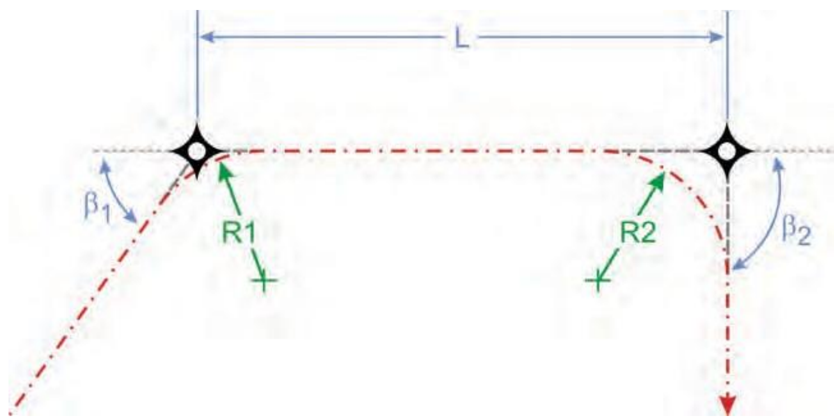
End if

(2) $$Minimum\ Length = \max\left[\lambda, \text{round}\left[\text{R1} \times tan\left(\frac{\beta 1^o}{2} \times \frac{\pi}{180^o}\right) + \text{R2} \times \tan\left(\frac{\beta 2^o}{2} \times \frac{\pi}{180^o}\right), 2\right]\right]$$

Where

RNP = Segment RNP value (input if RNP AR)
R1 = turn radius for first fix from calculator 1-3c
R2 = turn radius for subsequent fix from formula 1-3c
Note: zero when β2° is fly-over

β1° = degrees of heading change at initial fix
β2° = degrees of heading change at termination fix



7.1.11. Radius-to-Fix (RF) Turn. Incorporation of an RF segment may limit the number of aircraft served by the procedure.

a. RF legs are used to control the ground track of a turn where obstructions prevent the design of a FB or FO turn, or to accommodate other operational requirements.* The curved leg begins tangent to the previous segment course at its terminating fix and ends tangent to the next segment course at its beginning fix (see figure 7-1-7). OEA construction limits turn radius to a minimum value equal-to or greater-than the OEA (primary and secondary) half-width. The RF segment OEA boundaries are parallel arcs.

***Note:** RF legs segments are not applicable to the final segment or section 1 of the missed approach segment. RF legs in the intermediate segment must terminate at least 2 NM prior to the PFAF. Where RF legs are used, annotate the procedure (or segment as appropriate) "RF Required."

STEP 1: Determine the segment R that is required to fit the geometry of the terrain/airspace. Enter the required radius value into calculator 1-8 to verify the resultant bank angle is ≤ 25 degrees (maximum allowable bank angle). Where a bank angle other than 18 degrees is used, annotate the value in the remarks section of the appropriate procedure documentation form.

Calculator 1-8. RF Bank Angle

(1) Case (alt > 19500): $V_{ground} = round\left[min\left[570, \frac{0.9941 \times alt}{100} + 287\right], 0\right]$

(2) Case (alt ≤ 19500): $V_{ground} = \min[500, V_{KTAS} + V_{KTW}]$

(3) $\phi^{o} = \text{round}\left[atan\left(\frac{V_{ground}{}^{2}}{68625.4 \times R}\right) \times \frac{180^{o}}{\pi}, 0\right]$

where V_{KTAS} = *value from calculator 1-3a*
V_{KTW} = *value from calculator 1-3b*
R = required radius
alt = highest aircraft altitude in RF turn

Note: Where only categories A and B are published, verify the resultant bank angle is ≤ 15 degrees.

b. Segment length may be calculated using calculator 1-9. Minimum RF segment length is 2 NM. Where a TF segment is required between 2 RF segments, the minimum TF segment length is 1 NM.

Calculator 1-9. RF Segment Length

$$\text{Segment}_{\text{Lenght}} = round\left[\frac{\pi \times R \times \alpha^{o}}{180^{o}}, X\right]$$

where R = RF segment radius (answer will be in the units entered)
α^{o} = degrees of ARC
x = 0 if unit is feet, 2 if NM

STEP 2: Turn Center. Locate the turn center at a perpendicular distance R from the preceding and following segments.

STEP 3: Flight path. Construct an arc of radius R from the tangent point on the preceding course to the tangent point on the following course.

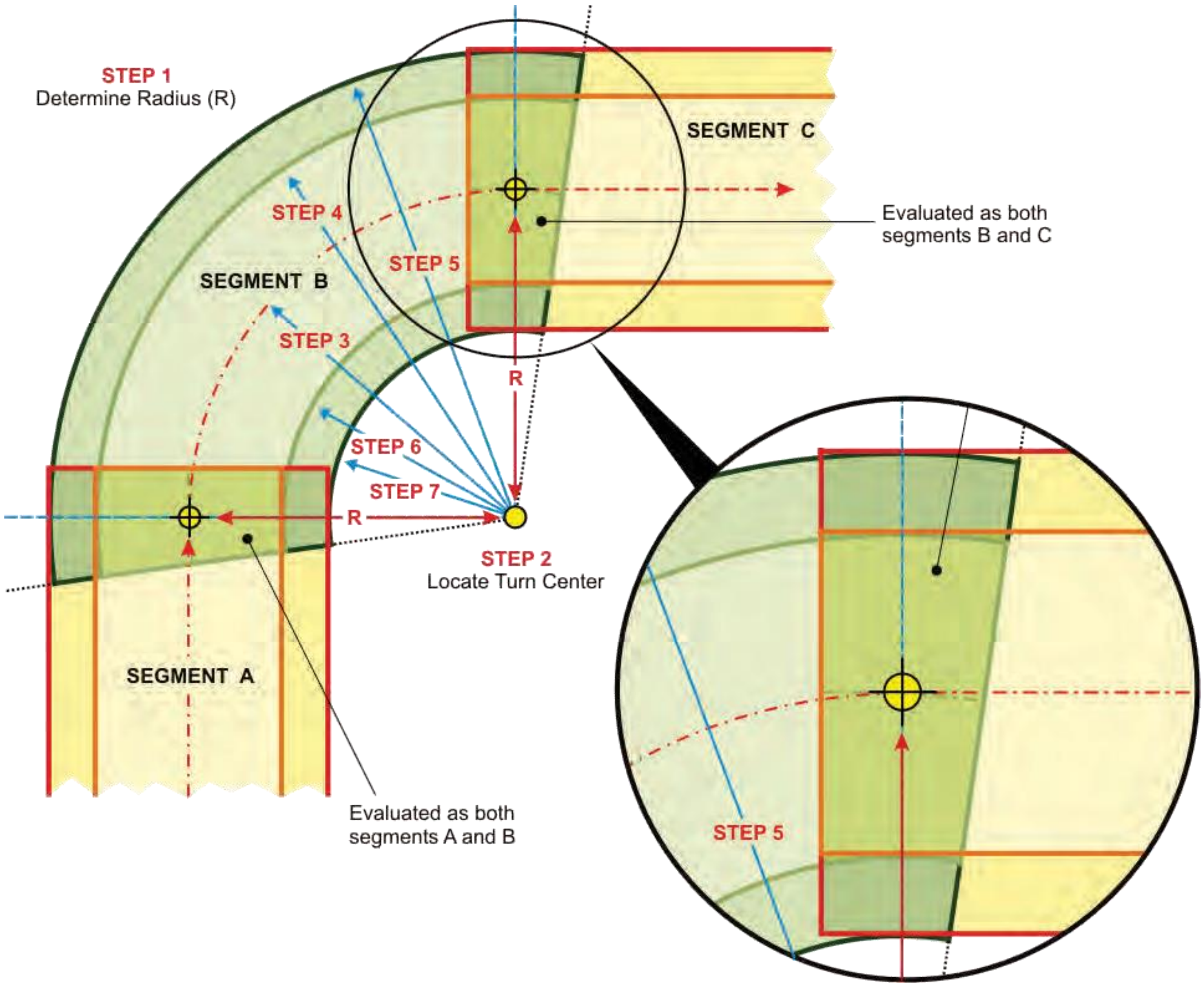
STEP 4: Primary area outer boundary. Construct an arc of radius R+Primary area half-width from the tangent point on the preceding segment primary area outer boundary to the tangent point on the following course primary area outer boundary.

STEP 5: Secondary area outer boundary. Construct an arc of radius R+Primary area half-width+secondary area width from the tangent point on the preceding segment secondary area outer boundary to the tangent point on the following course secondary area outer boundary.

STEP 6: Primary area inner boundary. Construct an arc of radius R-Primary area half-width from the tangent point on the preceding segment inner primary area boundary to the tangent point on the following course inner primary area boundary.

STEP 7: Secondary area inner boundary. Construct an arc of radius R-(Primary area half-width+secondary area width) from the tangent point on the preceding segment inner secondary area boundary to the tangent point on the following course inner secondary area boundary.

Figure 7-1-7. RF Turn Construction



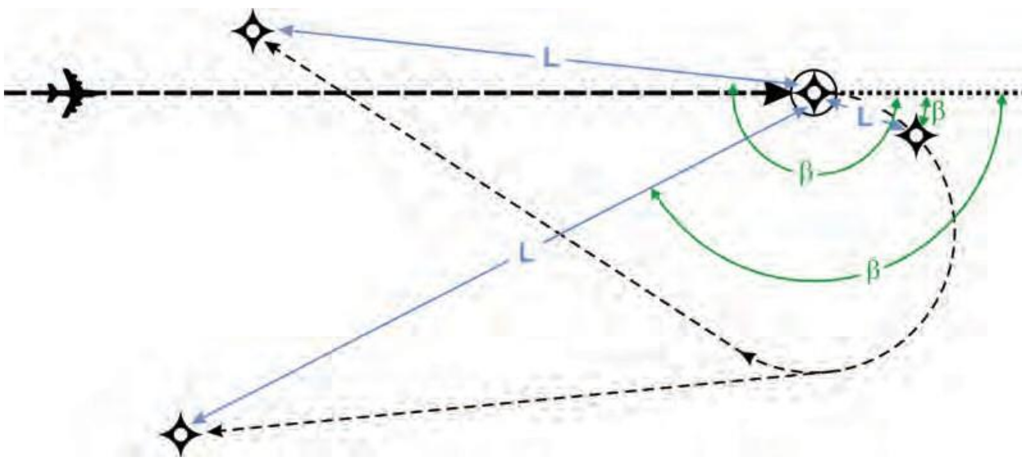
7.1.12. FO fix direct to fix. Use calculator 1-10 to determine minimum segment length (L).

Calculator 1-10. TF/CF Leg Followed by a DF Leg

Case $(\beta^o > 30^o)$ $$L = max\left[1, round\left[4 \times R \times \left(sin\left(\frac{\boldsymbol{\beta^o + 30^o}}{\mathbf{2}} \times \frac{\boldsymbol{\pi}}{\mathbf{180^o}}\right)^{\mathbf{2}} \times\right), 2\right]\right]$$

Case $(\beta^o \leq 30^o)$ $$L = max\left[1, round\left[2 \times R \times \left(sin\left(\boldsymbol{\beta^o} \times \frac{\boldsymbol{\pi}}{\mathbf{180^o}}\right) \quad \times\right), 2\right]\right]$$

where *β° = magnitude of turn*
R = turn radius for first fix from calculator 1-3c



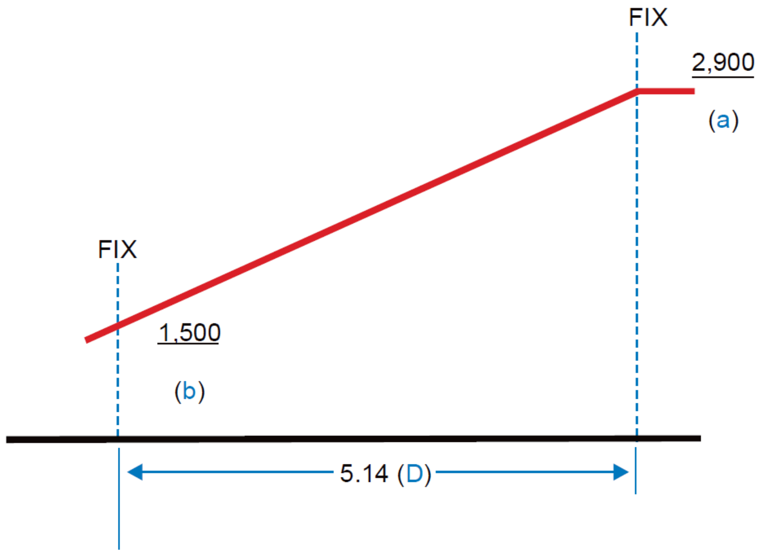
7.1.13. Descent Gradient.

The **optimum** descent gradient in the initial segment is 250 ft/NM (4.11%, 2.36 degrees); **maximum** is 500 ft/NM (8.23%, 4.70 degrees). For high altitude penetrations, the **optimum** is 800 ft/NM (13.17%, 7.50 degrees); **maximum** is 1000 ft/NM (16.46%, 9.35 degrees). The **optimum** descent gradient in the intermediate segment is 150 ft/NM (2.47%, 1.41 degrees); **maximum** is 318 ft/NM (5.23%, 3.0degrees).

7.1.14. Calculating Descent Gradient (DG).

Determine total altitude lost between the plotted positions of the fixes. Determine the distance (D) in NM. Divide the total altitude lost by D to determine the segment descent gradient (see figure 7-1-8 and calculator 1-11).

Figure 7-1-8. Calculating Descent Gradient



Calculator 1-11. Descent Gradient

$$DG = ceiling\left[\frac{r \times \ln\left(\frac{r+a}{r+b}\right)}{D}\right]$$

where *a = beginning altitude*
b = ending altitude
D = distance (NM) between fixes

7.1.15. Feeder, Q, and T Route Segments.

When the IAF is not part of the en route structure, it may be necessary to designate feeder routes from the en route structure to the IAF. The feeder segment may contain a sequence of TF segments (and/or RF segments). The maximum course change between TF segments is 70 degrees at and above FL195, and 90 degrees (70 degrees preferred) below FL195. Calculator 1-3c Notes 1 and 2 apply. Paragraphs 7.1.8 to 7.1.12 turn construction applies. The feeder segment terminates at the IAF (see figures 7-1-9A and 7-1-9B).

7.1.16. Length.

The **minimum** length of a sub-segment is the greater of the value calculated under paragraph 7.1.9, 7.1.10, or 7.1.11 (as appropriate), or the value required for OEA construction. The **maximum** length of a sub-segment is 500 miles. The total length of the feeder segment should be as short as operationally possible.

7.1.17. Width.

See Table 7-1-2 for
primary area width and secondary area width. These widths apply from the feeder segment initial fix to the approach IAF/termination fix. Where the initial fix is on an airway, chapter 2 construction applies.

Figure 7-1-9A. Feeder Route (Fly-by Protection)

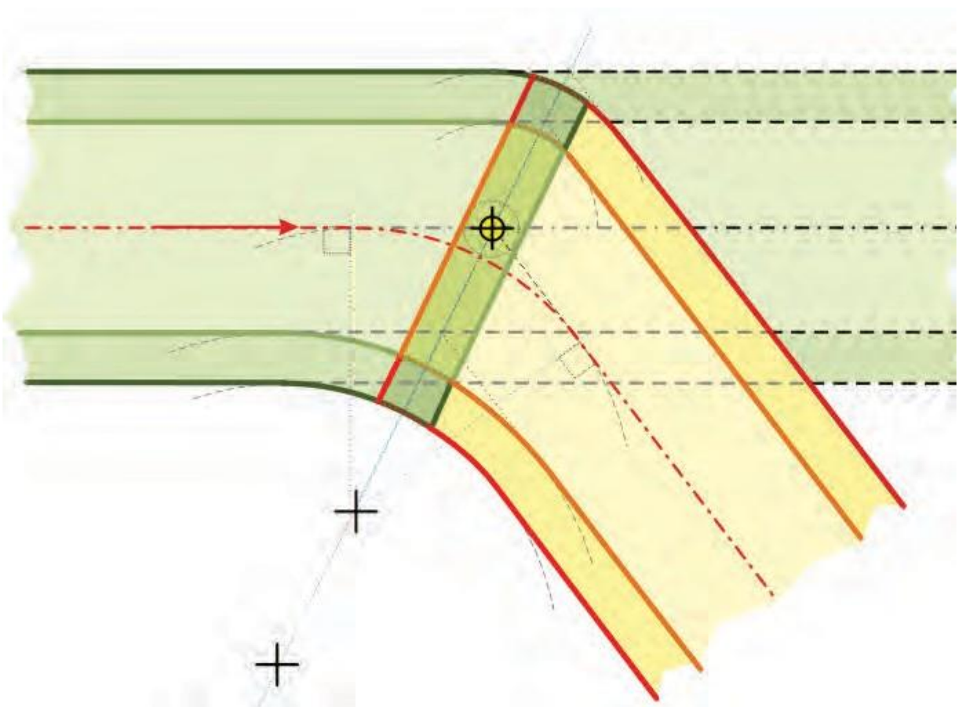
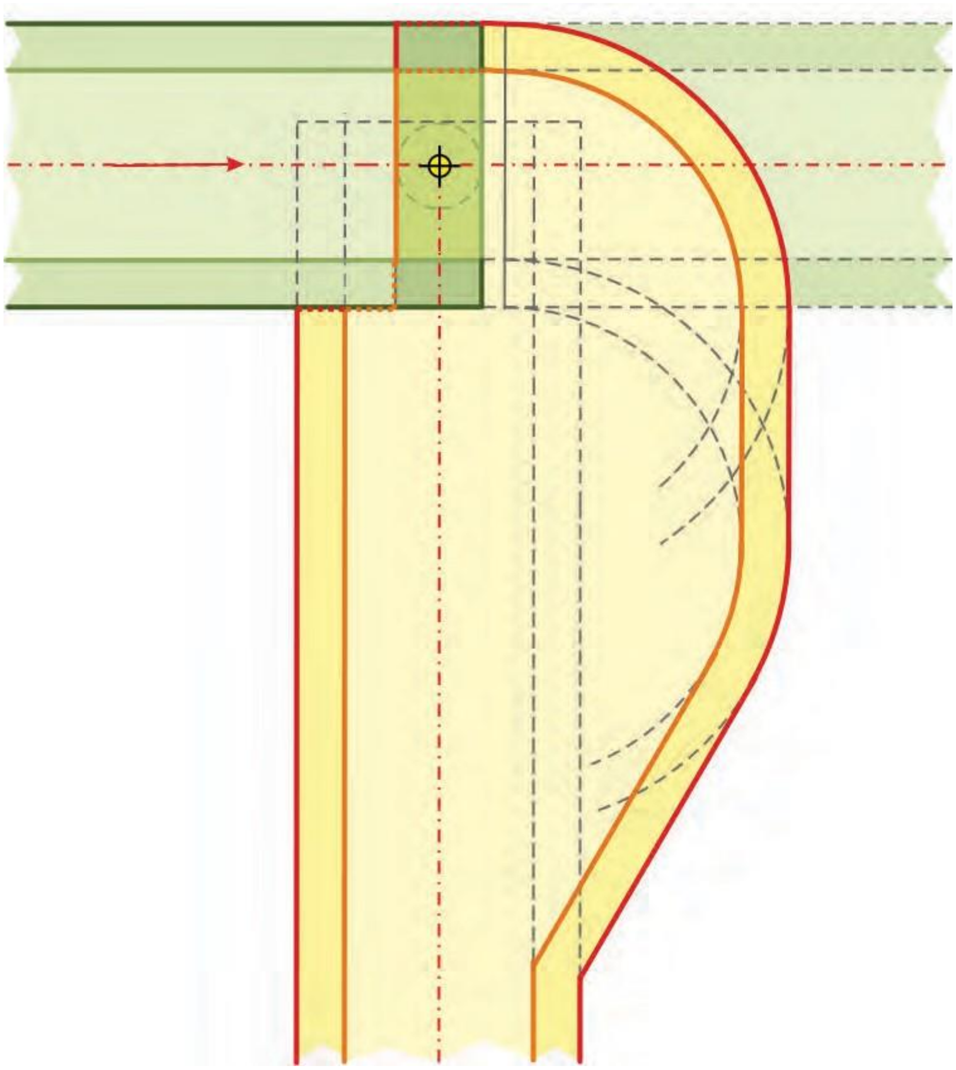


Figure 7-1-9B. Feeder Route (Fly-over Protection)



7.1.18. Obstacle Clearance.

The **minimum** ROC over areas not designated as mountainous under CAR 602.124 is 1000 ft. For region designated as “mountainous”, the **minimum ROC** is 1500 or 2000 ft, as appropriate, under CAR 602.124. The published minimum feeder route altitude must provide at least the **minimum** ROC value and must not be less than the altitude established at the IAF.

7.1.19. Descent Gradient (feeder, initial, intermediate segments).

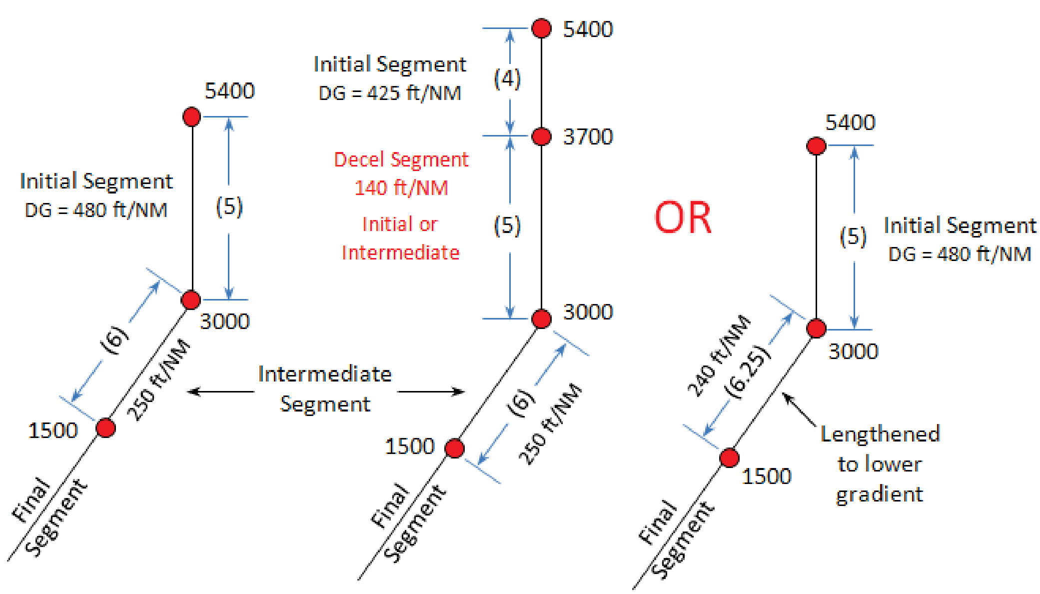
a. The **optimum** descent gradient in the feeder and initial segments is **250** ft/NM (4.11%, 2.36 degrees); **maximum** is 500 ft/NM (8.23%, 4.70 degrees). For high altitude penetrations, the **optimum** is 800 ft/NM (13.17%, 7.5 degrees); **maximum** is 1000 ft/NM (16.46%, 9.35 degrees).

b. The **optimum** descent gradient in the intermediate segment is 150 ft/NM (2.47%, 1.41 degrees); **maximum** is 318 ft/NM (5.23%, 3.0 degrees). Where the descent gradient of any leg in the intermediate segment exceeds 240 ft/NM due to terrain or obstacles, a deceleration segment must be constructed in the intermediate and/or initial segment leg(s) immediately preceding that leg (not applicable to procedures limited to CAT B or lower minimums or other procedures when approved by Flight Standards). The **minimum** deceleration length is dependent on segment descent gradient and magnitude of turn at the IF. The maximum allowable descent gradient in the deceleration segment is 150 ft/NM. Refer to table 7-1-4a to determine the minimum deceleration segment length (see figure 7-1-10 for examples).

Table 7-1-4a. Minimum Deceleration Segment Length

Segment Descent Gradient (ft/NM)	Turn at IF ≤ 45° Minimum Length	Turn at IF >45° Minimum Length
0-74	2	4
75-149	3	4
150	5	5

Figure 7-1-10. Example of Deceleration Segment



7.1.20. Reserved.

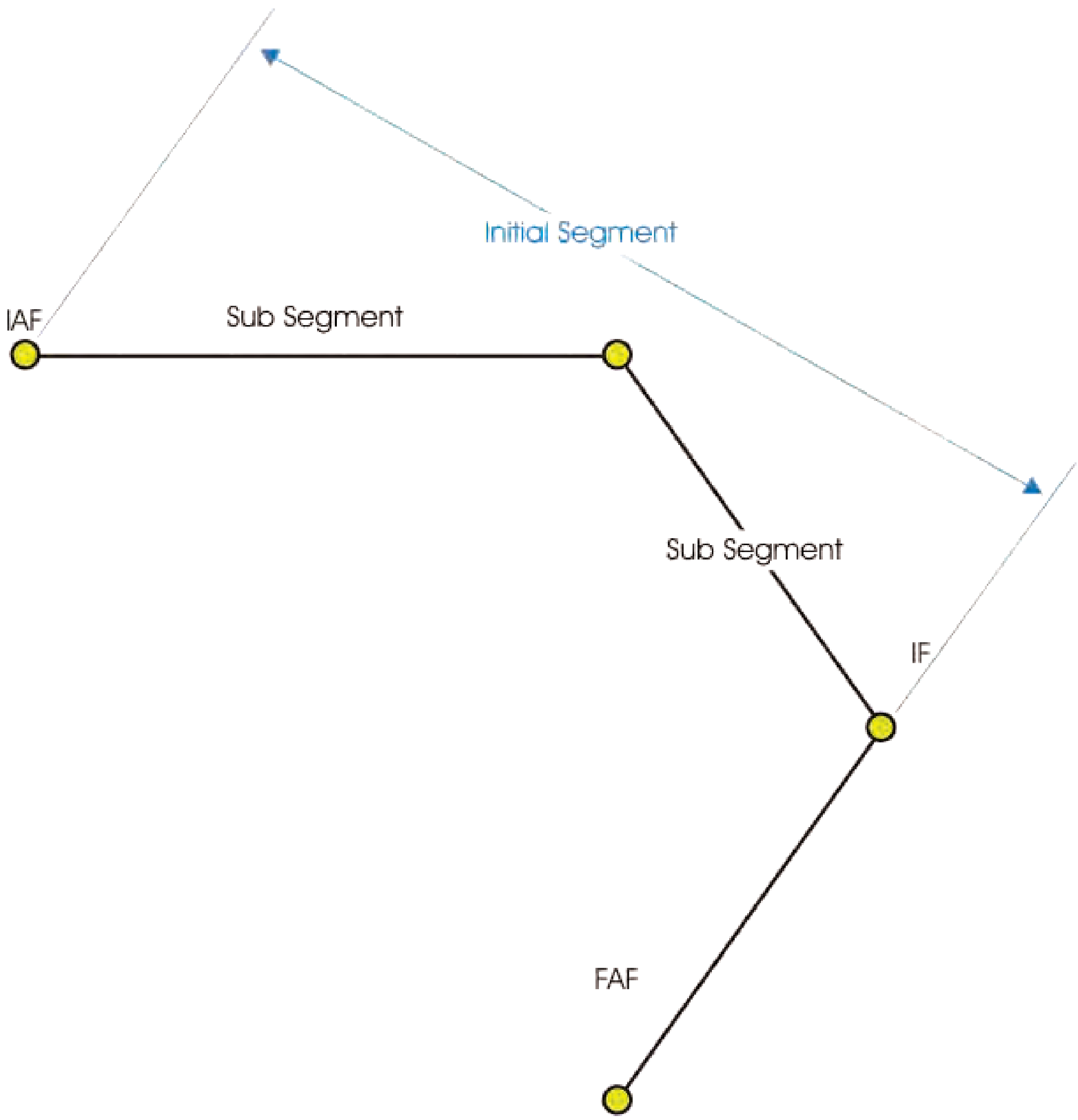
7.1.21. Reserved.

7.1.22. Terminal Segments.

7.1.23. Initial Segment.

The initial segment begins at the IAF and ends at the intermediate fix (IF). The initial segment may contain sequences of straight sub segments (see figure 7-1-11). Paragraphs 7.1.25, 7.1.26, 7.1.27, and 7.1.28 apply to all sub segments individually. For DG limits, see paragraph 7.1.19.

Figure 7-1-11. Initial Sub Segments



7.1.24. Course Reversal.

The **optimum** design incorporates the basic Y or T configuration. This design eliminates the need for a specific course reversal pattern. Where the optimum design cannot be used and a course reversal is required, establish a holding pattern at the initial or intermediate approach fix (see paragraph 7.1.29.c). The **maximum** course change at the fix (IAF/IF) is to 90 degrees (70 degrees above FL 190) within 0.03 degrees.

7.1.25. Alignment.

Design initial/initial and initial/intermediate TF segment intersections with the smallest amount of course change that is necessary for the procedure. No course change is optimum. Where a course change is necessary, it should normally be limited to 70 degrees or less; 30 degrees or less is preferred. The **maximum** allowable course change between TF segments is 90 degrees within 0.03 degrees.

7.1.26. Area – Length.

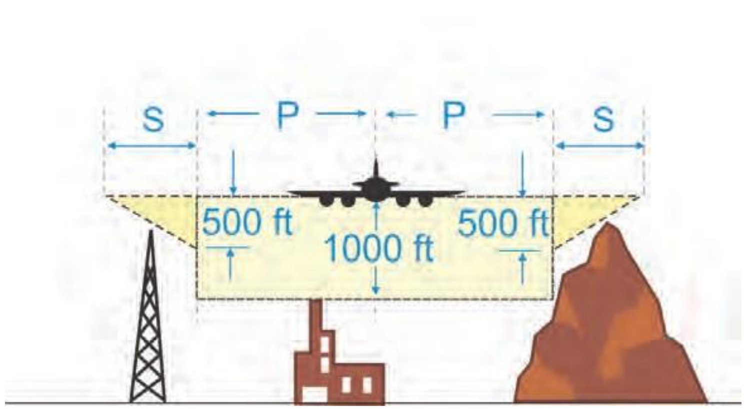
The **maximum** segment length (total of sub segments) is 50 NM. Minimum length of sub segments is determined as described in paragraphs 7.1.9, 7.1.10, or 7.1.11 as appropriate.

7.1.27. Area – Width (see table 7-1-2).

7.1.28. Obstacle Clearance.

a. Apply 1000 ft of ROC plus adjustments over the highest obstacle in the primary OEA. The ROC in the secondary area is 500 ft at the primary boundary tapering uniformly to zero at the outer edge (see figure 7-1-12).

Figure 7-1-12. Initial Segment ROC



b. Calculate the secondary ROC values using calculator 1-12a.

Calculator 1-12a. Secondary ROC

$$ROC_{secondary} = 500 \times \left(1 - \frac{d_{primary}}{W_S}\right)$$

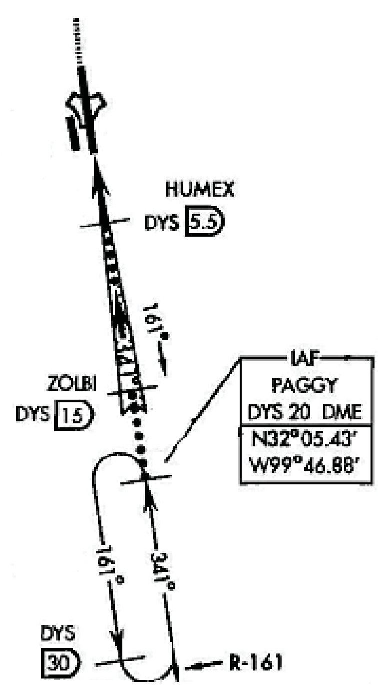
Where $d_{primary}$ = perpendicular distance (ft) from edge of primary area
W_S = Width of the secondary area

7.1.29. Holding Pattern Initial Segment.

a. A holding pattern may be incorporated into the initial segment procedure design where an operational benefit can be derived; e.g., arrival holding at an IAF, course reversal pattern at the IF, etc. See Volume 1 chapter 18 for RNAV holding pattern construction guidance.

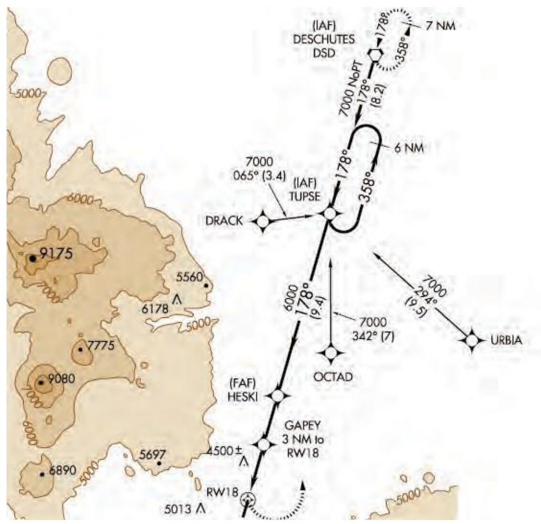
b. **Arrival Holding.** Ideally, the holding pattern inbound course should be aligned with the subsequent TF leg segment (tangent to course at the initial fix of the subsequent RF segment), see figure 7-1-13A. If the pattern is offset from the subsequent TF segment course, the subsequent segment length must accommodate the resulting DTA requirement. Maximum offset is 90 degrees (70 degrees above FL190) within 0.03 degrees. Establish the minimum holding altitude at or above the IAF/IF (as appropriate) minimum altitude. MEA minimum altitude may be lower than the minimum holding altitude.

Figure 7-1-13A. Arrival Holding Example



c. **Course Reversal (Hold-In-lieu of PT).** Ideally, establish the minimum holding altitude as the minimum IF fix altitude (see figure 7-1-13B). In any case, the published holding altitude must result in a suitable descent gradient in the intermediate segment: optimum is 150 ft/NM (2.47%, 1.41 degrees); maximum is 318 ft/NM (5.23%, 3.0 degrees). If the pattern is offset from the subsequent TF segment course, the subsequent segment length must accommodate the resulting DTA requirement. Maximum offset is 90 degrees within 0.03 degrees.

Figure 7-1-13B. Course Reversal Example



7.1.30. Intermediate Segment.

The intermediate segment primary and secondary boundary lines connect abeam the plotted position of the PFAF at the appropriate primary and secondary final segment beginning widths.

7.1.31. Alignment (Maximum Course Change at the PFAF).

a. LPV & LNAV/VNAV. Align the intermediate course within 15 degrees of the final approach course (15 degrees maximum course change).

b. LNAV & LP. Align the intermediate course within 30 degrees of the final approach course (30 degrees maximum course change).

Note: For RNAV transition to ILS final, no course change is allowed at the PFAF.

7.1.32. Length (Fix to Fix).

The **minimum** segment length is determined under paragraph 7.1.8. The optimum for CAT A/B length is 3NM. The **optimum** CAT C/D length is 5NM.

7.1.33. Width.

a. The intermediate segment primary area tapers uniformly from ± 2NM at a point 2NM prior to the PFAF to the outer boundary of the XOCS abeam the PFAF (1NM past the PFAF for LNAV and LNAV/VNAV). The secondary boundary tapers uniformly from 1NM at a point 2NM prior to the PFAF to the outer boundary of the YOCS abeam the PFAF (1NM past the PFAF for LNAV and LNAV/VNAV). See figures 7-1-14A and 1-14B.

Figure 7-1-14A. RNAV Intermediate Segment (LPV, ILS, LP)

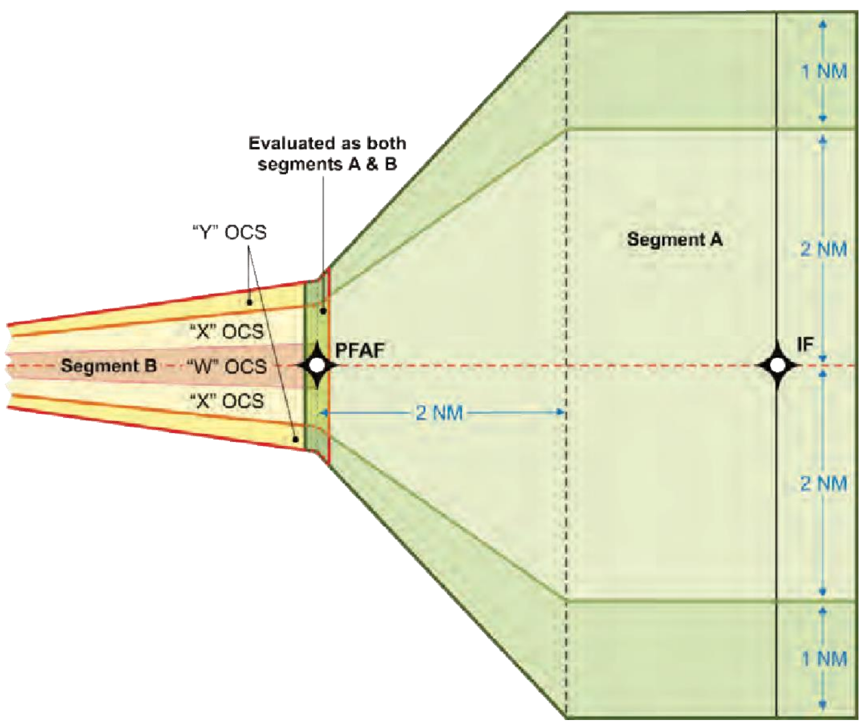
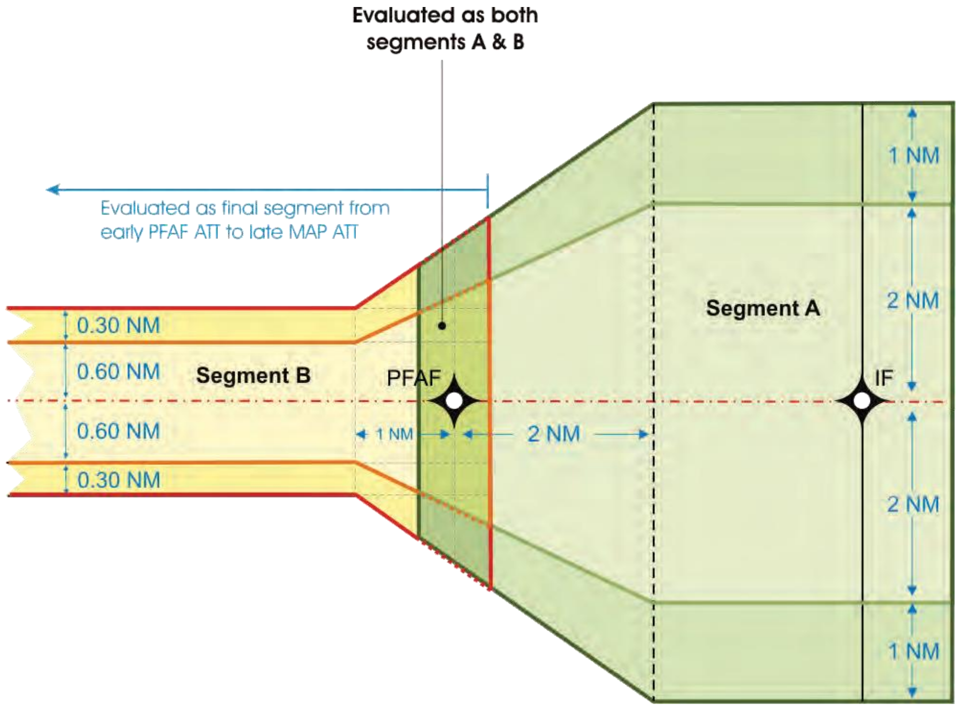


Figure 7-1-14B. RNAV Intermediate Segment (LNAV and LNAV/VNAV)



b. If a turn is designed at the IF, it is possible for the inside turn construction to generate boundaries outside the normal segment width at the taper beginning point 2 miles prior to the PFAF. Where these cases occur, the inside (turn side) boundaries are a simple straight line connection from the point 1 NM past the PFAF on the final segment, to the tangent point on the turning boundary arc as illustrated in figures 7-1-14C and 7-1-14D.

Figure 7-1-14C. LNAV, LNAV/VNAV Example

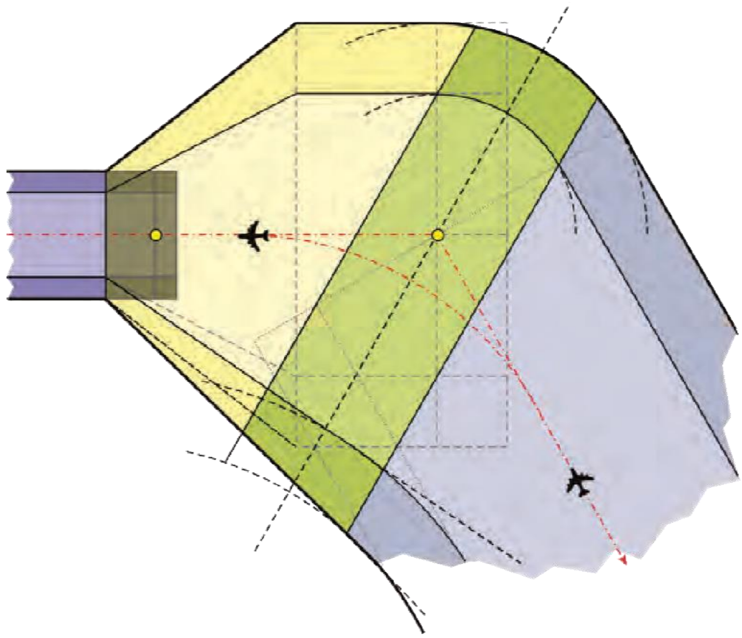
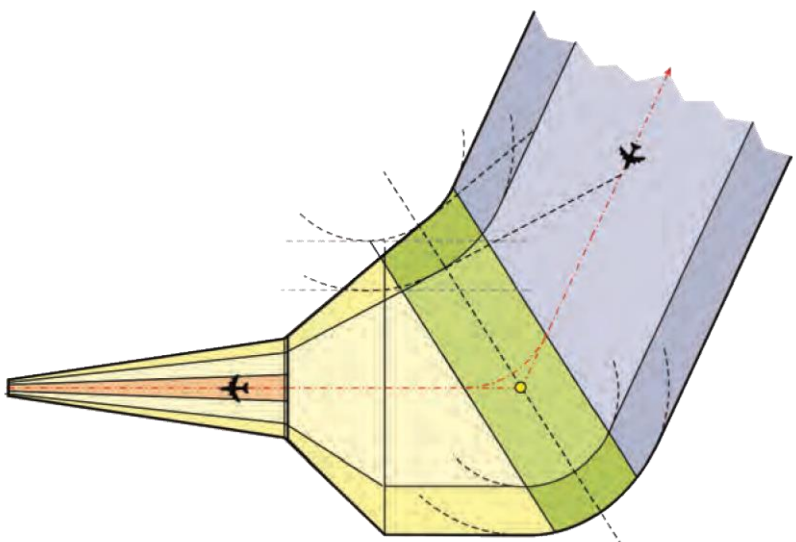


Figure 7-1-14D. LP, LPV Example



c. **LNAV/VNAV, LNAV Offset Construction.** Where LNAV intermediate course is not an extension of the final course, use the following construction (see figure 7-1-14E).

STEP 1: Construct line A perpendicular to the intermediate course 2 NM prior the PFAF.

STEP 2: Construct line B perpendicular to the intermediate course extended 1 NM past the PFAF.

STEP 3: Construct the inside turn boundaries by connecting the points of intersection of line A with the turn side intermediate segment boundaries with the intersection of line B with the turn side final segment boundaries.

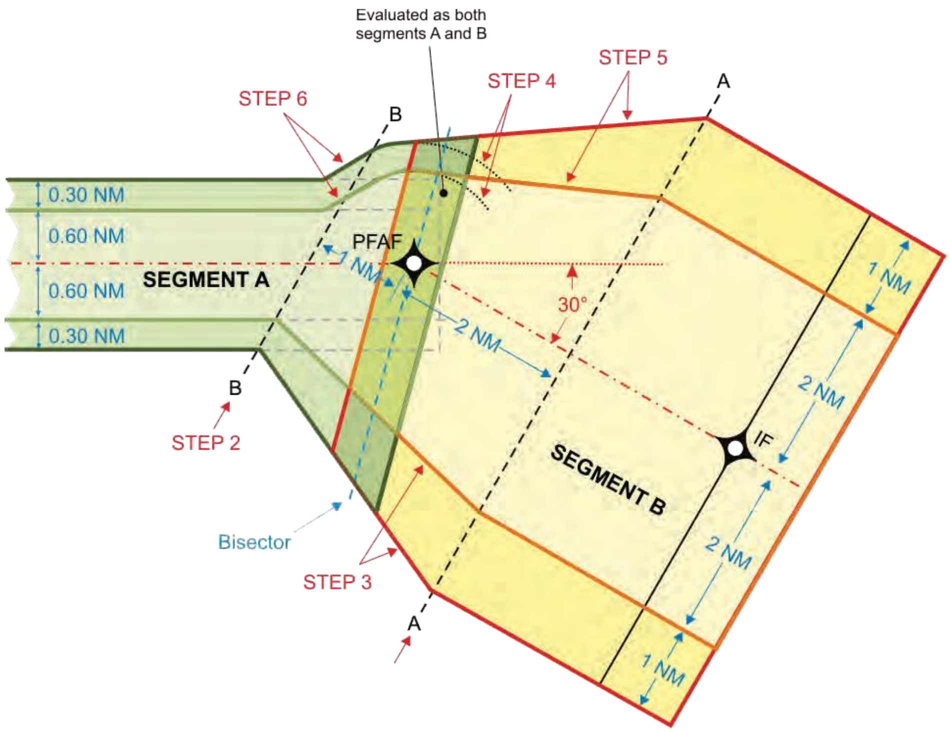
STEP 4: Construct arcs centered on the PFAFof 1 NMand 1.3 NM radius on the non-turn side of the fix.

STEP 5: Connect lines from the point of intersection of line A and the outside primary and secondary intermediate segment boundaries to tangent points on the arcs constructed in step 4.

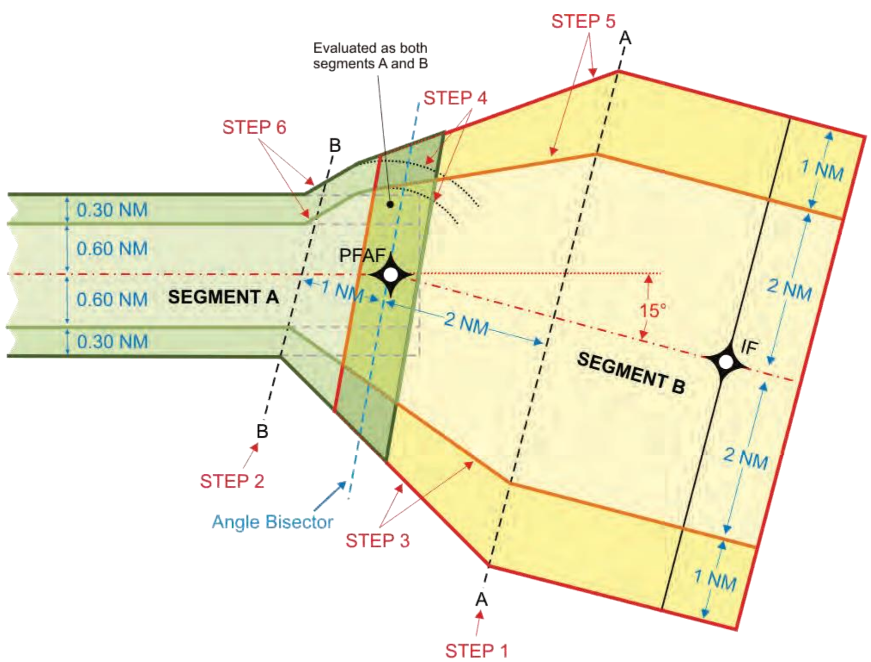
STEP 6: Connect lines tangent to the arcs created in step 4 that taper inward at 30degrees relative to the FAC to intersect the primary and secondary final segment boundaries as appropriate.

d. The final segment evaluation extends to a point ATT prior to the angle bisector. The intermediate segment evaluation extends ATT past the angle bisector. Therefore, the area within ATT of the angle bisector is evaluated for both the final and intermediate segments.

Figure 7-1-14E. Offset LNAV Construction



Offset LNAV/VNAV Construction



e. LPV, LP Offset Construction. Where LP intermediate course is not an extension of the final course, use the following construction (see figure 7-1-14F).

STEP 1: Construct line Aperpendicular to the intermediate course 2NMprior the PFAF.

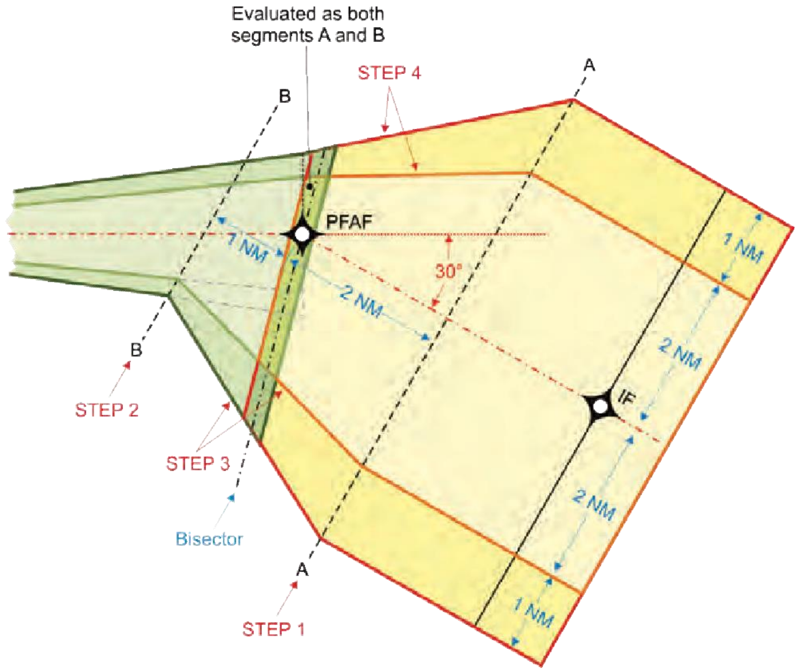
STEP 2: Construct line Bperpendicular to the intermediate course extended 1NM past the PFAF.

STEP 3: Construct the inside turn boundaries by connecting the points of intersection of line Awith the turn side intermediate segment boundaries with the intersection of line Bwith the turn side final segment boundaries.

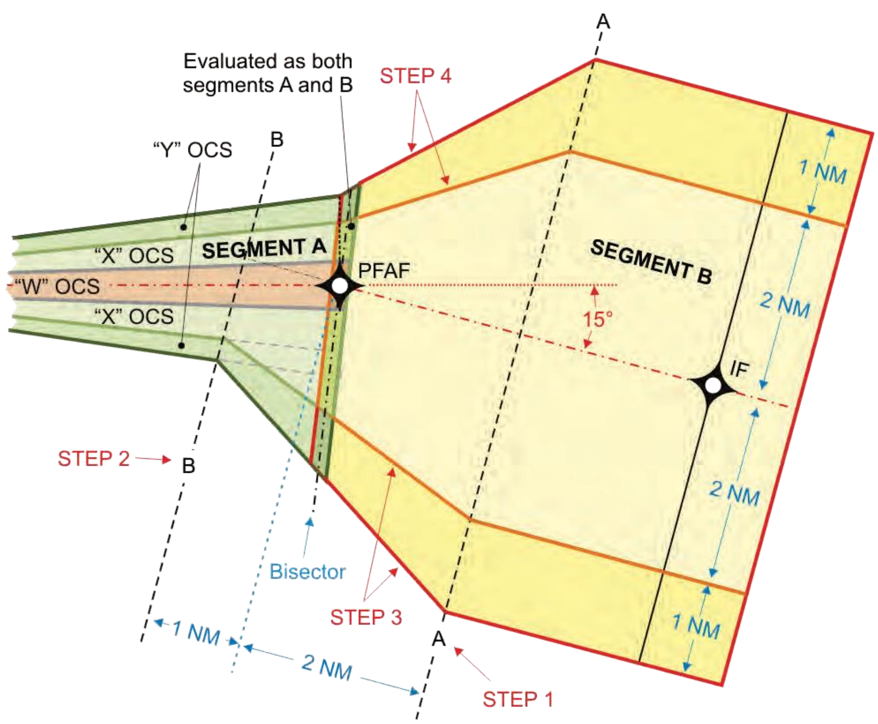
STEP 4: Connect lines from the point of intersection of line Aand the outside primary and secondary intermediate segment boundaries to the final segment primary and secondary final segment lines at a point perpendicular to the final course at the PFAF.

f. The final segment evaluation extends to a point ATT prior to the angle bisector. The intermediate segment evaluation extends ATT past the angle bisector. Therefore, the area within ATT of the angle bisector is evaluated for both the final and intermediate segments.

Figure 7-1-14F. Offset LP Construction



Offset LPV Construction

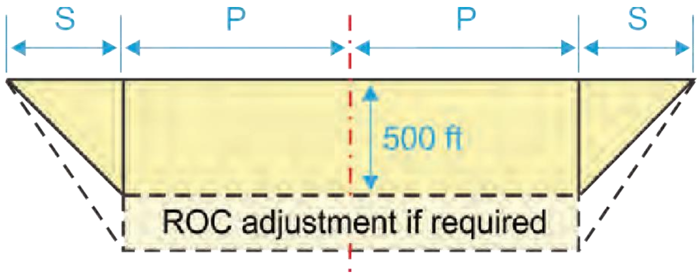


g. RF intermediate segments. Locate the intermediate leg's RF segment's terminating fix at least 2 NM outside the PFAF

7.1.34. Obstacle Clearance.

a. Apply 500 ft of ROC over the highest obstacle in the primary OEA. The ROC in the secondary area is 500 ft at the primary boundary tapering uniformly to zero at the outer edge (see figure 7-1-15).

Figure 7-1-15. Intermediate Segment ROC



b. Calculate the secondary ROC values using calculator 1-12b.

Calculator 1-12b. Secondary ROC

$$ROC_{secondary} = (500 + adj) \times \left(1 - \frac{d_{primary}}{W_S}\right)$$

Where

$d_{primary}$ = perpendicular distance (ft) from edge of primary area
W_S = Width of the secondary area
adj = TP308/GPH209 paragraph 323.

7.1.35. Minimum IF to LTP Distance. (Applicable for LPV and LP procedures with no turn at PFAF)

Locate the IF at least dIF (NM) from the LTP (see calculator 1-13).

Calculator 1-13. Min IF Distance

$$d_{IF} = 0.3 \times \frac{d}{a} - \frac{d}{fpnm}$$

Where *d = distance (ft) from FPAP to LTP/FTP*

a = calculator 1-14 $width_{feet}$ *output*

Basic Vertically Guided Final Segment General Criteria

7.1.36. Authorized Glidepath Angles (GPAs).

The optimum (design standard) GPA is 3 degrees. GPAs greater than 3 degrees that conform to table 7-1-4 are authorized without Flight Standards/ military authority approval only when obstacles prevent use of 3 degrees. Flight Standards approval is required for angles less than 3 degrees or for angles greater than the minimum angle required for obstacle clearance.

Table 7-1-4b. Maximum Allowable GPAs

Category	θ°
A**	5.7
B	4.2
C	3.6
D&E	3.1

Note:
* LPV: Where HATh < 250, CAT A-C Max 3.5 degrees, CAT D/E Max 3.1 degrees.
** CAT A 6.4 degrees if VKIAS limited to 80 kts maximum. Apply Volume 1 chapter 2 minimum HATh/(HAT) values based on GPA (table 7-3-5) where they are higher than the values in this Volume.

7.1.37. Threshold Crossing Height (TCH).

Select the appropriate TCH from table 7-1-5. Publish a note indicating VGSI not coincident with the procedures designed descent angle (VDA or GPA, as appropriate) when the VGSI angle differs by more than 0.2 degrees or when the VGSI TCH is more than 3 ft different from the designed TCH.

Note: If an ILS is published to the same runway as the RNAV procedure, its TCH and GPA values should be used in the RNAV procedure design. The VGSI TCH/angle should be used (if within table 7-1-5 tolerances) where a vertically guided procedure does not serve the runway.

Table 7-1-5. TCH Requirements

Representative Aircraft Type	Approximate Glidepath-to-Wheel Height	Recommended TCH ± 5 Ft	Remarks
HEIGHT GROUP 1 General Aviation, Small Commuters, Corporate turbojets: T-37, T-38, C-12, C-20, C-21, T-1, T-3, T-6, UC-35, Fighter Jets	10 ft or less	40 ft	Many runways less than 6,000 ft long with reduced widths and/or restricted weight bearing which would normally prohibit landings by larger aircraft.
HEIGHT GROUP 2 F-28, CV-340/440/580, B-737, C-9, DC-9, C-130, T-43, B-2, S-3	15 ft	45 ft	Regional airport with limited air carrier service.
HEIGHT GROUP 3 B-727/707/720/757, B-52, C-17, C-32, C-135, C-141, E-3, P-3, E-8	20 ft	50 ft	Primary runways not normally used by aircraft with ILS glidepath-to-wheel heights exceeding 20 ft.
HEIGHT GROUP 4 B-747/767/777, L-1011, DC-10, A-300, B-1, KC-10, E-4, C-5, VC-25	25 ft	55 ft	Most primary runways at major airports.

Notes:

1: To determine the minimum allowable TCH, add 20 ft to the glidepath-to-wheel height.

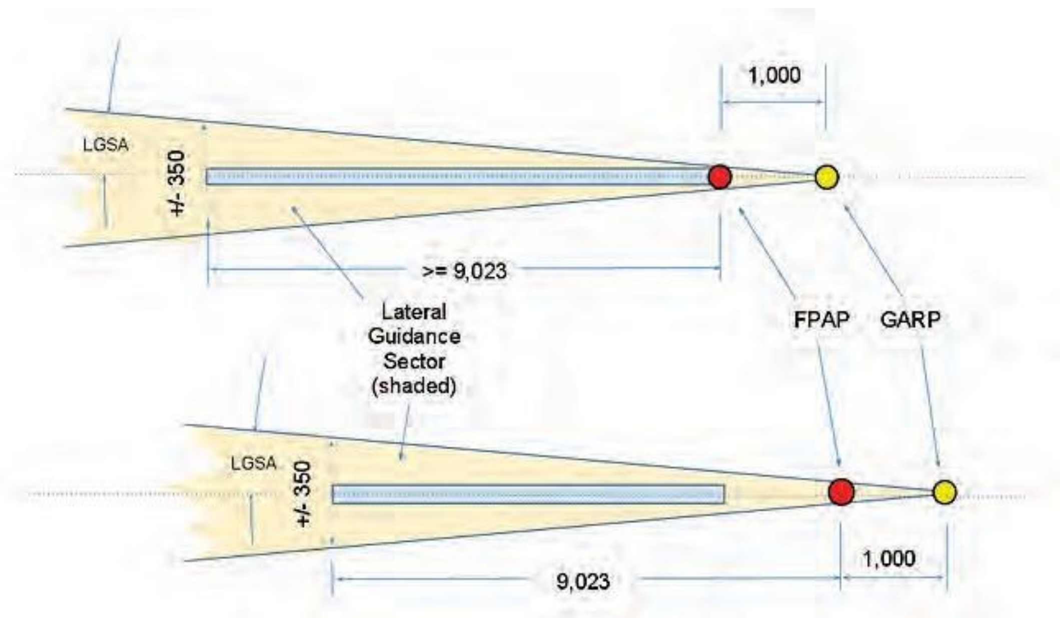
2: To determine the maximum allowable TCH, add 50 ft to the glidepath-to-wheel height.

3: Maximum LPV TCH is 60 ft.

7.1.38. Determining the Flight Path Alignment Point (FPAP) Location (LPV and LP only).

a. The FPAP is a WGS-84 latitude/longitude point that serves as the departure end of runway in the FAS data block in WAAS approach coding. The LTP/FTP and FPAP are used to define the final approach course alignment. The GNSS Azimuth Reference Point (GARP) is a calculated point 1000 ft beyond the FPAP lying on an extension of a geodesic line from the LTP/FTP through the FPAP. This point is used by the airborne system as the origin of the lateral guidance sector (see figure 7-1-16). It may be considered the location of an imaginary localizer antenna. The Lateral Guidance Sector Angle (LGSA) is the angular dimension of the lateral guidance sector boundaries relative to the course measured at the GARP. Specifying the calculated angle tailors the width of the lateral guidance sector to ±350 ft at the LTP/FTP. This angle is sometimes referred to as the splay. The Offset Length value is the distance between the departure end of runway and the FPAP.

Figure 7-1-16. FPAP Geometry



b. Locate the FPAP at the departure end of runway or 9023 ft from LTP/FTP, whichever is the greater distance from the LTP/FTP.

c. Use the following calculation to determine:

i. Distance from LTP/FTPto FPAP(d_{FPAP})

ii. Distance from LTP/FTPto GARP(d_{GARP}) Offset Length

iii. LGSA

iv. Width (the lateral guidance sector half width at LTP/FTP)

Calculator 1-14. FAS Data

(1) $d_{FPAP} = max(RWY_{Lenght}, 9023)$

(2) $d_{GRAP} = d_{FPAP} + 1000$

(3) $Offset_{Length} = d_{FPAP} - RWY_{Length}$

(4) $LGSA = round\ \left[atan\left(\frac{350}{d_{GRAP}}\right) \times \frac{180^{o}}{\pi}, 2\right]$

(5) $Width_{feet} = 350$

$Width_{meters} = 106.75$

(6) $case\ (RWY_{Length} > 12366)$

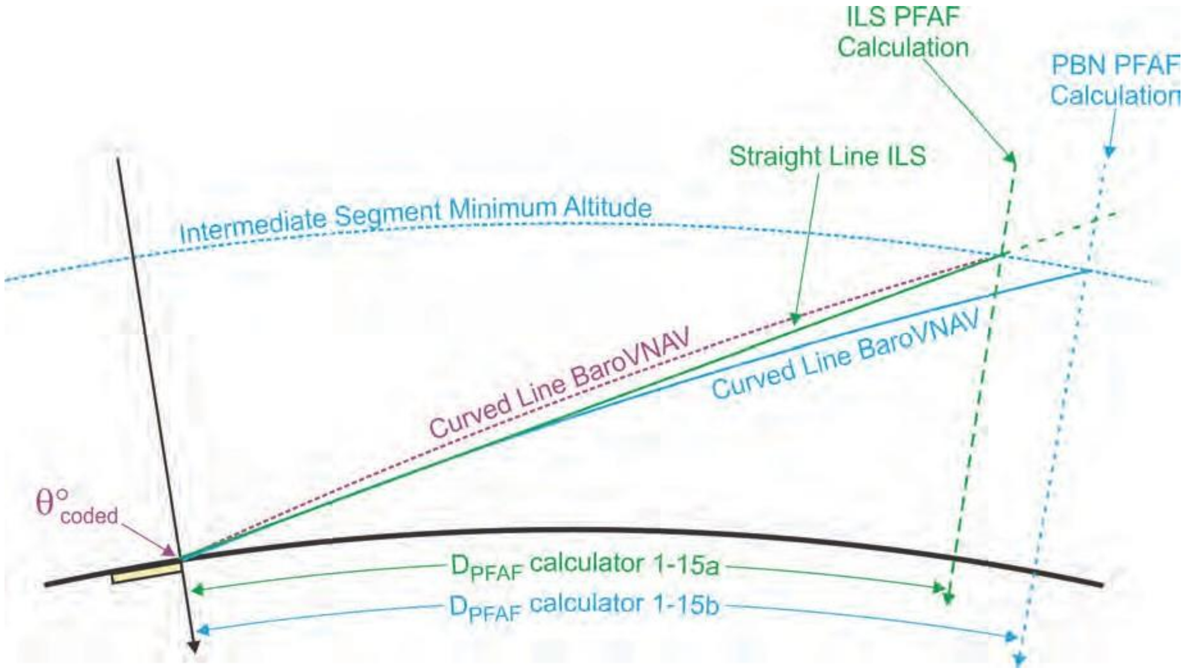
$LGSA = 1.5$

$Width_{feet} = round\left[tan\left(1.5^{o} \times \frac{\pi}{180^{o}}\right) \times d_{GARP}, 0\right]$

$Width_{meters} = \frac{round[4 \times Width_{feet} \times 0.3048,0]}{4}$

7.1.39. Determining PFAF Coordinates (see figure 7-1-17).

Figure 7-1-17. Determining PFAF Distance to LTP



The acronym PFAF replaces FAF because the fix is precisely located. Geodetically calculate the latitude and longitude of the PFAF using the true bearing from the LTP to the PFAF and the horizontal distance (DPFAF) from the LTP to the point the glidepath intercepts the intermediate segment altitude. The ILS/LPV glidepath is assumed to be a straight line in space. The LNAV/VNAV (BaroVNAV) glidepath is a curved line (logarithmic spiral) in space. The calculation of PFAF distance from the LTP for a straight line is different than the calculation for a curved line. Therefore, two calculators are provided for determining this distance. Calculator 1-15a calculates the PFAF and/or glide slope intercept point (PFAF, LPV nomenclature; GPIP, ILS nomenclature) distance from LTP; i.e., the point that the straight line glide slope intersects the minimum intermediate segment altitude). Calculator 1-15b calculates the LNAV/VNAV PFAF distance from LTP; i.e., the point that the curved line BaroVNAV based glidepath intersects the minimum intermediate segment altitude. If LNAV/VNAV minimums are published on the chart, use calculator 1-15b. If no LNAV/VNAV line of minima is published on the approach chart, use calculator 1-15a .

Note: Where an RNAV LNAV/VNAV procedure is published to an ILS runway and the ILS GPIP must be used, publish the actual LNAV/VNAV glidepath angle (θ_{BVNAV}) calculated using calculator 1-15c.

Calculator 1-15a. LPV PFAF/ILS GPIP

$$D_{PFAF}\ or\ D_{GPIP} = \text{round}\left[r \times \left(\frac{\pi}{2} - \theta^o \times \frac{\pi}{180^o} - \text{asin}\left(\frac{\cos\left(\theta^o \times \frac{\pi}{180^o}\right) \times \left(r + LTP_{elev}\right)}{r + alt}\right)\right), 0\right]$$

where alt = minimum intermediate segment altitude
LTP_{elev} = LTP MSL elevation
TCH = TCH value
θ° = glidepath angle

Calculator 1-15b. LNAV/VNAV PFAF

$$D_{PFAF} = \boldsymbol{round}\left[\frac{\ln\left(\frac{r + alt}{r + LTP_{elev} + TCH}\right) \times r}{\tan\left(\theta^o \times \frac{\pi}{180^o}\right)}, 0\right]$$

where alt = minimum intermediate segment altitude
LTP_{elev} = LTP MSL elevation
TCH = TCH value
θ° = glidepath angle

Calculator 1-15c. LNAV/VNAV Angle

$$\theta_{BVNAV} = \boldsymbol{round}\left[\boldsymbol{atan}\left(\boldsymbol{ln}\left(\frac{r + PFAF_{alt}}{r + LTP_{elev} + TCH}\right) \times \frac{r}{D_{PFAF}}\right) \times \frac{180^o}{\pi}, 2\right]$$

where LTP_{elev} = LTP MSL elevation
$PFAF_{alt}$= Minimum MSL altitude at PFAF
D_{PFAF} = distance of existing PFAF
θ° = glidepath angle

7.1.40. Determining Glidepath Altitude at a Fix.

Calculate the altitude ($Z_{glidepath}$) of the glidepath at any distance (DZ) from the LTP using calculator 1-16a for ILS and LPV, and calculator 1-16b for LNAV/VNAV.

Calculator 1-16a. ILS/LPV

$$Z_{glidepath} = round\left[\frac{(r + LTP_{elev} + TCH) \times \cos\left(\theta^o \times \frac{\pi}{180^o}\right)}{\cos\left(\frac{D_z}{r} + \theta^o \times \frac{\pi}{180^o}\right)}, 0\right]$$

where LTP_{elev} = LTP MSL elevation
TCH = TCH value
θ° = glidepath angle
D_Z = distance (ft) from LTP to fix

Calculator 1-16b. LNAV/VNAV

$$Z_{\text{glidepath}} = round\left[e^{\frac{D_Z \times \tan\left(\theta^o \times \frac{\pi}{180^o}\right)}{r}} \times (r + LTP_{elev} + TCH) - r, 0\right]$$

where LTP_{elev} *= LTP MSL elevation*
TCH = TCH value
θ° = glidepath angle
D_Z *= distance (ft) from LTP to fix*

7.1.41. Common Fixes.

Design all procedures published on the same chart to use the same sequence of charted fixes.

7.1.42. Clear Areas and Obstacle Free Zones (OFZ).

The Airport operator is responsible for maintaining obstruction requirements in TP312 Aerodromes Standards and Recommended Practices. Appropriate military directives apply at military installations. For the purpose of this volume, there are two OFZs that apply: the runway OFZ and the inner approach OFZ. The runway OFZ parallels the length of the runway and extends 200 ft beyond the runway threshold. The inner OFZ overlies the approach light system from a point 200 ft from the threshold to a point 200 ft beyond the last approach light. If approach lights are not installed or not planned, the inner OFZ does not apply. When obstacles penetrate either the runway or inner OFZ, visibility credit for lights is not authorized, and the lowest ceiling and visibility values are:

- For GPA ≤ 4.2°: 300-¾ (RVR 4000)
- For GPA > 4.2°: 400-1 (RVR 5000)

7.1.43. Glidepath Qualification Surface (GQS).

See, Volume 3, paragraph 2.11.

7.1.44. Precision Obstacle Free Zone (POFZ).

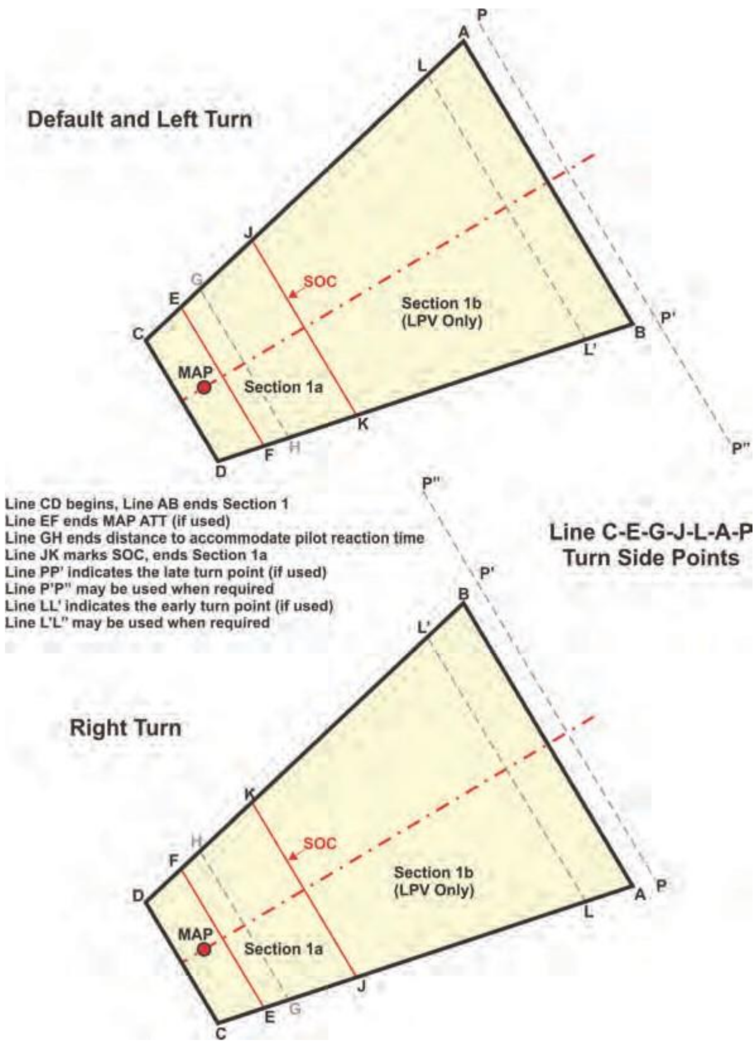
See, Volume 3, paragraph 3.3.

Missed Approach General Information

7.1.45. MAS Conventions.

a. Figure 7-1-18 defines the MAP point OEA construction line terminology and convention for section 1.

Figure 7-1-18. MAS Point/Line Identification



b. The missed approach obstacle clearance standard is based on a minimum aircraft climb gradient of 200 ft/NM, protected by a ROC surface that rises at 152 ft/NM. The MA ROC value is based on a requirement for a 48 ft/NM (200-152 = 48) increase in ROC value from the SOC point located at the JK line (AB line for LPV). The actual slope of the MA surface is (1 NM in feet)/152 ≈39.974. In manual application of TERPS, the rounded value of 40:1 has traditionally been applied. However, this Volume is written for automated application; therefore, the full value (to 15 significant digits) is used in calculations. The nominal OCS slope ($MAOCS_{slope}$) associated with any given missed approach climb gradient is calculated using calculator 1-17.

Calculator 1-17. MA OCS Slope

$$\mathrm{MA_{OCSsLope}} = \frac{\mathrm{fpnm}}{\mathrm{CG} - 48}$$

where *CG = Climb Gradient (nominally 200 ft/NM)*

7.1.46. Charted MA Altitude.

Apply Volume 1, paragraphs 277d and 277f to establish the preliminary and charted MA altitudes.

7.1.47. Climb-In-Holding.

Apply Volume 1, paragraph 277e for climb-in-holding guidance.

SECTION 2: NON-VERTICALLY GUIDED PROCEDURES

7.2. Non-Vertically Guided Procedures.

7.2.1. General.

This chapter contains obstacle evaluation criteria for LNAV and LP non-vertically guided approach procedures. For RNAV transition to LOC final, use LP criteria to evaluate the final and missed approach when RNAV is used for missed approach navigation. When constructing a “stand-alone” non-vertically guided procedure, locate the PFAF using calculator 1-15b, nominally based on a 3-degree vertical path angle. The PFAF location for circling procedures, that do not meet straight-in alignment, are based on the position of the MAP instead of the LTP.

7.2.2. Alignment.

a. Optimum non-vertically guided procedure final segment alignment is with the runway centerline extended through the LTP. When published in conjunction with a vertically guided procedure, alignment must be identical with the vertically guided final segment.

b. When the final course must be offset, it may be offset up to 30 degrees (published separately) when the following conditions are met:

i. For offset ≤ 5 degrees, align the course through LTP.

ii. For offset > 5 degrees and ≤ 10 degrees, the course must cross the runway centerline extended at least 1500 ft prior to LTP (5200 ft maximum).

iii. For offset > 10 degrees and ≤ 20 degrees, the course must cross the runway centerline extended at least 3000 ft prior to LTP (5200 ft maximum). (Offsets > 15 degrees, CAT C/D minimum published visibility 1 SM, minimum HATh of 300 ft)

iv. For offset > 20 to 30 degrees (CAT A/B only), the course must cross the runway centerline extended at least 4500 ft prior to the LTP (5200 ft maximum).

Note: Where paragraphs 7.2.2.b(i-iv) cannot be attained or the final course does not intersect the runway centerline or intersects the centerline more than 5200 ft from LTP, and an operational advantage can be achieved, the final may be aligned to lie laterally within 500 ft of the extended runway centerline at a point 3000 ft outward from LTP. This option requires Flight Standards approval.

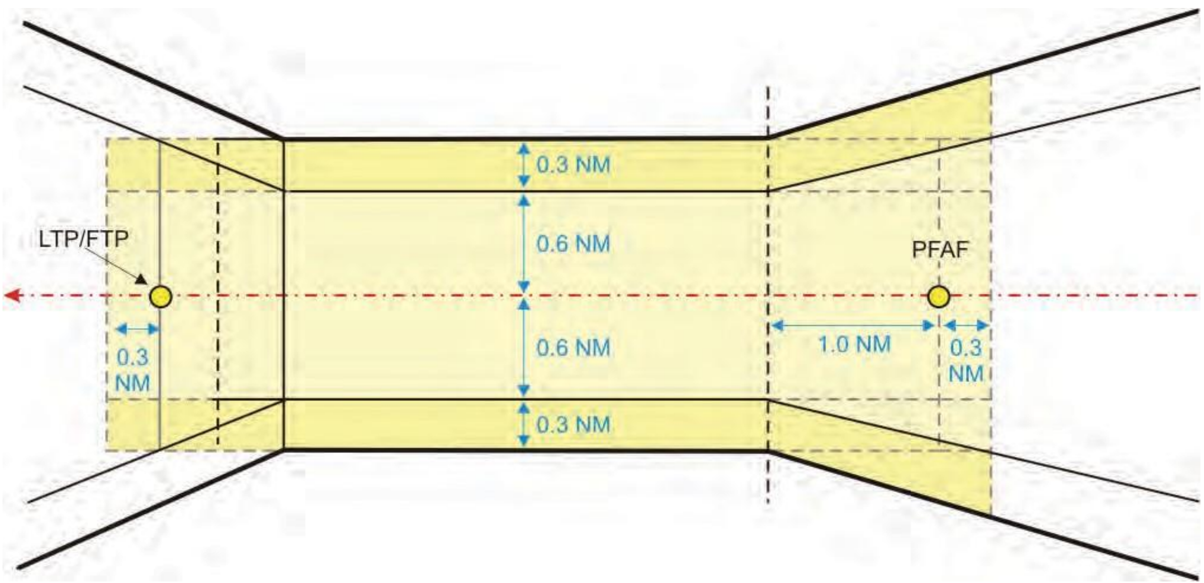
7.2.3. Circling.

The OPTIMUM final course alignment is to the center of the landing area, but may be to any portion of the usable landing surface. The latest point the MAP can be located is abeam the nearest usable landing surface.

7.2.4. Area - LNAV Final Segment.

The intermediate segment primary and secondary areas taper from initial segment OEA width (1-2-2-1) to the width of the final segment OEA. The taper begins at a point 2 NM prior to the PFAF and ends 1.0 NM past the PFAF. The final segment OEA primary and secondary areas follow the tapering boundaries of the intermediate segment from ATT prior to the PFAF to the point 1 NM past the PFAF, and then are a constant width to 0.3 NM past the MAP (see figure 7-2-1).

Figure 7-2-1. LNAV Final Segment OEA



7.2.5. Length.

The OEA begins 0.3 NM prior to the PFAF and ends 0.3 NM past the LTP. Segment length is the distance from the PFAF location to the LTP/FTP location. Determine the PFAF location per paragraph 7.1.39. The maximum length is 10 NM.

7.2.6. Width.

The final segment OEA primary and secondary boundaries are coincident with the intermediate segment boundaries (see paragraph 7.1.30) from a point 0.3 NM prior to the PFAF to a point 1.0 NM past the PFAF (see calculator 2-1). From this point, the Primary OEA boundary is ±0.6 NM (≈3,646 ft) from course centerline. A 0.3 NM (≈1,823 ft) secondary area is located on each side of the primary area. Where the intermediate segment is not aligned with the final segment, the segment boundaries are constructed under paragraph 7.1.33c. Determine the half- width of the primary area (½Wp) and the width of the secondary area (Ws) using calculator 2-1.

Calculator 2-1. Tapering Segment Width

$$(1) \qquad \frac{1}{2}W_p = \frac{1.4+d}{3} + 0.6$$

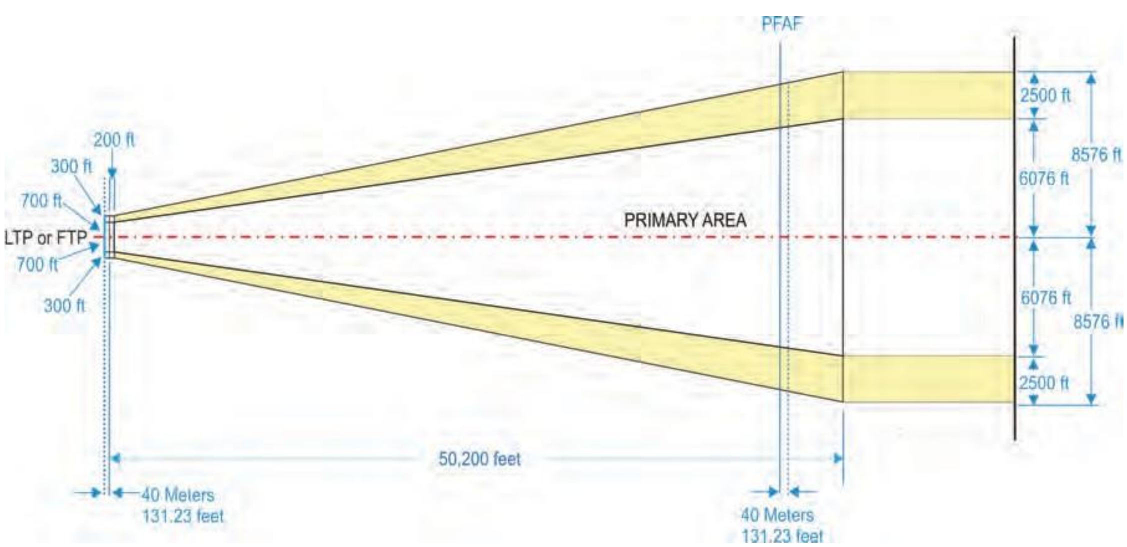
$$(2) \qquad W_s = \frac{0.7+d}{3} + 0.3$$

where d = along-track distance from line "B" (see figure 7-1-13E)

7.2.7. Area – LP Final Segment.

The intermediate segment primary and secondary areas taper from initial segment OEA width (1-2-2-1) to the width of the final segment OEA. The taper begins at a point 2NM prior to the PFAF and ends abeam the PFAF. The final segment OEA primary and secondary areas are linear (constant width) at distances greater than 50200 ft from LTP. Inside this point, they taper uniformly until reaching a distance of 200 ft from LTP. From this point the area is linear to the OEA end 131.23 ft (40m) past the LTP (see figure 7-2-2).

Figure 7-2-2. LP Final Area



7.2.8. Length.

The OEA begins 131.23 ft (40 m) prior to the PFAF and ends 131.23 ft (40 m) past the LTP. Segment length is the distance from the PFAF location to the LTP/FTP location. Determine the PFAF location per paragraph 7.1.39. The maximum length is 10NM.

7.2.9. Width (see figure 7-2-2).

a. The perpendicular distance (½Wp) from the course centerline to the outer boundary of the primary area is a constant 700 ft from a point 131.23 ft (40 m) past (inside) the LTP to a point 200 ft prior to (outside) the LTP. It expands from this point in a direction toward the PFAF. Calculate ½Wp from the 200 ft point to a point 50200 from LTP using calculator 2-2. The value of ½Wp beyond the 50200-ft point is 6076 ft.

Calculator 2-2. Primary Area Width

$$\frac{1}{2}W_p = 0.10752 \times \mathrm{D} + 678.496$$

where *D = Along-track distance*
(≥ 200 ≤ 50200) from LTP/FTP

b. The perpendicular distance (Ws) from the course centerline to the outer boundary of the secondary area is a constant 1000 ft from a point 131.23 ft (40 m) past (inside) the LTP to a point 200 ft prior to (outside) the LTP. It expands from this point in a direction toward the PFAF. Calculate Ws from the 200 ft point to a point 50200 from LTP using calculator 2-3. The value of Ws beyond the 50200-ft point is 8576 ft.

Supplementary note: The "W_S" in paragraph 7.2.9b is the perpendicular distance from the course centerline to the outer boundary of the secondary area (full OEA width). Calculator 2-4 requires input of variable "W_S" but does not specify a clear definition. This value is not the same as the "W_S" output from calculator 2-3. For the purposes of calculator 2-4, "W_S" must be interpreted to be equal to the total width of the secondary area measured from the edge of the primary area. However for calculator 2-7b, the "W_S" output from calculator 2-3 can be used.

Calculator 2-3. Secondary Area Width

$$\mathrm{W_s} = 0.15152 \times \mathrm{D} + 969.696$$

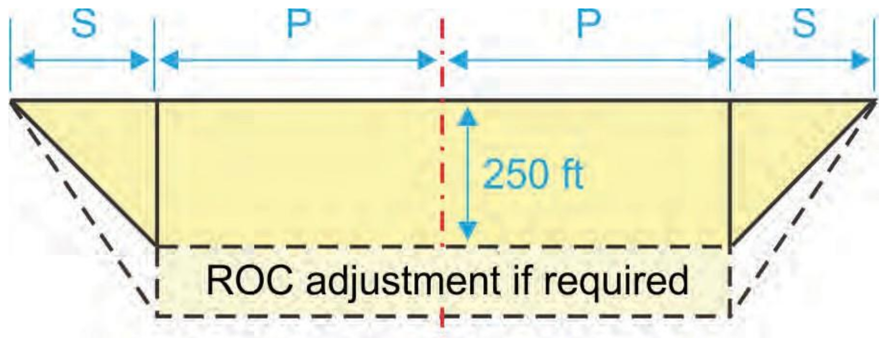
where *D = Along-track distance*
(≥ 200 ≤ 50200) from LTP/FTP

7.2.10. Obstacle Clearance.

a. **Primary Area.** Apply 250 ft of ROC to the highest obstacle in the primary area. Order, Volume 1, chapter 3 precipitous terrain, remote altimeter, and excessive length of final adjustments apply.

b. **Secondary Area.** Secondary ROC tapers uniformly from 250 ft (plus adjustments) at the primary area boundary to zero at the outer edge (see figure 2-3).

Figure 7-2-3. Primary/Secondary ROC



c. Calculate the secondary ROC value using calculator 2-4.

Calculator 2-4. Secondary Area ROC

$$ROC_{secondary} = (250 + adj) \times \left(1 - \frac{d_{primary}}{W_s}\right)$$

where $d_{primary}$ *= perpendicular (relative to course centerline) distance (ft) from edge of primary area*
W_S *= the total width of the secondary area measured from the edge of the primary area*
adj = Volume 1, chapter 3 adjustments

7.2.11. Final Segment Stepdown Fixes.

a. Where the MDA can be lowered at least 60 ft or a reduction in visibility can be achieved, SDFs may be established in the final approach segment.

b. Volume 1, paragraph 288 applies, with the following:

i. Establish step-down fix locations in 0.10 NM increments from the LTP/FTP.

ii. The minimum distance between stepdown fixes is 1 NM.

iii. For step-down fixes published in conjunction with vertically-guided minimums, the published altitude at the fix must be equal to or less than the computed glidepath altitude at the fix

Note: Glidepath altitude is calculated using the calculator associated with the basis of the PFAF calculation.

iv. The altitude at any stepdown fix may be established in 20-ft increments and shall be rounded to the next HIGHER 20-ft increment. For example, 2104 becomes 2120.

v. Where a RASS adjustment is in use, the published stepdown fix altitude must be established no lower than the altitude required for the greatest amount of adjustment (i.e., the published minimum altitude must incorporate the greatest amount of RASS adjustment required).

vi. Volume 1, paragraph 252 applies to LNAV and LP descent angles.

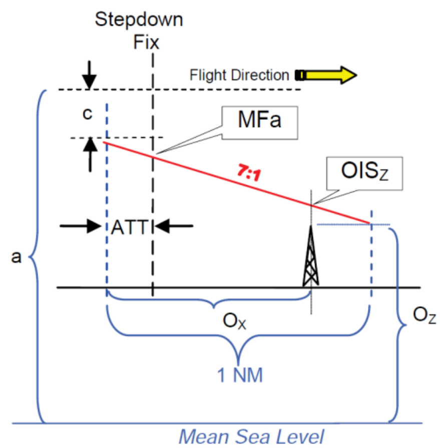
vii. Where turns are designed at the PFAF, Volume 1, paragraph 289 applies with the following exception: the 7:1 OIS starts ATT prior to the angle bisector, and extends 1 NM parallel to the final approach centerline. See figure 7-1-13E (LNAV) and figure 7-1-13F (LP). Use the following calculators to determine OISZ at an obstacle and MFa based on an obstacle height (see calculator 2-5).

Calculator 2-5. $\mathrm{OIS_Z}$ & Minimum Fix Altitude

$$(1)\ \mathrm{OIS_Z} = \boldsymbol{a} - \boldsymbol{c} - \frac{\mathrm{O_X}}{7}$$

$$(2)\ \mathrm{MFa} = \boldsymbol{O_Z} + \boldsymbol{c} + \frac{\mathrm{O_X}}{7}$$

where c = ROC plus adjustments (Vol 1, paragraph 323)
a = MSL fix altitude
O_X = Obstacle along-track distance (ft) from ATT prior to fix (1 NM max)
O_Z = MSL obstacle elevation



7.2.12. Minimum Descent Altitude (MDA).

The MDA value is the sum of the controlling obstacle elevation MSL (including vertical error value when necessary) and the ROC + adjustments. Round the sum to the next higher 20-ft increment; e.g., 623 rounds to 640. The minimum HATh value is 250 ft.

7.2.13. MA Section 1. (MAS-1).

The beginning of Section 1 MA uses the applicable final segment ATT from Chap 2, Table 2-2-1 and begins ATT prior to the MAP and extends to the SOC or the point where the aircraft is projected to cross 400 ft above airport elevation, whichever is the greater distance from MAP (see figure 7-2-4).

7.2.14. Length.

a. Flat Surface Length (FSL).

i. LNAV. Section 1 flat surface begins at the CD line (0.3NM prior to the MAP) and extends (distance FSL feet) to the JK line.

ii. LP. Section 1 flat surface begins at the CD line 131.23 ft (40 m) prior to the MAP and extends (distance FSL feet) to the JK line.

iii. Calculate the value of FSL using calculator 2-6.

b. Location of end of section 1 (AB line).

i. MDA ≥ 400 ft above airport elevation. The AB line is coincident with the JK line.

ii. MDA < 400. The AB line is located $\frac{1852}{(0.3048 \times CG)}$ feet beyond the JK line for each foot of altitude needed to reach 400 ft above airport elevation. The surface between the JK and AB lines is a rising surface with a slope commensurate with the rate of climb (nominally 40:1).

Calculator 2-6. Flat Surface Length

$$FSL = 12 \times \frac{fpnm}{3600} \times \left(\left(V_{KIAS} \times \frac{171233 \times \sqrt{303 - 0.00198 \times MDA}}{(288 - 0.00198 \times MDA)^{2.628}} \right) + 10 \right) + 2 \times ATT$$

where V_{KIAS} *= is the appropriate final approach speed from Chap 7, Table 7-1-3 for each category.*

7.2.15. Width. LNAV and LP.

a. **LNAV.** The primary area boundary splays uniformly outward from the edge of the primary area at the CD line until it reaches a point 2 NM from course centerline. The secondary area outer boundary lines splay outward 15 degrees relative to the missed approach course from the outer edge of the secondary areas at the CD line is 131.23ft (40m) prior to MAP until it reaches a point 3 NM from course centerline. Calculate the distance from course centerline to the primary and outer secondary boundary of the MAS-1 OEA at any distance from the CD line using calculator 2-7a.

Calculator 2-7a. LNAV Primary & Secondary Width

(1) $MAS_{Yprimary} = d \times \frac{tan\left(15^{o} \times \frac{\pi}{180^{o}}\right) \times 1.4 \times fpnm}{2.1 \times fpnm} + 0.6 \times fpnm$

(2) $MAS_{Ysecondary} = d \times tan\left(15^{o} \times \frac{\pi}{180^{o}}\right) + 0.9 \times fpnm$

where d = along-track distance (ft) from the CD line ≤ 47620.380

b. **LP.** The primary area boundary splays uniformly outward from the edge of the primary area at the CD line until it reaches a point 2 NM from course centerline. The secondary area outer boundary lines splay outward 15 degrees relative to the missed approach course from the outer edge of the secondary areas at the CD line (0.3 NM prior to MAP) until it reaches a point 3 NM from course centerline. Calculate the distance from course centerline to the primary and outer secondary boundary of the MAS-1 OEA at any distance from the CD line using calculator 2-7b.

Calculator 2-7b. LP Primary & Secondary Width

(1) $MAS_{primary} = d \times \frac{tan\left(15^{o} \times \frac{\pi}{180^{o}}\right) \times \left(2 \times fpnm - 1/2 \cdot W_{p}\right)}{3 \times fpnm - W_{s}} + 1/2 \cdot W_{p}$

where $1/2W_{P}$ = output from calculator 2-2

(2) $MAS_{secondary} = d \times tan\left(15^{o} \times \frac{\pi}{180^{o}}\right) + W_{s}$

where d = along-track distance (ft) from the CD line ≤ 64297.064

7.2.16. Obstacle Clearance. LNAV and LP.

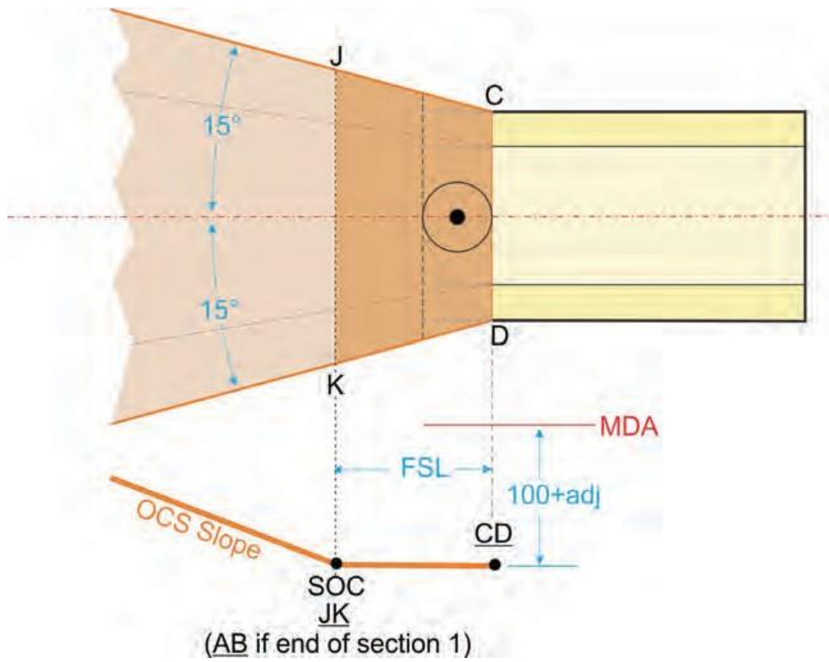
The MAS-1 OCS is a flat surface. The MSL height of the surface (HMAS) is equal to the MDA minus 100 ft plus precipitous terrain, remote altimeter (only if full time), and excessive length of final adjustments (see calculator 2-8).

Calculator 2-8. HMAS

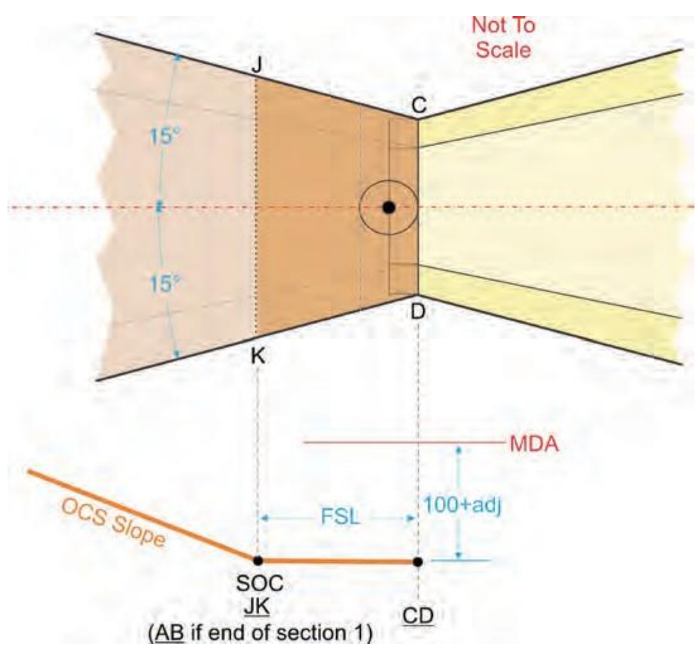
$$HMAS = MDA - (100 + adj)$$

where *adj = final segment precipitous terrain, remote altimeter (only if full time), and excessive length of final adjustments*

Figure 7-2-4. MA Section 1 LNAV



LP



SECTION 3: LATERAL NAVIGATION WITH VERTICAL GUIDANCE (LNAV/VNAV)

7.3. Lateral Navigation with Vertical Guidance (LNAV/VNAV).

7.3.1. General.

An LNAV/VNAV approach is a vertically-guided approach procedure using Baro-VNAV or WAAS VNAV for the vertical guidance. Obstacle evaluation is based on the LNAV OEA dimensions and Baro-VNAV OCS. The actual vertical path provided by Baro-VNAV is influenced by temperature variations; i.e., during periods of cold temperature, the effective glidepath may be lower than published and during periods of hot weather, the effective glidepath may be higher than published. Because of this phenomenon, minimum and maximum temperature limits (for aircraft that are not equipped with temperature compensating systems) are published on the approach chart. Additionally, LNAV/VNAV approach procedures at airports where remote altimeter is in use or where the final segment overlies precipitous terrain must be annotated to indicate the approach is not authorized for Baro-VNAV systems. TERPS ROC adjustments for excessive length of final do not apply to LNAV/VNAV procedures. LNAV/VNAV minimum HATh value is 250 ft.

7.3.2. FAC Alignment.

a. Optimum final segment alignment is with the runway centerline (± 0.03 degree) extended through the LTP.

b. Where lowest minimums can only be achieved by offsetting the final course, it may be offset up to 15 degrees when the following conditions are met:

i. For offset ≤ 5 degrees, align the course through LTP.

ii. For offset > 5 degrees and ≤ 10 degrees, the course must cross the runway centerline extended at least 1500 ft (5200 ft maximum) prior to LTP. (d1=1500) Determine the minimum HATh value using calculator 3-1.

iii. For offset > 10 degrees and ≤ 15 degrees, the course must cross the runway centerline extended at least 3000 ft (5200 ft maximum) prior to LTP (d1=3000). Determine the minimum HATh value (MINHATh) using calculator 3-1.

Calculator 3-1. Offset Alignment Minimum DA

(1) $$d2 = \frac{V_{KIAS}{}^2 \times tan\left(\frac{\alpha^o}{2} \times \frac{\pi}{180^o}\right)}{68625.4 \times tan\left(18^o \times \frac{\pi}{180^o}\right)} \times fpnm$$

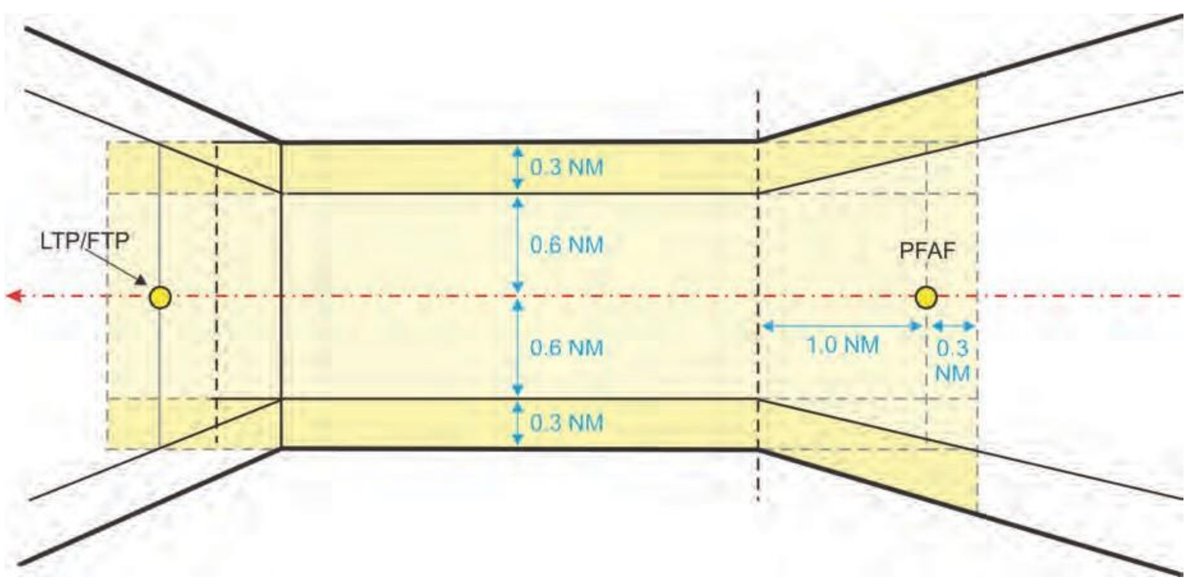
(2) $$Min_{HATh} = e^{\left(\frac{(d1+d2)\times tan\left(\theta^o \times \frac{\pi}{180^o}\right)}{r}\right)} \times (r + LTP_{elev} + TCH) - (r + LTP_{elev})$$

Where α^o= degree of offset
θ^o= glidepath angle (degrees)
LTP_{elev} = LTP MSL elevation
d1 = value from paragraph 7.3.2b ii/iii as appropriate

7.3.3. Area.

The intermediate segment primary and secondary areas taper from initial segment OEA width (1-2-2-1) to the width of the final segment OEA width (0.3-0.6-0.6-0.3). The taper begins at a point 2 NM prior to the PFAF and ends 1.0 NM following (past) the PFAF. The final segment OEA primary and secondary areas follow the tapering boundaries of the intermediate segment from ATT prior to the PFAF to the point 1 NM past the PFAF, and then are a constant width to 0.3 NM past the MAP (see figure 7-3-1).

Figure 7-3-1. LNAV/VNAV Final Segment OEA



7.3.4. LENGTH

The LNAV final segment OEA ends at the final segment ATT past the MAP. Segment length is determined by PFAF location. Determine the PFAF location per paragraph 7.1.39. The maximum length is 10 NM.

7.3.5. Width.

The final segment primary and secondary boundaries are coincident with the intermediate segment boundaries (see paragraph 7.1.30) from a point 0.3 NM prior to the PFAF to a point 1 NM past the PFAF. From this point, the Primary OEA boundary is $\pm$0.6 NM ($\approx$3,646 ft) from course centerline. A 0.3 NM ($\approx$1,823 ft) secondary area is located on each side of the primary area. Where the intermediate segment is not aligned with the final segment, the segment boundaries are constructed under paragraph 7.1.33c.

7.3.6. Obstacle Clearance Surface (OCS).

a. Obstacle clearance is provided by application of the Baro-VNAV OCS. The OCS originates at LTP elevation at distance Dorigin from LTP as calculated by calculator 3-2.

Calculator 3-2. OCS Origin

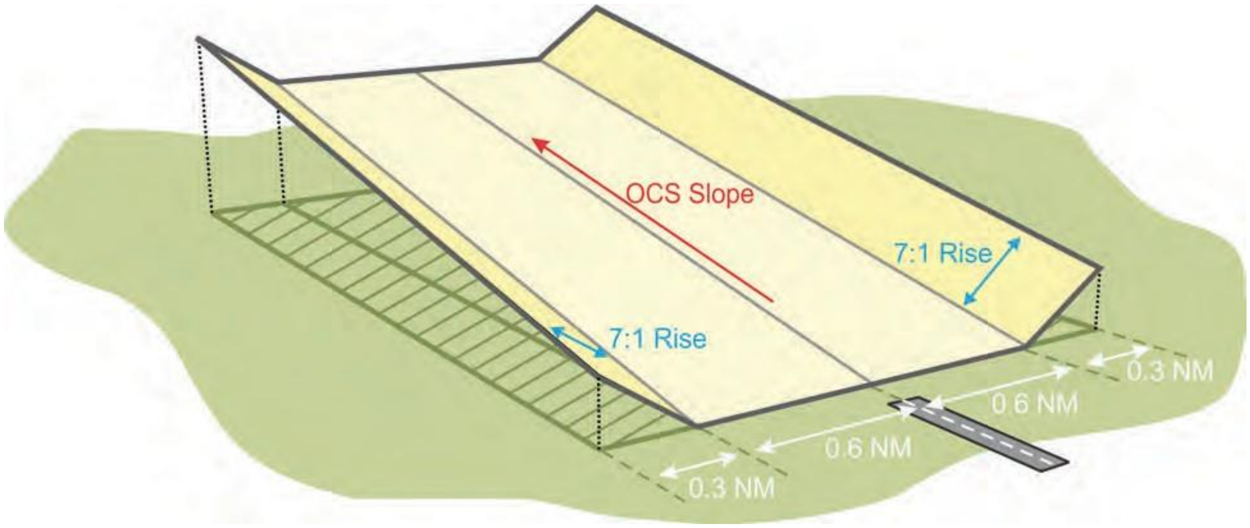
$$D_{\text{origin(ft)}} = \frac{250 - \text{TCH}}{\tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)}$$

where

θ° = *glidepath angle*

b. The OCS is a sloping plane in the primary area, rising along the course centerline from its origin toward the PFAF. The OCS slope ratio is calculated under paragraph 7.3.9. In the primary area, the elevation of the OCS at any point is the elevation of the OCS at the course centerline abeam it. The OCS in the secondary areas is a 7:1 surface sloping upward from the edge of the primary area OCS perpendicular to the flight track (see figure 7-3-2).

Figure 7-3-2. Final Segment OCS



c. The primary area OCS slope varies with the designed glidepath angle. The effective glidepath angle (actual angle flown) depends on the deviation from ISA temperature associated with airport elevation. Calculate the ISA temperature (Celsius and Fahrenheit) for the airport using calculator 3-3.

Calculator 3-3. Airport ISA

$$ISA_{airport°C} = 15 - 0.00198 \times airport\ elevation$$

$$ISA_{airport°F} = 1.8 \times ISA_{airport°C} + 32$$

7.3.7. Determining Average Cold Temperature.

a. The OCS slope ratio (run/rise) provides obstacle protection within a temperature range that can reasonably be expected to exist at the airport. The slope ratio is based on the temperature spread between the airport ISA and the temperature to which the procedure is protected. This value is termed ΔISA_{low}. To calculate ΔISA_{low}, determine the ACT for which the procedure will be protected.

b. Establish a 5-year history window starting with the most recent year in which history is available for the entire calendar year (CY) (i.e., January 1 – December 31). The earliest year of the reporting window must be within six years of the current year.

Example:

The current year is 2010; the allowable reporting period is 2004 thru 2009. Complete data for CY 2009 is not yet available, but complete data is available for CY 2008 and preceding years. Use the complete 5-year history from January 1, 2004 to December 31, 2008 to establish the ACT. If complete data is available for CY 2009 and preceding years dating back to 2004, use the 5-year history from January 1, 2005 to December 31, 2009 to establish the ACT.

c. If a 5-year history is not available, then use a 4-year history. If a 4-year history is not available, then use a 3-year history. A 3-year history is the minimum history required. The 3 or 4-year history may include any years within the 5-year window defined above provided each of the years contains complete data for the full calendar year.

d. Calculate the preliminary ACT as follows:

i. Within each of the years used, find the month with the average coldest temperature.

Example:

2004	2005	2006	2007	2008
45.4°F	44.7°F	43.4°F	42.2F	45.0°F

ii. Within each of the average coldest months determined in (1), find the coldest day.

Example:

2004	2005	2006	2007	2008
37°F	35°F	35°F	29°F	35°F

iii. Average the coldest day temperatures.

Example:

$$(°F)\ \frac{37+35+35+29+35}{5} = 34.2$$

Note: If Fahrenheit values are used, convert to Celsius using calculator 3-4.

Example:

$$\frac{34.2 - 32}{1.8} = 1.22$$

`preliminary ACT = 1.22°C`

iv. Round the Celsius value from (iii) to the next warmer whole degree; e.g., -15.00 remains -15; -14.99 becomes -14). The resultant rounded value is the ACT.

Example from (iii): ACT = 2°C

v. For procedure documentation use: "Average Cold Temperature based on (# years used)-year history (inclusive years; e.g., 2004-2008 or if individual years used; e.g., 2004, 2006, 2008)".

Examples:

vi. "Average Cold Temperature based on 5-year history (2004-2008)" "Average Cold Temperature based on 3-year history (2004, 2006, 2008)".

e. If historical temperature data is not available, determine the ACT as follows:

i. Determine the temperature deviation from the airport ISA (ΔISA) using table 7-3-1 based on the Airport Reference Point geographical area:

Table 7-3-1. Standard (ΔISA Values)

Location	Value below airport ISA°C / °F
Conus	-30°C / -54°F
Alaska	-40°C / -72°F
Hawaii	-20°C / -36°F

ii. Use calculator 3-3 to calculate the airport ISA in degrees Celsius:

Example: `15-0.00198×677.4=13.66`

iii. Determine the preliminary ACT based on the selected ΔISA value by adding ΔISA to the airport ISA value: Preliminary ACT=ΔISA +ISA

Example: `-30+13.66=-16.34`

iv. Round the calculated value to the next warmer whole degree; e.g., -15.00 remains -15; -15.01 thru -15.99 becomes -15. The resultant rounded value is the ACT.

Example from (3): `ACT = -16°C`

v. For procedure documentation identify the temperature deviation used to determine the ACT.

Example:

vi. "Average Cold Temperature based on standard -30°C ISA deviation."

f. Determine the published low temperature limit using calculator 3-4.

7.3.8. Determining Low Temperature Limit.

Normally, the low temperature limit is the calculated ACT. Where the ACT results in an effective glidepath that is less than 2.5 degrees, raise the low temperature limit to the temperature required to achieve an effective 2.5 degree glidepath. Use calculator 3-4 to determine the low temperature limit.

Calculator 3-4. Low Temperature Limit

{*Low temperature based on warmer of effective glidepath angle of 2.5 degrees or ACT*}

(1) $\Delta ISA_{ACT} = ACT - (15 - 0.00198 \times airport_{\ elev})$

(2) $\Delta DA_{alt_{ACT}} = \frac{250 \times \Delta ISA_{ACT}}{288 + \Delta ISA_{ACT} - 0.5 \times 0.00198 \times (LTP_{elev} + 250)}$

(3) $d_{DA_{ft}} = ceiling\left[\frac{r \times In\left(\frac{r + LTP_{elev} + 250}{r + LTP_{elev} + TCH}\right)}{tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)}\right]$

(4) $\theta_{effective} = \frac{180}{\pi} \times atan\left(\frac{r}{d_{DA\_ft}} \times In\left(\frac{r + LTP_{elev} + 250 + \Delta DA_{alt\_ACT}}{r + LTP_{elev} + TCH}\right)\right)$

(5) $\Delta DA_{alt\_2.5} = (r + LTP_{elev} + TCH) \times e^{\frac{d_{DA\_ft}}{r} \times tan\left(2.5 \times \frac{\pi}{180}\right)} - (r + LTP_{elev} + 250)$

(6) $\Delta ISA_{2.5} = \frac{\Delta DA_{alt\_2.5} \times (288 - 0.5 \times 0.00198 \times (LTP_{elev} + 250))}{250 - \Delta DA_{alt\_2.5}}$

(7) $ACT_{2.5} = ISA_{airport} + \Delta ISA_{2.5}$

(8) $Case \quad \theta_{effective} \geq 2.5^{o} \qquad NA_{below°C} = ceiling[ACT]$

$NA_{below°F} = ceiling[ACT_{2.5} \times 1.8 + 32]$

$\Delta ISA_{low°C} = \Delta ISA_{2.5}$

(9) $Case \quad \theta_{effective} < 2.5^{o} \qquad NA_{below°C} = ceiling[ACT_{2.5}]$

$NA_{below°F} = ceiling[ACT_{2.5} \times 1.8 + 32]$

$\Delta ISA_{low°C} = \Delta ISA_{2.5}$

where

$\theta°$ = *designed glidepath angle in degrees*

LTP_{elev} = *LTP elevation in feet*

TCH = Threshold crossing height in feet

$airport_{elev}$ = *Airport elevation in feet above mean sea level*

ACT = Average cold temperature at the airport in degrees celsius

7.3.9. Determining High Temperature Limitation.

a. The maximum temperature limit is the temperature that yields an effective glidepath angle equal to 1.13 times the maximum allowed glidepath angle for the published fastest category (see calculator 3-5).

Calculator 3-5. High Temperature Limit

```
- - - - -{ Determination of Max glidepath angles and indicated airspeeds }- - - - - -
      if CAT="A" then
           V_KIAS = 90
          α = 5.7
      end if
      if CAT = "B" then
           V_KIAS = 120
          α = 4.2
      end if
if CAT = "C" then
V_KIAS = 140
           α = 3.6
      end if
      if CAT = "D" then
           V_KIAS = 165
           α = 3.1
      end if
      if CAT = "E" then
           V_KIAS = 250
           α = 3.1
      end if
  - - - -{Determination of Descent Rates (DR) at high temp limit and ISA standard temperature }- - - - - -
```

(1) $MDR_{angle} = 1.13 \times \propto \times \frac{\pi}{180}$

(2) $DR_{high_{temp}} = \text{ceiling}\left[\sin\left(MDR_{angle}\right) \times \left(\frac{(\text{V}_{\text{KIAS}})\times 171233\times\sqrt{303-0.00198\times(\text{LTP}_{\text{elev}}+250)}}{(288-0.00198\times(\text{LTP}_{\text{elev}}+250))^{2.628}} + 10\right) \times 101.26859\right]$

(3) $DR_{standard\_temp} = \text{ceiling}\left[\sin\left(\theta \times \frac{\pi}{180}\right) \times \left(\frac{(\text{V}_{\text{KIAS}})\times 171233\times\sqrt{303-0.00198\times(\text{LTP}_{\text{elev}}+250)}}{(288-0.00198\times(\text{LTP}_{\text{elev}}+250))^{2.628}} + 10\right) \times 101.26859\right]$

- - - - - - - - - - - - - - - - -{ *High Temperature Limit* }- - - - - - - - - - - - - - - - -

{High temperature limit based on 1.13 times the max allowable glidepath angle for the fastest published aircraft category}

(4) $ISA_{airport} = 15 - 0.00198 \times airport_{elev}$

(5) $d_{DA\_ft} = ceiling\left[\frac{r \times In\left(\frac{r+LTP_{elev}+250}{r+LTP_{elev}+TCH}\right)}{tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)}\right]$

(6) $\Delta DA_{alt} = e^{\frac{d_{DA\_ft}}{r} \times tan(MDR_{angle})} \times (r + LTP_{elev} + TCH) - (r + LTP_{elev} + 250)$

(7) $\Delta ISA_{high} = \frac{\Delta DA_{alt} \times (288 - 0.5 \times 0.00198 \times (LTP_{elev} + 250))}{250 - \Delta DA_{alt}}$

(8) $temp_{high°C} = ISA_{airport} + \Delta ISA_{high}$
$temp_{high°F} = temp_{high°C} \times 1.8 + 32$

(9) *Case* $temp_{high°C} \geq 54$ $NA_{above°C} = 54$

$NA_{above°F} = 130$

(10) c

Case $temp_{high°C} < 54$ $NA_{above°C} = floor[\ temp_{high°C}]$

$NA_{above°F} = floor[\ temp_{high°F}]$

where

CAT = Aircraft approach category
θ = designed glidepath angle in degrees
LTP_{elev}= LTP elevation in feet
TCH = Threshold crossing height in feet
$airport_{elev}$= Airport elevation in feet above mean sea level

b. The calculator also determines the maximum expected descent rate at the high temperature limit, for the airport standard temperature, and the delta-ISA low value appropriate for the low temperature limit. Record this information in the procedure documentation.

7.3.10. OCS Slope.

The OCS slope is dependent upon the published GPA (θ), airport ISA, and the ACT temperatures. Determine the OCS slope value using calculator 3-6.

Calculator 3-6. OCS Slope

$$OCS_{sLope} = \frac{1}{tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right) \times \left(0.928 + 0.0038 \times (ACT°\mathrm{C} - ISA°\mathrm{C})\right)}$$

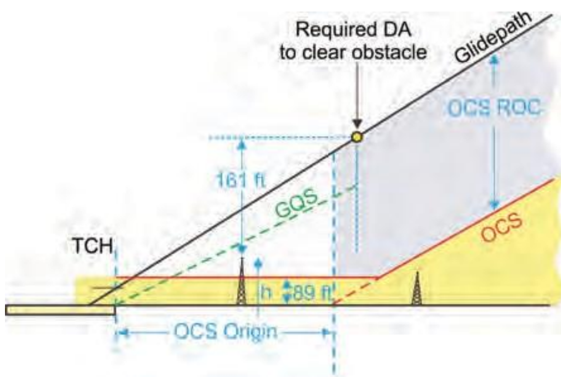
where

θ° = Glidepath angle (degrees)
ISA°C = Airport ISA from calculator 3-3
ACT°C = Value from paragraph 7.3.7 and is the NA_{below}(°C) output from Chap 7, Calculator 3-4.

7.3.11. Final Segment Obstacle Evaluation.

a. The final segment OEA is evaluated by application of an ROC and an OCS. ROC is applied from the LTP to the point the OCS reaches 89 ft above LTP elevation. The OCS is applied from this point to a point 0.3 NM outside the PFAF (see figure 7-3-3).

Figure 7-3-3. Obstacle Evaluation



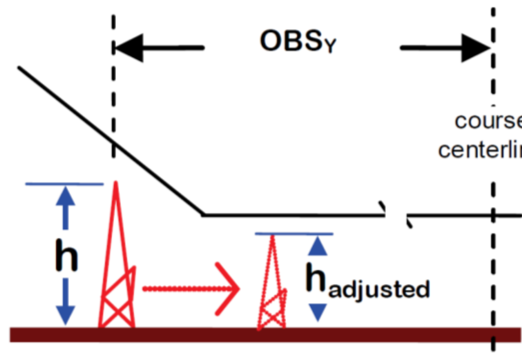
b. If an obstacle is in the secondary area (transitional surface), adjust the height of the obstacle using calculator 3-7, then evaluate it at the adjusted height as if it is in the primary area.

Calculator 3-7. Secondary Area Adjusted Obstacle Height

$$h_{adjusted} = h - \frac{OBS_y - Width_{primary}}{7}$$

where

h = obstacle MSL elevation
$Width_{primary}$ = perpendicular distance (ft) of primary boundary from course centerline
OBS_Y = obstacle perpendicular distance (ft) from course centerline



7.3.12. ROC application.

a. Apply the appropriate value from table 7-3-2 to the higher of the following:

i. height of the obstacle exclusion area or
ii. highest obstacle above the exclusion area.

b. Calculate the DA based on ROC application (DAROC) using calculator 3-8. Round the result to the next higher foot value.

Calculator 3-8. DA Based on ROC Application

$$DA_{ROC} = h + hL$$

where

h = higher of: Obstacle MSL elevation ($h_{adjusted}$ if in secondary)
or
height of obstacle exclusion surface (89 ft above LTP elevation)
hL = value from table 7-3-2

7.3.13. OCS Evaluation.

a. The OCS begins DORIGIN from LTP at LTP elevation. Application of the OCS begins at the point the OCS reaches 89 ft above LTP elevation. Determine the distance from LTP that the OCS reaches 89 ft above LTP using calculator 3-9a. The MSL elevation of the OCS (OCSelev) at any distance (OBS_X) from LTP (OBS_X>Dorigin) is determined using calculator 3-9b.

Calculator 3-9a. Distance from LTP that OCS Application Begins

$$D_{OCS} = D_{origin} + r \times OCS_{sLope} \times In\left(\frac{LTP_{elev} + 89 + r}{r + LTP_{elev}}\right)$$

where

D_{origin} = distance from calculator 3-2

OCS_{sLope} = slope from calculator 3-6

Calculator 3-9b. OCS Elevation

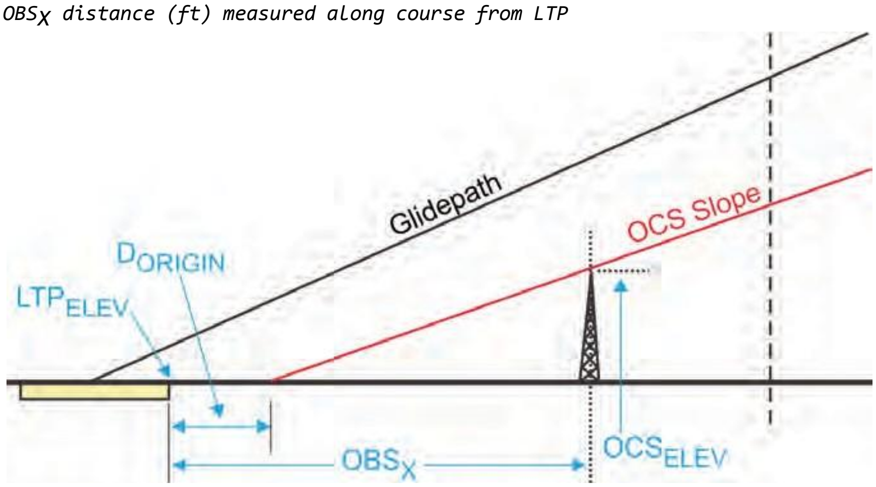
$$OCS_{elev} = (r + LTP_{elev}) \times e^{\frac{OBS_X - D_{origin}}{r \times OCS_{sLope}}} - r$$

where

D_{origin} = distance (ft) from LTP to OCS origin

OCS_{sLope} = OCS slope ration (run/rise; e.g., 34)

OBS_X distance (ft) measured along course from LTP



b. Where obstacles penetrate the OCS, determine the minimum DA value (DAOCS) based on the OCS evaluation by applying calculator 3-10 using the penetrating obstacle with the highest MSL value (see figure 7-3-4).

Calculator 3-10. DA Based On OCS

$$(1)\ d = (r + LTP_{elev}) \times OCS_{sLope} \times In\left(\frac{r+O_{MSL}}{r \times LTP_{elev}}\right) + D_{origin}$$

$$(2)\ DA_{OCS} = e^{\frac{d \times tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)}{r}} \times (r + LTP_{elev} + TCH) - r$$

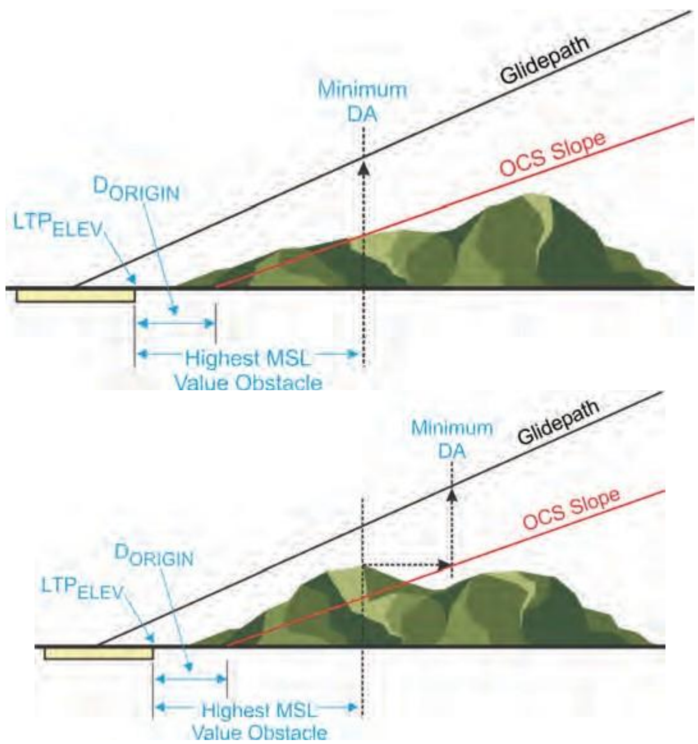
where

O_{MSL}= *obstacle MSL elevation*

D_{origin} = *value from calculator 3-2*

OCS_{slope} = *value from calcualtor 3-6*

Figure 7-3-4. OCS Penetrations



7.3.14. Final Segment DA. The published DA is the higher of DA_{ROC} (calculator 3-8) or DA_{OCS} (calculator 3-10).

7.3.15. Calculating DA to LTP distance. Calculate the distance from LTP to DA using calculator 3-11.

Calculator 3-11. Distance to DA

$$\boldsymbol{D_{DA}} = \frac{In\left(\dfrac{r + DA}{\boldsymbol{r + LTP_{elev} + TCH}}\right) \times r}{\boldsymbol{tan}\left(\theta^{o} \times \dfrac{\pi}{180^{o}}\right)}$$

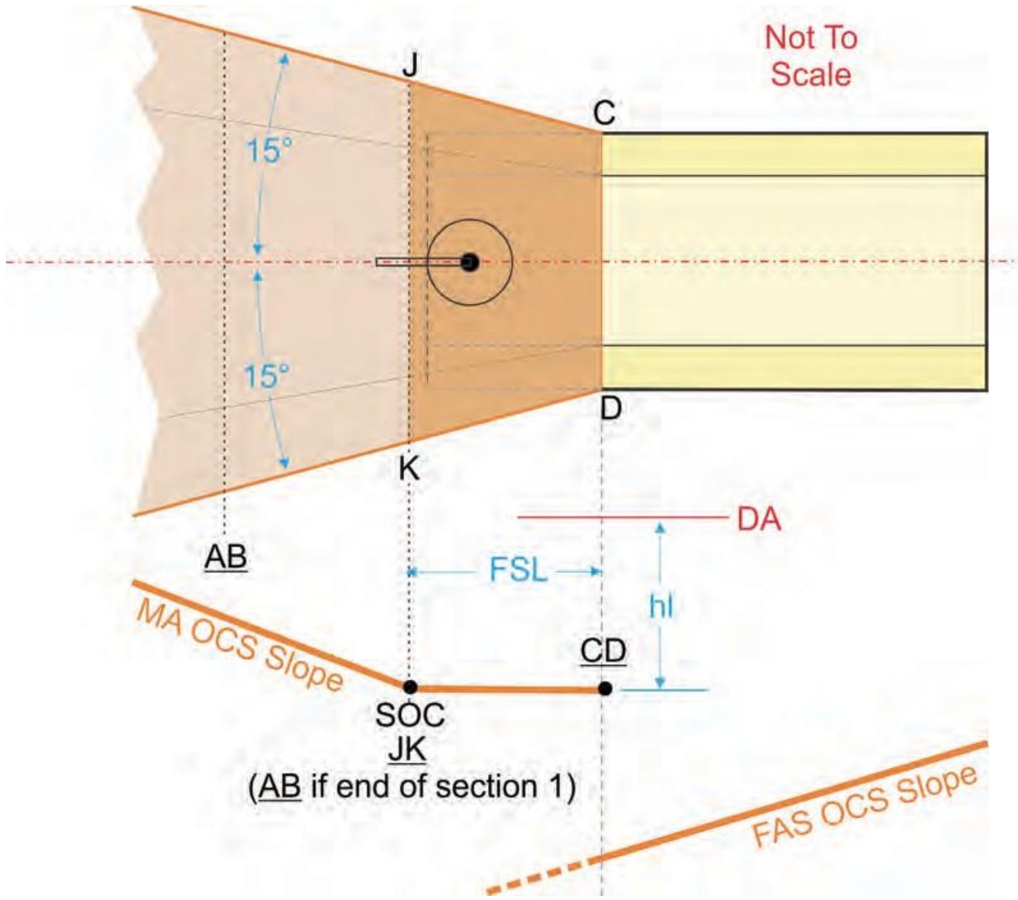
7.3.16. MA Section 1.

Section 1 extends from DA along a continuation of the final course to the SOC point or the point where the aircraft reaches 400 ft above airport elevation, whichever is farther. Turns are not allowed in section 1 (see figures 7-3-5 and 7-3-6).

7.3.17. Area.

Section 1 provides obstacle protection allowing the aircraft to arrest descent, and configure the aircraft to climb. It begins at the CD line which is perpendicular to the final approach track at DA (DDA prior to threshold) and extends along the missed approach track to the AB line (the SOC point or the point the aircraft reaches 400 ft above airport elevation, whichever is farther from the DA point). The OEA contains a flat ROC surface and a rising OCS (40:1 standard) if climb to 400 ft above airport elevation is necessary (see figures 7-3-5 and 7-3-6).

Figure 7-3-5. Section 1 Area



7.3.18. Length.

a. The area from the DA point to SOC is termed the "Flat Surface." Calculate the Flat Surface Length in feet (FSLft) using calculator 3-12a based on final approach airspeed.

Calculator 3-12a. Flat Surface Length

$$FSL_{ft} = 15 \times \frac{fpm}{3600}\left(\left(V_{KIAS} \times \frac{171233 \times \sqrt{303 - 0.00198 \times DA}}{(288 - 0.00198 \times DA)^{2.628}}\right) + 10\right)$$

b. The end of the flat surface ends at the SOC, marked by the JK construction line. If the published DA is lower than 400 ft above airport, a 40:1 rising surface extension is added to section 1. Calculate the length (in feet) of the s1extension using calculator 3-12b.

Calculator 3-12b. Calculation of Extension for Climb to 400 ft

$$S1_{extension(ft)} = \frac{Z}{CG} \times fpnm$$

where

Z = number of feet to climb to reach 400 ft above airport
CG = climb gradient (standard 200 ft/NM)

7.3.19. Width.

The OEA splays at an angle of 15 degrees relative to the FAC from the outer edge of the final segment secondary area (perpendicular to and 5468.5 ft from FAC) at the DA point. The splay ends when it reaches a point 3 NM from the missed approach course centerline (47620.38 ft [7.8 NM] from DA point).

7.3.20. OCS

a. The HMAS below the DA point is determined by calculator 3-13 using the ROC value (hl) from table 7-3-2. Select the hl value for the fastest aircraft category for which minimums are published.

Table 7-3-2. Level Surface ROC Values (hl)

Aircraft Category	hl (ft)
A	131
B	142
C	150
D/E	161

Calculator 3-13. HMAS Elevation

$$HMAS = DA - hL$$

where

hL = level surface ROC from table 7-3-2

b. The missed approach surface remains level (flat) from the DA (CD line) point to the SOC point (JK line). Obstacles must not penetrate the flat surface. Where obstacles penetrate the flat surface, raise the DA by the amount of penetration and re-evaluate the missed approach segment (see figure 7-3-6).

c. At SOC, the surface begins to rise along the missed approach course centerline at a slope ratio (40:1 standard) commensurate with the minimum required rate of climb (200 ft/NM standard); therefore, the OCS surface rise at any obstacle position is equal to the along-track distance from SOC (JK line) to a point abeam the obstacle. Obstacles must not penetrate the 40:1 surface. Where obstacles penetrate the 40:1 OCS, adjust DA by the amount (ΔDA) calculated by calculator 3-14 and re-evaluate the missed approach segment.

Calculator 3-14. DA Adjustment Value

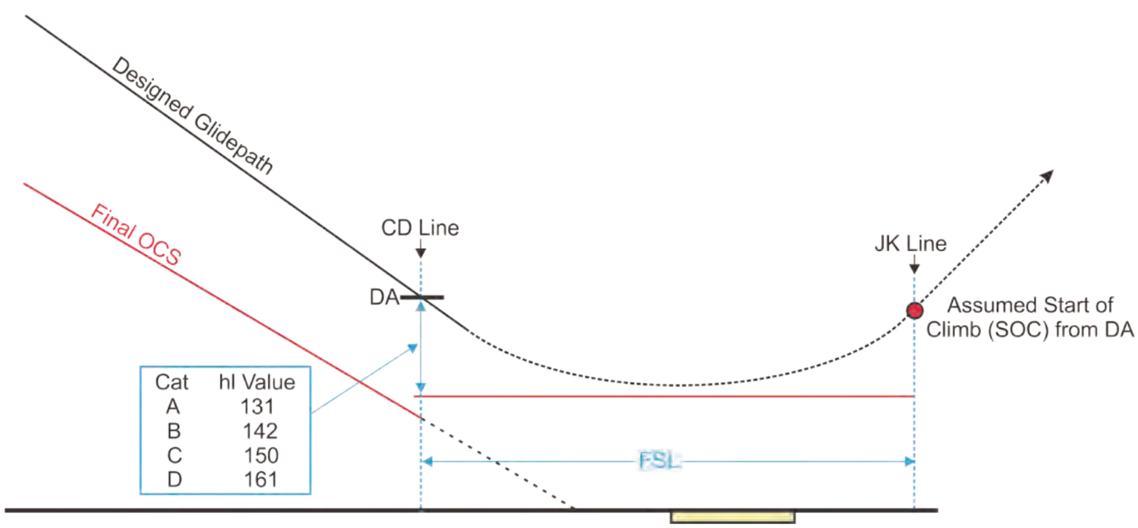
$$\Delta DA = r \times e^{\frac{p \times \frac{MA_{sLope} \times \tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)}{1 + MA_{sLope} \times \tan\left(\theta^{o} \times \frac{\pi}{180^{o}}\right)}}{r}} - r$$

where

p = amount of penetration

MA_{sLope} = MA OCS slope (nominally 40:1)

Figure 7-3-6. Missed Approach Flat Surface



SECTION 4: LPV/ILS/GLS FINAL APPROACH SEGMENT (FAS) EVALUATION

7.4. LPV/ILS/GLS Final Approach Segment (FAS) Evaluation.

7.4.1. General.

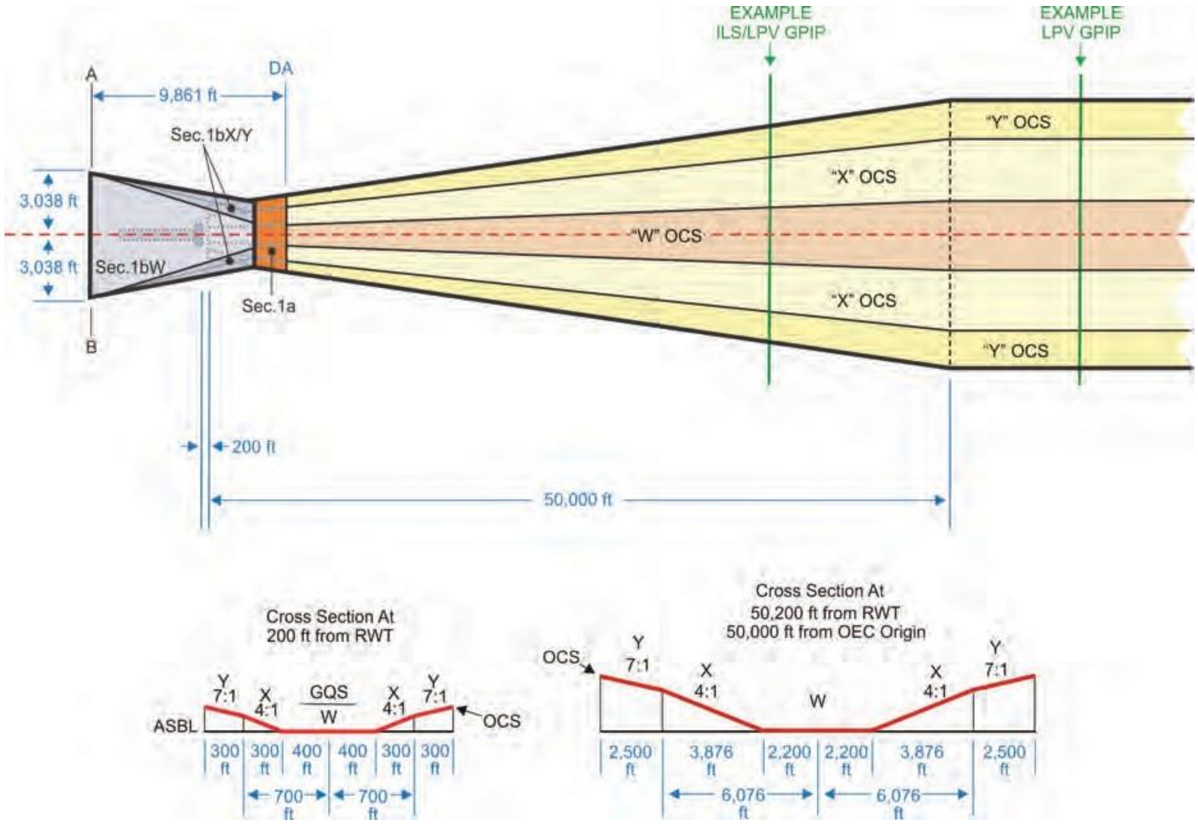
The OEA and associated OCSs are applicable to LPV final approach segments. These criteria may also be applied to construction of an RNAV transition to an ILS final segment where the GPIP is located within 50200 ft of the LTP. For an RNAV transition to an ILS/GLS final, use LPV criteria to evaluate the final and MA section 1. For GLS procedures, design final track intercept within 20 NM of the airport using PBN or conventional routing.

7.4.2. Final Segment OEA.

The OEA originates 200 ft from LTP or FTP as appropriate, and extends to a point≈131 ft (40 m ATT) beyond the GPIP (GPIP is determined using calculator 1-15a) or PFAF as applicable (see paragraph 7.2.18) . It is centered on the final approach course and expands uniformly from its origin to a point 50000 ft from the origin where the outer boundary of the X surface is 6076 ft perpendicular to the course centerline. Where the GPIP must be located more than 50200 ft from LTP, the OEA continues linearly (boundaries parallel to course centerline) to the GPIP (see figure 7-4-1)*. The primary area OCS consists of the W and X surfaces. The Y surface is an early missed approach transitional surface. The W surface slopes longitudinally along the final approach track, and is level perpendicular to track. The X and Y surfaces slope upward from the edge of the W surface perpendicular to the final approach track. Obstacles located in the X and Y surfaces are adjusted in height to account for perpendicular surface rise and evaluated under the W surface.

***Note:** ILS continues the splay, only LPV and GLS are linear outside 50200 ft.

Figure 7-4-1. LPV/ILS Final/Missed Section 1 OCSs

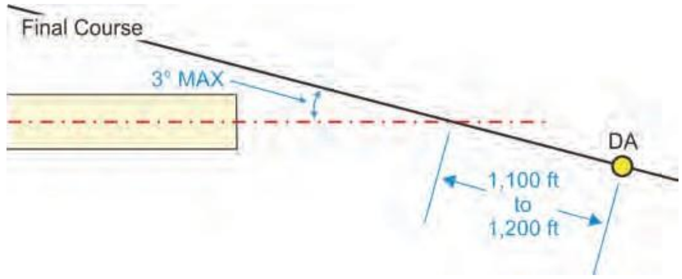


7.4.3. OEA Alignment.

The final course is normally aligned with the RCL extended (±0.03 degree) through the LTP (±5 ft). Where a unique operational requirement indicates a need to offset the course from RCL, the offset must not exceed 3 degrees measured geodetically* at the point of intersection. If the course is offset, it must intersect the RCL at a point 1100 to 1200 ft inside the DA point (see figure 7-4-2). Where the course is not aligned with RCL, the minimum HATh value is 250.

*** Note:** Geodetic measurements account for the convergence of lines of longitude. Plane geometry calculations are not compatible with geodetic measurements. See TP308 Volume 2, appendix A for geodetic calculation explanation.

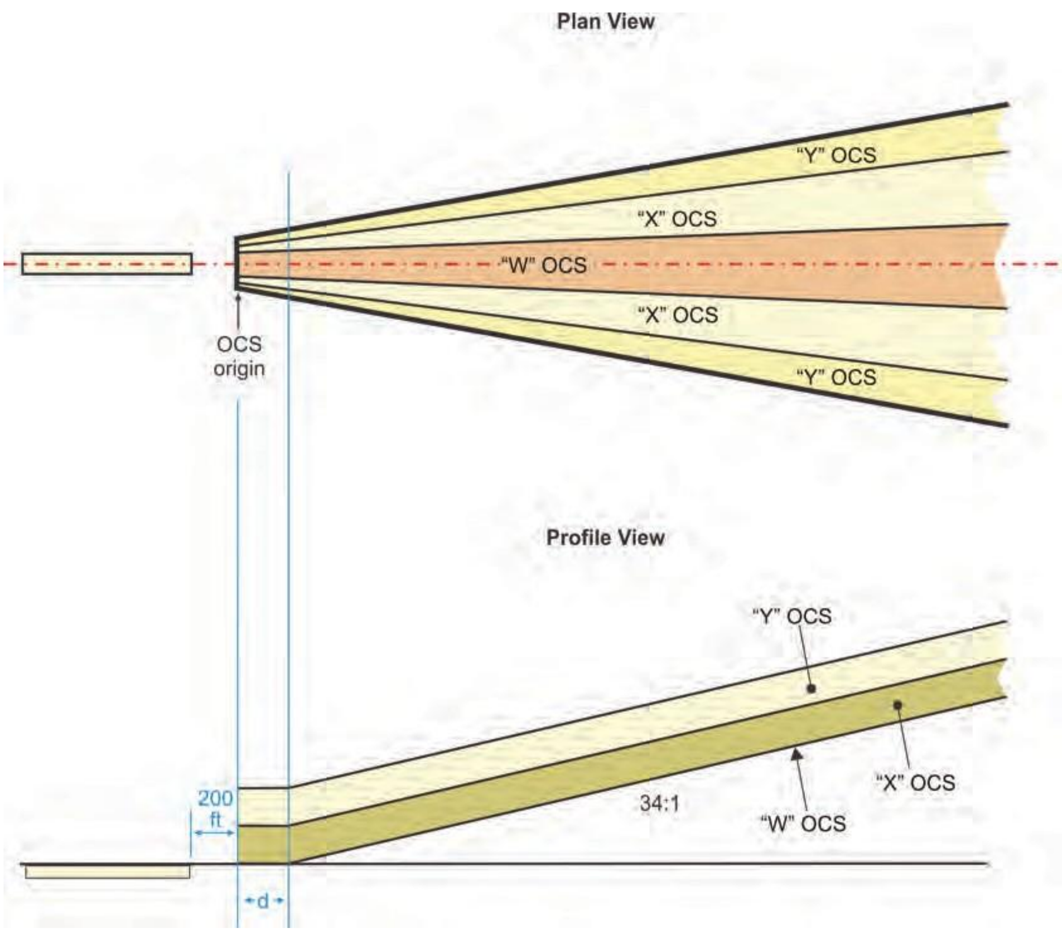
Figure 7-4-2. Offset Final Course



7.4.4. OCS Slope(s) (see figure 7-4-3).

In this document, slopes are expressed as run over rise; e.g., 34:1. Determine the OCS slope (S) associated with a specific glidepath angle (θ) using calculator 4-1.

Figure 7-4-3. OCS Slope Origin



Calculator 4-1. OCS Slope

$$S = \frac{102}{\theta}$$

7.4.5. OCS Origin.

The OEA (all OCS surfaces) originates from LTP elevation at a point 200 ft from LTP (see figure 7-4-3) measured along course centerline and extends to the GPIP. The longitudinal (along-track) rising W surface slope begins at a point 200+d feet from OEA origin. The value of d is dependent on the TCH/GPA relationship.

Where $\frac{TCH}{\tan\left(\theta^o \times \frac{\pi}{180^o}\right)} \geq 954\text{ , } d \text{ equals } 0.$

Where $\frac{TCH}{\tan\left(\theta^o \times \frac{\pi}{180^o}\right)} > 954\text{ , calculate the value of } d \text{ using calculator } 4-2.$

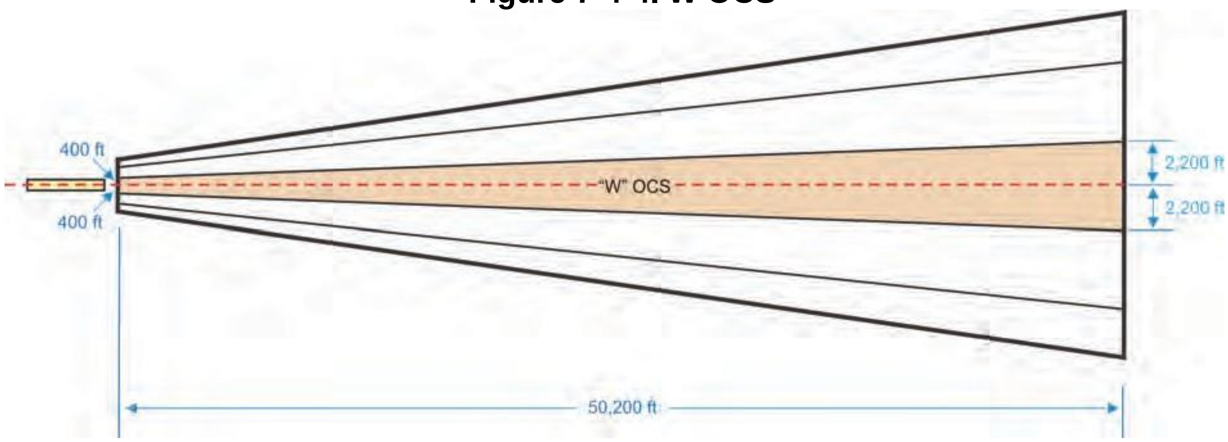
Calculator 4-2. Slope Origin Distance (d)

$$d = 954 - \frac{TCH}{\tan\left(\theta^o \times \frac{\pi}{180^o}\right)}$$

7.4.6. W OCS. (See figure 7-4-4)

All final segment OCS (W,X, and Y) obstacles are evaluated relative to the height of the W surface based on their along-track distance (OBS_X) from the LTP, perpendicular distance (OBSY) from the course centerline, and MSL elevation (OBSMSL) adjusted for earth curvature and X/Y surface rise if appropriate. This adjusted elevation is termed obstacle evaluation elevation (O_{EE}) and is covered in paragraph 7.4.8.

Figure 7-4-4. W OCS



7.4.7. Width (perpendicular distance from course centerline to surface boundary).

The perpendicular distance (Wboundary) from course centerline to the boundary is 400 ft at the origin, and expands uniformly to 2200 ft at a point 50200 ft from LTP/FTP. Calculate Wboundary for any distance from LTP using calculator 4-3. For obstacle evaluation purposes, the distance from LTP is termed OBS_X.

Calculator 4-3. W OCS ½ Width

$$W_{boundary} = 0.036 \times OBS_X + 392.8$$

Where

OBS_X = *along-track distance (ft) from LTP to obstacle*

7.4.8. Height.

a. Calculate the MSL height (ft) of the W OCS (WMSL) at any distance OBS_X from LTP using calculator 4-4.

Calculator 4-4. W OCS MSL Elevation

$$MSL = \frac{(r - LTP_{elev}) \times \cos\left(atan\left(\theta^o \times \frac{\pi}{102^o}\right)\right)}{\cos\left(\frac{OBS_X - (200 + d)}{r} + atan\left(\theta^o \times \frac{\pi}{102^o}\right)\right)} - r$$

Where

OBS_X = *obstacle along-track distance (ft) from LTP/FTP d = value from paragraph 7.4.5*

b. The LPV (and ILS) glidepath is considered to be a straight line in space extending from TCH. The OCS is; therefore, a flat plane (does not follow earth curvature) to protect the straight-line glidepath. The elevation of the OCS at any point is the elevation of the OCS at the course centerline abeam it. Since the earth's surface curves away from these surfaces as distance from LTP increases, the MSL elevation (OBSMSL) of an obstacle is reduced to account for EC. This reduced value is termed the obstacle effective MSL elevation (O_{EE}). Calculate O_{EE} using calculator 4-5.

Calculator 4-5. EC Adjusted Obstacle MSL Elevation

$$O_{EE} = OBS_{MSL} - \left((r + LTP_{elev}) \times \left(\frac{1}{cos\left(\frac{OBS_Y}{r}\right)} - 1 \right) + Q \right)$$

where

OBS_{MSL}= obstacle MSL elevation
OBSy = perpendicular distance (ft) from course centerline to obstacle
Q = adjustment for "X" or "Y" surface rise (0 if in W Surface). See calculator 4-7

7.4.9. W OCS Evaluation.

Compare the obstacle O_{EE} to WMSL at the obstacle location. Lowest minimums are achieved when the W surface is clear. To eliminate or avoid a penetration, take one or more of the following actions listed in the order of preference.

a. **Remove or adjust the obstruction location and/or height.**

b. **Displace the RWT.**

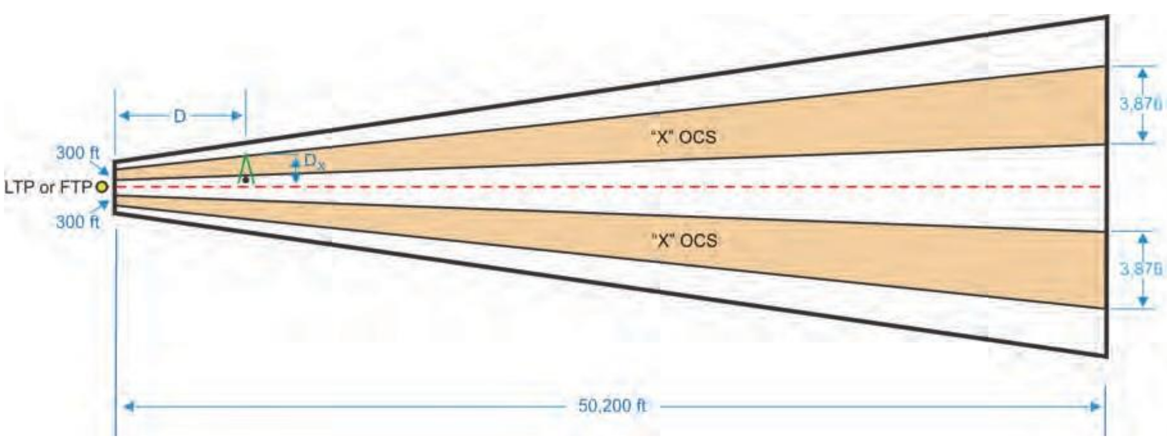
c. **Raise the GPA**(see paragraph 7.4.19) within the limits of table 7-1-5.

d. **Adjust DA**(for existing obstacles only) see paragraph 7.5.18.

e. **Raise TCH**(see paragraph 7.5.20).

7.4.10. X OCS (see figure 7-4-5).

Figure 7-4-5. X OCS



7.4.11. Width.

The perpendicular distance from the course centerline to the outer boundary of the X OCS is 700 ft at the origin and expands uniformly to 6076 ft at a point 50200 ft from LTP/FTP. Calculate the perpendicular distance ($X_{boundary}$) from the course centerline to the X surface boundary using calculator 4-6.

Calculator 4-6. Perpendicular Dist to X Boundary

$$X_{boundary} = 0.10752 \times OBS_X + 678.496$$

Where

OBS_X = *obstacle along-track distance (ft) from LTP/FTP*

Note: Where the intermediate segment is NOT aligned with the FAC, take into account the expansion of the final segment based on the intermediate segment taper.

7.4.12. X Surface Obstacle Elevation Adjustment (Q).

The X OCS begins at the height of the W surface and rises at a slope of 4:1 in a direction perpendicular to the final approach course. The MSL elevation of an obstacle in the X surface is adjusted (reduced) by the amount of surface rise. Use calculator 4-7 to determine the obstacle height adjustment (Q) for use in calculator 4-5. Evaluate the obstacle under paragraphs 7.5.8 and 7.5.9.

Calculator 4-7. X OCS Obstacle Height Adjustment

$$Q = \frac{OBS_Y - W_{boundary}}{4}$$

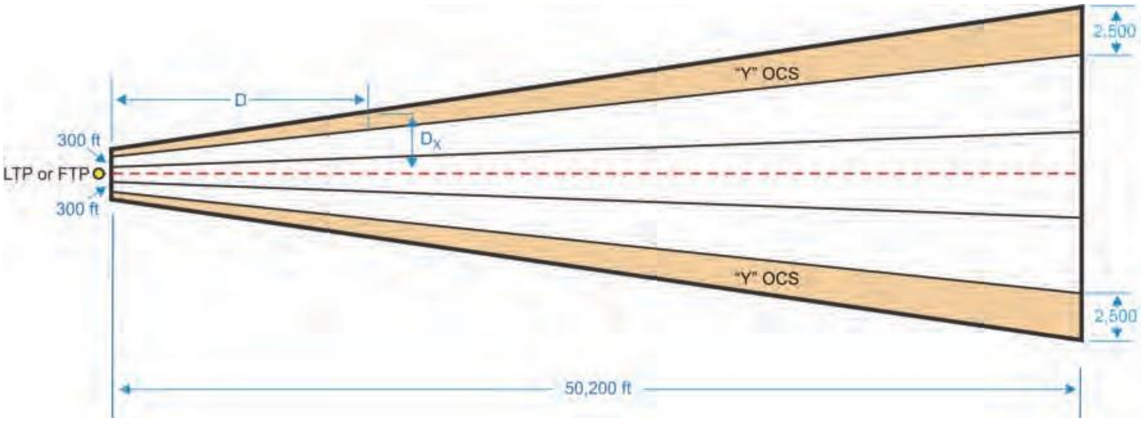
Where

OBS_Y = *perpendicular distance (ft) from course centerline to obstacle*

$W_{boundary}$ = *half-width of W surface abeam obstacle (calculator 4-3)*

7.4.13. Y OCS (see figure 7-4-6).

Figure 7-4-6. Y Surface



7.4.14. Width.

The perpendicular distance from the course centerline to the outer boundary of the Y OCS is 1000 ft at the origin and expands uniformly to 8576 ft at a point 50200 ft from LTP/FTP. Calculate the perpendicular distance (Yboundary) from the course centerline to the Y surface boundary using calculator 4-8.

Calculator 4-8. Perpendicular Distance to Y Boundary

$$Y_{boundary} = 0.15152 \times OBS_X + 969.696$$

Where OBS_X = *obstacle along-track distance (ft) from LTP/FTP*

Note: Take into account the expansion of the final segment based on the intermediate segment taper.

7.4.15. Y Surface Obstacle Elevation Adjustment (Q).

The Y OCS begins at the height of the X surface and rises at a slope of 7:1 in a direction perpendicular to the final approach course. The MSL elevation of an obstacle in the Y surface is adjusted (reduced) by the amount of X and Y surface rise. Use calculator 4-9 to determine the obstacle height adjustment (Q) for use in calculator 4-5. Evaluate the obstacle under paragraphs 7.5.8 and 7.5.9.

Calculator 4-9. Y OCS Obstacle Height Adjustment

$$Q = \frac{X_{boundary} - W_{boundary}}{4} + \frac{OBS_Y - X_{boundary}}{7}$$

Where

$W_{boundary}$ = *perpendicular distance (ft) from course centerline to the W surface boundary*
$X_{boundary}$ = *perpendicular distance (ft) from course centerline to the X surface outer boundary*
OBS_Y = *perpendicular distance (ft) from course centerline to the obstacle in the Y surface*

7.4.16. HATh and DA.

The DA value may be derived from the HATh. Where the OCS is clear, the minimum HATh for LPV operations is the greater of 200 ft or the limitations noted on table 7-1-4. If the OCS is penetrated, minimum HATh is 250. Round the DA result to the next higher whole foot.

7.4.17. DA Calculation (Clear OCS).

a. Calculate the DA using calculator 4-10.

Calculator 4-10. DA Calculation

$$DA = \mathbf{ceiling}\left[HATh + LTP_{elev}\right]$$

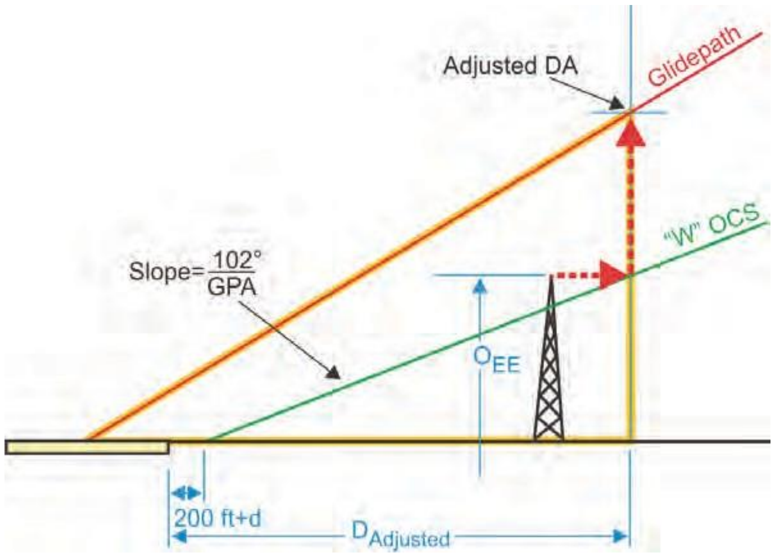
b. Calculate the along-course distance in feet from DA to LTP/FTP (XDA) using calculator 4-11.

Calculator 4-11. Distance LTP to DA

$$X_{DA} = r \times \left(\frac{\pi}{2} - \theta \times \frac{\pi}{180^o} - asin\left(\frac{cos\left(\theta^o \times \frac{\pi}{180^o}\right) \times (\boldsymbol{r} + \boldsymbol{LTP_{elev}} + \boldsymbol{TCH})}{r + DA}\right)\right)$$

7.4.18. DA Calculation (OCS Penetration), see figure 7-4-7.

Figure 7-4-7. DA Adjustment



a. Calculate the adjusted DA for an obstacle penetration of the OCS using calculator 4-12.

Calculator 4-12. Adjusted DA

$$(1)\ D_{adjusted} = r \times \left(\frac{\pi}{2} - atan\left(\frac{\theta^o}{102^o}\right) - asin\left(\frac{cos\left(atan\left(\frac{\theta^o}{102^o}\right)\right) \times \left(r + LTP_{elev} - \frac{\theta^o \times (200+d)}{102^o}\right)}{r + O_{EE}}\right)\right)$$

$$\mathbf{(2)}\ DA_{adjusted} = \frac{(r + LTP_{elev} + TCH) \times cos\left(\theta^o \times \frac{\pi}{180^o}\right)}{cos\left(\frac{D_{adjustded}}{r} + \theta^o \times \frac{\pi}{180^o}\right)} - r$$

Where

d = value from paragraph 7.5.5

O_{EE} = from calculator 4-5

7.4.19. Revising GPA for OCS Penetrations.

Raising the GPA may eliminate OCS penetrations. To determine the revised minimum GPA, use calculator 4-13.

Calculator 4-13. GPA Adjustment

(1) $\boldsymbol{SRD} = \sqrt{(\boldsymbol{r} + \boldsymbol{O_{EE}})^2 + (\boldsymbol{r} + \boldsymbol{LTP_{elev}})^2 - \boldsymbol{2} \times (\boldsymbol{r} + \boldsymbol{O_{EE}}) \times (\boldsymbol{r} + \boldsymbol{LTP_{elev}}) \times \boldsymbol{cos}\left(\frac{\boldsymbol{OBS_X} - (\boldsymbol{200} + \boldsymbol{d})}{\boldsymbol{r}}\right)}$

(2) $\boldsymbol{RS} = \frac{\boldsymbol{1}}{\boldsymbol{tan}\left(\boldsymbol{acos}\left(\frac{\boldsymbol{SRD^2} + (\boldsymbol{r} + \boldsymbol{LTP_{elev}})^2 - (\boldsymbol{r} + \boldsymbol{O_{EE}})^2}{\boldsymbol{2} \times \boldsymbol{SRD} \times (\boldsymbol{r} + \boldsymbol{LTP_{elev}})}\right) - \frac{\boldsymbol{\pi}}{\boldsymbol{2}}\right)}$

(3) $\theta°_{required} = \frac{102°}{RS}$

Where

O_{EE} = value from calculator 4-5
OBS_X = along-track distance (ft) from LTP to penetrating obstacle
d = value from paragraph 7.5.5

7.4.20. Adjusting TCH to Reduce/Eliminate OCS Penetrations.

This paragraph is applicable ONLY where d from paragraph 7.5.5, calculator 4-2, is greater than zero. Adjusting TCH is the equivalent to relocating the glide slope antenna in ILS criteria. The goal is to move the OCS origin toward the LTP/FTP (no closer than 200 ft) sufficiently to raise the OCS at the obstacle location. To determine the maximum W surface vertical relief (Z) that can be achieved by adjusting TCH, apply calculator 4-14. If the value of Z is greater than the penetration (p), you may determine the amount to increase TCH by applying calculator 4-15. If this option is selected, re-evaluate the final segment using the revised TCH value.

Calculator 4-14. Vertical Relief

$$Z = \frac{d \times \theta^o}{102^o}$$

Where d = "d" from paragraph 7.5.5, calculator 4-2

Calculator 4-15. TCH Adjustment

$$\boldsymbol{TCH_{adjustment}} = \boldsymbol{tan}\left(\boldsymbol{\theta^o} \times \frac{\boldsymbol{\pi}}{\boldsymbol{180^o}}\right) \times \frac{\boldsymbol{102^o} \times \boldsymbol{p}}{\boldsymbol{\theta^o}}$$

Where p = penetration (ft) [p ≤ Z]

7.4.21. Missed Approach Section 1 (Height Loss and Initial Climb).

Section 1 begins at DA (CD line) and ends at the AB line. It accommodates height loss and establishment of missed approach climb gradient. Obstacle protection is based on an assumed minimum climb gradient of 200 ft/NM (≈30.38:1 slope). Section 1 is centered on a continuation of the final approach track and is subdivided into sections 1a and 1b (see figures 7-4-8A and 7-4-8B).

Figure 7-4-8A. Section 1 3D Perspective

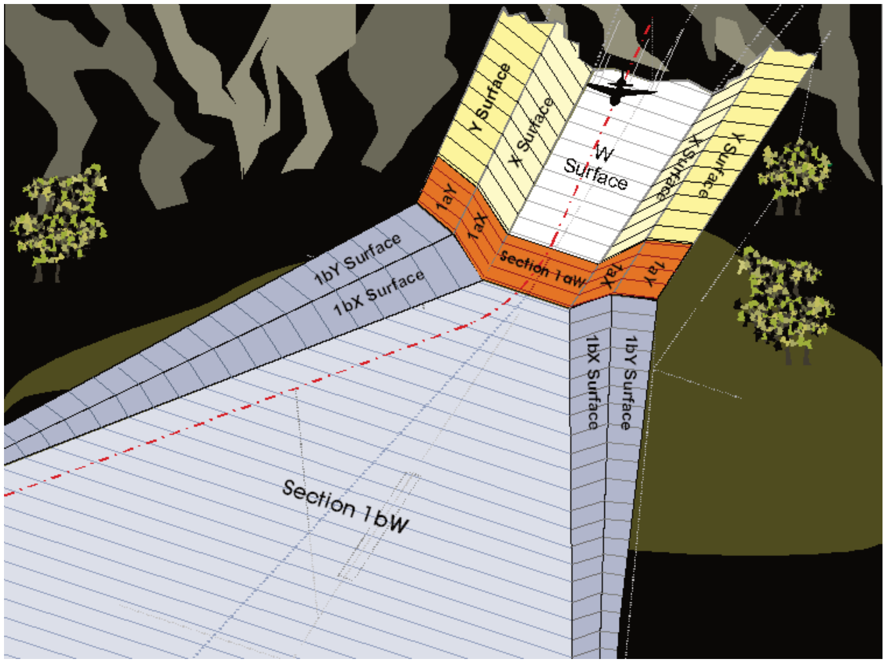
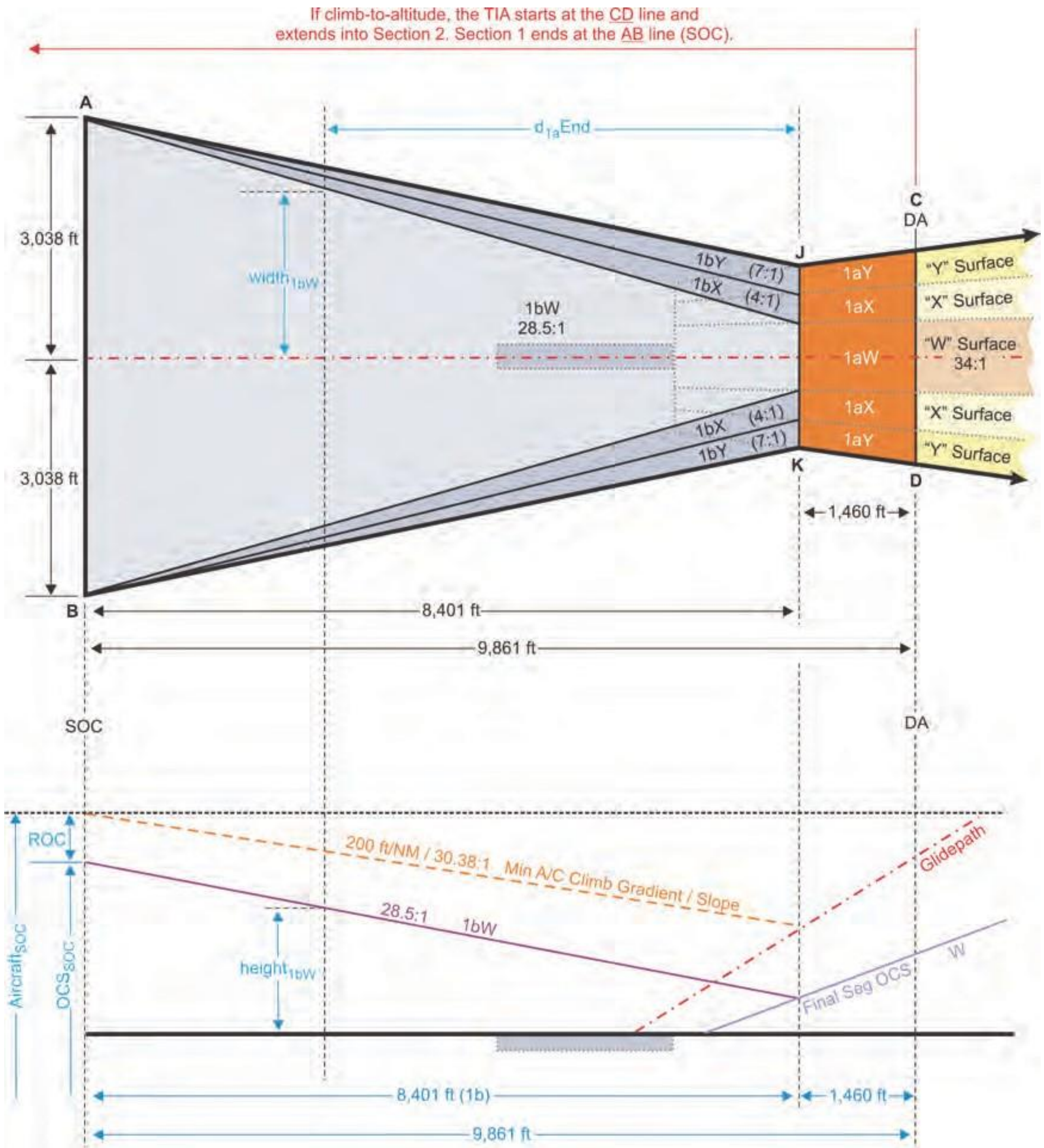


Figure 7-4-8B. Section 1 (a/b) 2D Perspective



7.4.22. Section 1a.

Section 1a is a 1460 ft continuation of the FAS OCS beginning at the DA point to accommodate height loss. The portion consisting of the continuation of the W surface is identified as section 1aW. The portions consisting of the continuation of the X surfaces are identified as section 1aX. The portions consisting of the continuation of the Y surfaces are identified as section 1aY. Calculate the width and elevation of the section 1aW, 1aX, and 1aY surfaces at any distance from LTP using the final segment calculators.

7.4.23. Section 1b.

The section 1b surface extends from the JK line at the end of section 1a as an up-sloping surface for a distance of 8401 ft to the AB line. Section 1b is subdivided into sections 1bW, 1bX, and 1bY (see figure 7-4-8B).

a. **Section 1bW.** Section 1bW extends from the end of section 1aW for a distance of 8401 ft. Its lateral boundaries splay from the width of the end of the 1aW surface to a width of $\pm$3038 ft either side of the missed approach course at the ,401 ft point. Calculate the width of the 1bW surface (width_{1bW}) at any distance d_{1aEnd} from the end of section 1a using calculator 4-16.

Calculator 4-16. Section 1bW Boundary Perpendicular Distance

$$width_{1bW} = \frac{d_{1aEnd} \times (3038 - C_W)}{8401} + C_W$$

Where

d_{1aEnd} = along-track distance (ft) from end of section 1a
C_W = half-width of 1aW surface at section 1a end

b. Calculate the elevation of the end of the 1aW surface ($elev_{1aEnd}$) using calculator 4-17.

Calculator 4-17. W OCS End Elevation

$$elev_{1aEnd} = \frac{(r + LTP_{elev}) \times \cos\left(atan\left(\frac{\theta^o}{102^o}\right)\right)}{\cos\left(\frac{X_{DA} - d - 1660}{r} + atan\left(\frac{\theta^o}{102^o}\right)\right)} - r$$

Where

X_{DA}= along-track distance (ft) from LTP to DA
d = value from paragraph 7.5.5

c. The surface rises from the elevation of the 1aW surface at the end of section 1a at a slope ratio of 28.5:1. Calculate the elevation of the surface ($elev_{1bW}$) using calculator 4-18.

Calculator 4-18. Section 1bW OCS Elevation

$$\boldsymbol{elev_{1bW} = (r + elev_{1aEnd}) \times e^{\left(\frac{d1_{aEnd}}{28.5 \times r}\right)} - r}$$

Where

$d1_{aEnd}$ = *along-track distance (ft) from end of section 1a*

d. **Section 1bX.** Section 1bX extends from the end of section 1aX for a distance of 8401 ft. Its inner boundary is the outer boundary of the 1bW surface. Its outer boundary splays from the end of the 1aX surface to a width of ±3038 ft either side of the missed approach course at the 8401 ft point. Calculate the distance from the missed approach course centerline to the surface outer boundary ($width_{1bX}$) using calculator 4-19.

Calculator 4-19. Section 1bX Boundary Perpendicular Distance

$$width_{1bX} = \frac{d_{1aEnd} \times (3038 - C_X)}{8401} + C_X$$

Where

d_{1aEnd} = *along-track distance (ft) from end of section 1a*

C_X = *perpendicular distance (ft) from course centerline to 1aX outer edge at section 1a end*

e. The surface rises at a slope ratio of 4:1 perpendicular to the missed approach course from the edge of the 1bW surface. Calculate the elevation of the 1bX missed approach surface (elev1bX) using calculator 4-20.

Calculator 4-20. Section 1bX OCS Elevation

$$\boldsymbol{elev_{1bX} = elev_{1bW} + \frac{a - width_{1bW}}{4}}$$

Where

a = perpendicular distance (ft) from the MA course

f. **Section 1bY.** Section 1bY extends from the end of section 1aY for a distance of 8401 ft. Its inner boundary is the outer boundary of the 1bX surface. Its outer boundary splays from the outer edge of the 1aY at the surface at the end of section 1a to a width of ±3038 ft either side of the missed approach course at the 8401 ft point. Calculate the distance from the missed approach course centerline to the surface outer boundary ($width_{1bY}$) using calculator 4-21.

Calculator 4-21. Section 1bY Boundary Perpendicular Distance

$$width_{1bY} = \frac{d_{1aEnd} \times (3038 - C_Y)}{8401} + C_Y$$

Where

d_{1aEnd} = *along-track distance (ft) from end of section 1a*
C_Y = *perpendicular distance (ft) from course centerline to 1aY outer edge at section 1a end*

g. The surface rises at a slope ratio of 7:1 perpendicular to the missed approach course from the edge of the 1bX surface. Calculate the elevation of the 1bY missed approach surface ($elev_{1bY}$) using calculator 4-22.

Calculator 4-22. Section 1bY OCS Elevation

$$\boldsymbol{elev_{1bY} = elev_{1bX} + \frac{a - width_{1bX}}{7}}$$

Where

a = perpendicular distance (ft) from the MA course

7.4.24. Surface Height Evaluation.

7.4.25. Section 1a.

Obstacles that penetrate these surfaces are mitigated during the final segment **OCS** evaluation. However in the missed approach segment, penetrations are not allowed; therefore, penetrations must be mitigated by:

- Raising TCH(if GPIis less than 954ft).
- Removing or reducing obstruction height.
- Raising glidepath angle.
- Adjusting DA(for existing obstacles).

7.4.26. DA Adjustment for a Penetration of Section 1b Surface.

a. The DA is adjusted (raised and consequently moved further away from LTP) by the amount necessary to raise the 1b surface above the penetration. For a 1b surface penetration of p ft, the DA point must move ΔX_{DA} feet farther from the LTP as determined by calculator 4-23.

Calculator 4-23. Along-track DA adjustment

$$\Delta X_{DA} = \frac{2907 \times p}{28.5 \times \theta^{o} + 102^{o}}$$

Where

p = amount of penetration (ft)

b. This increase in the DA to LTP distance raises the DA (and HATh). Calculate the adjusted DA (DAadjusted) using calculator 4-24. Round up the result to the next 1-ft increment.

Calculator 4-24. Adjusted DA

$$DA_{adjusted} = ceiling\left[tan\left(\theta^{\circ} \times \frac{\pi}{180^{\circ}}\right) \times (X_{DA} + \Delta X_{DA}) + LTP_{elev} + TCH\right]$$

Where

ΔX_{DA} = from calculator 4-23

X_{DA} = from calculator 4-11

7.4.27. End of Section 1 Values.

Calculate the assumed MSL altitude of an aircraft on missed approach, the OCS MSL elevation, and the ROC at the end of section 1 (AB line) using calculator 4-25. The end of section 1 (AB line) is considered SOC.

Calculator 4-25. Section 1 End (SOC) Values

(1) $Aircraft_{SOC} = DA - tan\left(\theta^{\circ} \times \frac{\pi}{180^{\circ}}\right) \times 1460 + 276.525$

(2) $OCS_{SOC} = (r + elev_{1aEnd})e^{\left(\frac{8401}{28.5 \times r}\right)} - r$

(3) $ROC_{SOC} = Aircraft_{SOC} - OCS_{SOC}$

Where

DA = published decision altitude (MSL)

$elev_{1aEnd}$ = value from calculator 4-17

d = value from paragraph 7.5.5

SECTION 5: MISSED APPROACH SECTION 2

7.5. Missed Approach Section 2.

7.5.1. General.

a. Word Usage.

i. Nominal refers to the designed/standard value, whether course/track or altitude, etc.

ii. Altitude refers to elevation (MSL).

iii. Height refers to the vertical distance from a specified reference (geoid, ellipsoid, runway threshold, etc.).

b. These criteria cover two basic MA constructions:

i. Straight missed approach.

ii. Turning missed approach.

Note: These two construction methods accommodate the traditional combination of straight and turning missed approaches.

c. Refer to individual chapters for MA section 1 information. The section 2 OEA begins at the end of section 1 (AB line), and splays at 15 degrees relative to the nominal track to reach full width (1-2-2-1 within 30 NM), see figure 7-5-1. See paragraph 7.1.2 for segment width and expansion guidance. The section 2 standard OCS slope begins at the AB line (see paragraph 7.1.43 and calculator 1-20 for information and to calculate the OCS values).

Note: All references to 'standard OCS slope' and use of '40:1' or the '40:1 ratio' refer to the output of calculator 1-21 with an input CG of 200 ft/NM.

d. Where a higher CG than the standard OCS slope is required, apply the CG and its associated OCS from SOC (see chapter 4 for the section 1 OCS exception). Apply secondary areas as specified in this chapter. Measure the 12:1 secondary OCS perpendicular to the nominal track. In expansion areas, the slope rises in a direction perpendicular from the primary boundary (arc, diagonal corner-cutter, etc.), except where obstacles cannot be measured perpendicularly to a boundary, then measure to the closest primary boundary (see figures 7-5-1 through 7-5-14). Multiple higher than standard CGs require Flight Standards approval.

7.5.2. Straight MA.

The straight MA course is a continuation of the FAC. The straight MA section 2 OEA begins at the end of section 1, (the AB line) and splays at 15 degrees relative to the nominal track until reaching full primary and secondary width (1-2-2-1 within 30 NM). Apply the section 2 standard OCS (calculated for automation), or the OCS associated with a higher CG, beginning at the AB line from the section 1 end OCS elevation. Revert to the calculated standard OCS when the increased CG is no longer required. To determine primary OCS elevation at an obstacle, measure the along-track distance from the AB line to a point at/abeam the obstacle. Where the obstacle is located in the secondary area, apply the primary OCS slope to a point abeam the obstacle, then apply the 12:1 secondary slope (perpendicular to the track), from the primary boundary to the obstacle (see figure 7-5-1).

7.5.3. Turning MA (First Turn).

a. Apply turning criteria when requiring a turn at or beyond SOC. Where secondary areas exist in section 1, they continue, (splaying if necessary to reach full width) into section 2, including non-turn side secondary areas into the first-turn wind spiral and outside arc construction (see figures 7-5-2 and 7-5-4 through 7-5-13). Terminate turn-at-fix turn-side secondary areas not later than the early turn point. Do not apply turn-side secondary areas for turn-at-altitude construction.

b. There are two types of turn construction for the first MA turn:

i. Turn at an altitude (see paragraph 7.5.4).

- Always followed by a DF leg ending with a DF-TFconnection or holding pattern entry.

ii. Turn at a fix (see paragraph 7.5 .7).

- Followed by a TF leg ending with holding pattern entry, TF-TF connection, (or TF-RF, which requires advanced avionics) when the initial straight leg is less than full width.
- May be followed by an RF leg (which requires advanced avionics) when the initial straight leg has reached full width, ending with an RF-TF or RF-RF connection.

c. Following a turn, the minimum segment length (except DF legs) must be the greater of:

i. The minimum length calculated using the chapter 1 calculators 1-5 and 1-7; or,

ii. The distance from previous fix to the intersection of the 30 degrees converging outer boundary line extension and the nominal track, plus the greater of the segment end fix DTA or ATT.

d. Minimum DF leg length is the greater of:

i. The length that is needed to accommodate rr distance value from calculator 1-4 based on the KTAS expected to use the procedure, applied between the WS direct-to-fix-line tangent point, and the earliest maneuvering point (early turn point) for the DF-TF fix. Convert to TAS using the TIA turn altitude plus the altitude gained at 250 ft/NM (CAT A/B), or 500 ft/NM (CAT C/D) from the TIA end center point to the DF fix.

ii. Results of calculator 1-10.

Supplementary note: Calculator 1-10 does not apply to a DF leg following a VA leg.

7.5.4. Turn-At-An-Altitude.

a. Apply turn-at-an-altitude construction unless the first missed approach turn is at a fix. Since pilots may commence a missed approach at altitudes higher than the DA/MDA and aircraft climb rates differ, turn-at-an-altitude construction protects the large area where turn initiation is expected. This construction also provides protection for 'turn as soon as practicable' and combination straight and tuning operations.

b. When a required aircraft turning altitude exceeds the minimum turning altitude (typically 400 ft above the airport), specify the turning altitude.

7.5.5. Turn Initiation Area (TIA).

a. Construct the TIA as a straight MA to the climb-to altitude, beginning from the earliest MA turn point (CD line) and ending where the specified minimum turning altitude (STEP 1) is reached (AB or LL' line, as appropriate). Base the TIA length on the climb distance required to reach the turning altitude (see appropriate. STEP 2 below). The TIA minimum length must place the aircraft at an altitude from which obstacle clearance is provided in section 2 outside of the TIA. The TIA boundary varies with length, the shortest B-A-C-D, occurs where AB overlies JK. Where the TIA is contained within section 1, B-A-J-C-D-K defines the boundary. Where the required turn altitude exceeds that supported by section 1, the TIA extends into section 2, (see figure 7-5-2) and points L'-L-A-J-C-D-K-B define its boundary. In this case, L-L' is the early turn point based on the aircraft climbing at the prescribed CG. Calculate TIA length using calculators 5-2a1 through 5-2c2 as appropriate.

Note: Points E and F may not be used or may be overridden by the JK line.

STEP 1: Turn altitude. The turn altitude is either operationally specified (must be at or above altitude required by obstacles) or determined by obstacle evaluation. Evaluate the nominal standard OCS slope (40:1). If the OCS is penetrated, mitigate the penetration with one or a combination of the following:

i. Raise DA/MDA.
ii. Establish a climb gradient that clears the obstacle.
iii. Move MAP.
iv. If penetration is outside TIA, consider raising the climb-to altitude.

(1) Determine the aircraft required minimum turning altitude based on obstacle evaluation:

i. Identify the most significant obstacle in section 2 (straight MA).
   - For straight OCS/CG/length options.

ii. Identify the most significant/controlling obstacle outside the TIA, (typically turn-side).

iii. Find the shortest distance from the TIA lateral boundary to the obstacle.

iv. Apply this distance and the standard OCS slope, (or higher CG associated slope) to find the TIA-to-obstacle OCS rise.

v. The minimum TIA OCS boundary elevation, (and OCS end elevation) equals the obstacle elevation minus OCS rise.

vi. The minimum turn altitude is the sum of TIA OCS boundary elevation and:
   - 100 ft for non-vertically guided procedures, or
   - The table 7-3-2 ROC value for vertically guided procedures, rounded to the next higher 100-ft increment.

Note 1: TIA lateral boundary is the straight segment (portion) lateral boundary until the required minimum turn altitude and TIA length are established.

Note 2: Repeat STEP 1 until acceptable results are obtained.

b. The specified turn altitude must equal or exceed the section 1 end aircraft altitude. Apply calculator 4-25 to find LPV section 1 end altitude (AircraftSOC), and section 1 OCS end elevation (OCSSOC). Find non-LPV section 1 end altitude using calculator 5-1.

Calculator 5-1. Section 1 End Aircraft Altitude (Non-LPV)

$$Aircraft_{SOC} = (r + MDA\ or\ DA) \times e^{\frac{AB_{NM} \times CG}{r}} - r$$

Where

AB_{NM} = SOC to AB distance (NM)
CG = applied climb gradient (ft/NM)

c. The section 2 standard OCS slope, [or the higher slope associated with the prescribed climb (CG)] begins at the AB line OCS elevation (see figures 7-5-2 through 7-5-7). See appropriate final chapters for the variable values associated with each final type.

STEP 2 (LPV): Calculate LPV TIA length using calculator 5-2a1/5-2a2 (see paragraph 7.4.21 for further section 1 details). Apply TIA calculated lengths from the CD line.

d. Where an increased CG terminates prior to the TIA turn altitude, apply calculator 5-2a1, otherwise apply calculator 5-2a2.

Calculator 5-2a1. TIA Length Multi-CG (LPV)

$$\mathrm{TIA_{Length}} = 9861 + \frac{\mathrm{r}}{\mathrm{CG1}} \times fpnm \times In\left(\frac{\mathrm{r + CG1_{termaLt}}}{\mathrm{r + Aircraft_{SOC}}}\right) + \frac{\mathrm{r}}{\mathrm{CG2}} \times fpnm \times In\left(\frac{\mathrm{r + turn_{aLt}}}{\mathrm{r + CG1_{termaLt}}}\right)$$

Where

$CG1_{termalt}$ = Initial CG termination altitude
$turn_{alt}$ = required turn altitude

$Aircraft_{SOC}$ = SOC Aircraft Altitude (calculator 4-25)
CG1 = Initial Climb Gradient (≥ Standard 200 ft/NM)
CG2 = Second Climb Gradient (Standard 200 ft/NM)

Calculator 5-2a2. TIA Length Single-CG (LPV)

$$TIA_{Length} = 9861 + \frac{r}{CG} \times fpnm \times In\left(\frac{r + turn_{alt}}{r + Aircraft_{SOC}}\right)$$

Where

$turn_{alt}$ = required turn altitude

$Aircraft_{SOC}$ = SOC Aircraft Altitude (calculator 4-25)

CG = Climb Gradient (Standard 200 ft/NM)

e. **STEP 2 (LNAV/LP):** Calculate LNAV and LP TIA length using the appropriate FSL value (see paragraph 7.2.13 for further section 1 details). Where an increased CG terminates prior to the TIA turn altitude, apply calculator 5-2b1, otherwise apply calculator 5-2b2.

Calculator 5-2b1. TIA Length Multi-CG (LNAV/LP)

$$TIA_{Length} = FSL \times \frac{r}{(r + MDA)} + \frac{r}{CG1} \times fpnm \times In\left(\frac{r + CG1_{termaLt}}{r + MDA}\right) + \frac{r}{CG2} fpnm \times In\left(\frac{r + turn_{alt}}{r + CG1_{termaLt}}\right)$$

Where

$CG1_{termaLt}$ = Initial CG termination altitude
MDA = Aircraft Final MDA
CG1 = Initial Climb Gradient (≥ Standard 200 ft/NM)
CG2 = Second Climb Gradient (Standard 200 ft/NM)

Calculator 5-2b2. TIA Length Single-CG (LNAV/LP)

$$TIA_{Length} = FSL \times \frac{r}{(r + MDA)} + \frac{r}{CG} \times fpnm \times In\left(\frac{r + turn_{alt}}{r + \mathrm{MDA}}\right)$$

Where

$turn_{aLt}$ = required turn altitude
DA = Final DA
CG = Climb Gradient (Standard 200 ft/NM)

f. **<u>STEP 2 (LNAV/VNAV):</u>** Calculate LNAV/VNAV TIA length using calculator 5-2c1 (see paragraph 7.3.16 for further section 1 details). Where an increased CG terminates prior to the TIA turn altitude, apply calculator 5-2c1, otherwise apply calculator 5-2c2.

Calculator 5-2c1. TIA Length Multi-CG (LNAV/VNAV)

$$TIA_{Length} = FSL \times \frac{r}{(r + DA)} + \frac{r}{CG1} \times fpnm \times In\left(\frac{r + CG1_{termaLt}}{r + DA}\right) + \frac{r}{CG2} fpnm \times In\left(\frac{r + turn_{alt}}{r + CG1_{termaLt}}\right)$$

Where

$CG1_{termaLt}$ = Initial CG termination altitude
DA = Aircraft Final DA
CG1 = Initial Climb Gradient (≥ Standard 200 ft/NM)
CG2 = Second Climb Gradient (Standard 200 ft/NM)

Calculator 5-2c2. TIA Length Single-CG (LNAV/VNAV)

$$TIA_{Length} = FSL \times \frac{r}{(r + DA)} + \frac{r}{CG} \times fpnm \times In\left(\frac{r + turn_{alt}}{r + DA}\right)$$

Where

$turn_{aLt}$ = required turn altitude
DA = Final DA
CG = Climb Gradient (Standard 200 ft/NM)

g. **STEP 3**: Locate the TIA end at a TIA distance length beyond CD (from STEP 2) (LL'), see figure 7-5-2.

7.5.6. OEA Construction after TIA.

a. The OEA includes areas to protect the earliest and latest direct tracks from the TIA to the fix. Construct the obstacle areas about each of the tracks as described below. See figures 7-5-2 through 7-5-9 for various turn geometry construction illustrations.

(1) Early-Turn Track and OEA Construction.

i. Where the early track from the FAC/CD intersection defines a turn less than or equal to 75 degrees relative to the FAC, the tie-back point is point C (see figure 7-5-3); if the early track defines a turn greater than 75 degrees relative to the FAC, the tie-back point is point D (see figure 7-5-4). Where the early track represents a turn greater than 165 degrees, begin the early turn track and the 15-degree splay from the non-turn side TIA end + rr (calculator 1-4) (PP'), see figure 5-5.

STEP 1: Construct a line (representing the earliest-turn flight track) from the tie-back point, to the fix (see figure 7-5-2).

STEP 2: Construct the outer primary and secondary OEA boundary lines parallel to this line (1-2-2-1 segment width) (see figure 7-15-2).

STEP 3: From the tie-back point, construct a line splaying at 15 degrees to intersect the parallel boundary lines or segment end, whichever occurs earlier (see figure 7-5-2 and 7-5-3).

ii. Apply secondary areas only after the 15-degree splay line intersects the primary boundary line.

(2) Late-Turn Track and OEA Construction.

i. Apply WS for late-turn outer boundary construction using the following calculations, construction techniques, and 15-degree bank angles. Calculate WS construction parameters for the appropriate aircraft category.

STEP 1: Find the no-wind R using calculator 5-3a.

Note: Apply the category's indicated airspeed from table 7-1-3 and the minimum assigned turn altitude when converting to true airspeed for this application.

Calculator 5-3a. No Wind R

$$R = \frac{(V_{KTAS} + 0)^2}{tan\left(15° \times \frac{\pi}{180°}\right) \times 68625.4}$$

STEP 2: Calculate the Turn Rate (TR) using calculator 5-3b. Maximum TR is 3 degrees per second. Apply the lower of 3 degrees per second or calculator 5-3b output.

Calculator 5-3b. TR

$$TR = min\left[3, \frac{3431 \times tan\left(15° \times \frac{\pi}{180°}\right)}{\pi \times V_{KTAS}}\right]$$

STEP 2a: Calculate the Turn Magnitude (TMAG) using the appropriate no-wind turn radius and the arc distance (in degrees) from start of turn (at PP') to the point of tangency with a line direct to the fix.

STEP 2b: Calculate the highest altitude under paragraph 7.1.5. Determine altitude at subsequent fixes using fix-to-fix direct measurement and 500 ft/NM climb rate.

STEP 3: Find the omni-directional wind component (VKTW) for the highest altitude in the turn using calculator 1-3b.

STEP 4: Apply this common wind value (**STEP 3**) to all first-turn wind spirals.

STEP 5: Calculate the wind spiral radius increase (ΔR) (relative R), for a given turn magnitude (β) using calculator 5-4.

Calculator 5-4. WS ΔR

$$\Delta R = \frac{V_{KTW \times \beta°}}{3600 \times TR}$$

Where

β = Degrees of turn
TR = Calculator 5-3b (Max 3 degrees/second)
V_{KTW} = Calculator 1-3b Wind Speed

Note: See ΔR examples in figures 7-5-2 to 7-5-5.

STEP 6: WS Construction (see paragraph 7.5.13).

7.5.7. Turn-At-A-Fix.

The first MA turn-at-a-fix may be a FB or FO fix. Use FB unless a FO is required for obstacle avoidance or where mandated by specific operational requirements. The turn fix early-turn-point must be at or beyond section 1 end.

a. Early/Late Turn Points.

i. The FB fix early-turn-point is located at (FIX-ATT-DTA) prior to the fix.

ii. The FB fix late-turn-point is located at a distance (FIX + ATT – DTA + rr) from the fix.

iii. The FO early-turn-point is located at a distance (FIX - ATT) prior to the fix.

iv. The FO late-turn-point is located at a distance (FIX + ATT + rr) beyond the fix.

v. FB fixes (see figure 7-5-10).

$$EarLy_{TP} = Fix - ATT - DTA$$

$$Late_{TP} = Fix + ATT - DTA + rr$$

vi. FO fixes (see figure 7-5-10).

$$EarLy_{TP} = Fix - ATT$$

$$Late_{TP} = Fix + ATT + rr$$

b. Turn-at-a-Fix (First MA turn) Construction.

i. The recommended maximum turn is 70 degrees; the absolute maximum is 90 degrees. The first turn fix must be located on the final approach track extended.

STEP 1: Calculate aircraft altitude at the AB line using calculator 5-1.

STEP 2: Calculate fix distance based on minimum fix altitude. Where the first fix must be located at the point the aircraft reaches or exceeds a specific altitude, apply calculator 5-5 (using the assigned/applied CG), to calculate fix distance (Dfix) (NM) from the AB line.

Calculator 5-5. Fix Distance (D_{fix})

$$D_{fix} = In\left(\frac{ALt_{fix} + r}{Aircraft_{SOC} + r}\right) \times \frac{r}{CG}$$

Where

Alt_{fix} = Minimum altitude required at fix
$Aircraft_{SOC}$ = Aircraft AB line (SOC) altitude
CG = Climb Gradient (Standard 200 ft/NM)

STEP 3: Calculate the altitude an aircraft would achieve climbing at the assigned CG would achieve over an established fix using calculator 5-6.

Calculator 5-6. Altitude Achieved at Fix

$$ALt_{fix} = (r + Aircraft_{SOC}) \times e^{\left(\frac{CG \times D_{fix}}{r}\right)} - r$$

Where

D_{fix} = Minimum altitude required at fix
$Aircraft_{SOC}$ = Aircraft AB line (SOC) altitude
CG = Climb Gradient (Standard 200 ft/NM)

7.5.8. FB Turn Calculations and Construction. (Consider same direction-of-flight-distance as positive, opposite-flight-direction distance as negative).

a. **FB** Turn Calculations.

STEP 1: Calculate the fix to early-turn distance ($D_{earlyTP}$) using calculator 5-7.

Calculator 5-7. Early Turn Distance

$$D_{earlyTP} = ATT + DTA$$

b. Early-Turn Area Construction.

Table 7-5-1. Inside Turn Expansion Guide

Outbound Segment Boundary Relative ETP Connections	Expansion Line Required
Secondary & Primary **Prior** ETP	15° Line
Secondary **Prior** ETP	15° Line
Primary **Beyond** ETP	A/2
Secondary & Primary **Beyond** ETP	A/2

Note: ETP = LL' early-turn point connection, 15-degree line relative outbound segment, A/2 = half turn-angle

c. **Inside turn (FB) Construction** is predicated on the location of the LL' line and primary/secondary boundary intersections (early turn connections), relative to the outbound segment (see table 7-5-1 and figures 7-5-11A, 7-5-11B, and 7-5-11C).

i. See similar construction figure 7-5-6.

ii. Where no inside turn secondary area exists in section 1, apply secondary areas only after the turn expansion line/s intersect the outbound segment boundaries.

iii. Apply the same technique to primary and secondary area connections when both inbound segment connection points fall either outside the outbound segment, or inside the outbound segment primary area. When both inbound connection points are within the outbound segment secondary area, or its extension, table 7-5-1 displays a connection method for each point.

Note: Where half-turn-angle construction is indicated, apply a line splaying at the larger of, half-turn-angle, or 15 degrees relative to the outbound track. Where a small angle turn exists and standard construction is suitable for one, but not both splays, connect the uncommon splay, normally primary, to the outbound primary boundary at the same along-track distance as the secondary connection. Maintain or increase primary area as required.

STEP 1: Construct a baseline (LL') perpendicular to the inbound track at distance DearlyTP (calculator 5-7) prior to the fix.

CASE 1: The outbound segment boundary, or its extension, is beyond the baseline (early-turn connection points are prior to the outbound segment boundary).

STEP 1: Construct the inside turn expansion area with a line, drawn at one-half the turn angle from the inbound segment primary early-turn connection point, to intercept the outbound segment primary boundary (see figures 7-5-6 and 7-5-11A).

STEP 2 (if required): Construct the inside turn expansion area with a line, drawn at one-half the turn angle, from the inbound segment secondary early-turn connection point, to intercept the outbound segment secondary boundary (see figure 7-5-11A).

CASE 2: The outbound segment secondary boundary or its extension is prior to the LL' baseline and outbound segment primary boundary or its extension is beyond the LL' baseline, (early-turn connection points are both within the outbound segment secondary area or its extension).

STEP 1: Construct the inside-turn expansion area with a line splaying at 15 degrees relative to the outbound track from the inbound segment secondary early-turn connection point to intersect the outbound segment boundary.

STEP 1 Alt: Begin the splay from L' when the turn angle exceeds 75 degrees.

STEP 2: Construct the primary boundary with a line, drawn at one-half the turn angle, from the inbound segment primary early-turn connection point to intercept the outbound segment primary boundary (see figure 7-5-11B).

CASE 3: The outbound segment secondary and primary boundaries, or their extensions, are prior to the LL' baseline (early-turn connection points are inside the outbound segment primary area).

STEP 1: Construct the inside turn expansion area with a line, splaying at 15 degrees (relative to the outbound track) from the more conservative point, (L') or (the intersection of LL' and the inbound segment inner primary boundary), to intersect the outbound segment boundaries.

STEP 1 Alt: Begin the splay from L' when the turn angle exceeds 75 degrees.

iv. In this case, the inside turn secondary area is terminated at the outbound segment primary boundary, as it falls before the early-turn points, LL' (see figure 7-5-11C for L' connection).

d. Outside Turn (**FB**) Construction.

STEP 1: Construct the outer primary boundary using a radius of one-half primary width (2 NM), centered on the plotted fix position, drawn from the inbound segment extended primary boundary until tangent to the outbound segment primary boundary (see figures 7-5-7 and 7-5-11A through 7-5-11C).

STEP 2: Construct the secondary boundary using a radius of one-half segment width (3 NM), centered on the plotted fix position, drawn from the inbound segment extended outer boundary until tangent to the outbound segment outer boundary (see figures 7-5-7 and 7-5-11A through 7-5-11C).

e. FO Turn Construction.

i. Inside Turn (FO) Construction.

STEP 1: Construct the early-turn baseline (LL') at distance ATT prior to the fix, perpendicular to the inbound nominal track.

STEP 2: Refer to paragraph 7.5 .8.c, (skip STEP 1).

ii. Outside Turn (FO) Construction.

STEP 1: Construct the late-turn baseline (PP') at distance ATT + rr beyond the fix, perpendicular to the inbound nominal track. Calculate late-turn distance using calculator 5-8.

STEP 2: Apply wind spiral outer boundary construction for the first MA FO turn. See paragraph 7.5 .6.a.(2) for necessary data, using the higher of calculator 5-6 output, or the assigned fix crossing altitude for TAS and turn radius calculations. Apply paragraph 7.5 .13 for wind spiral construction. A non-turn side secondary area may extend into the WS1 area.

iii. Obstacle Evaluations (see paragraph 7. 5.9).

7.5.9. Section 2 Obstacle Evaluations.

a. Turn at an Altitude Section 2.

i. Apply the standard **OCS** slope, or the assigned **CG** associated slope to section 2 obstacles (during and after the turn) based on the shortest primary area distance (do) from the **TIA** boundary to the obstacle. Shortest primary area distance is the length of the shortest line kept within primary segments that passes through the early-turn baseline of all preceding segments.

STEP 1: Measure and apply the **OCS** along the do from the **TIA** boundary to the obstacle (single and multiple segments). See figures 7-5-2 through 7-5-13, (skip 7-5-10) for various obstacle measurement examples.

STEP 2: For obstacles located in secondary areas, measure and apply the OCS along the do from the TIA boundary to the primary boundary abeam the obstacle, then the 12:1 slope along the shortest distance to the obstacle, (taken perpendicular to the nominal track or in expansion areas, to the primary arc, the primary corner-cutter, corner apex, or other appropriate primary boundary). Where an obstacle requires multiple measurements (an obstacle is equidistant from multiple primary boundary points, or lies along perpendiculars from multiple primary boundary points, etc.), apply the most adverse result from each of the combined primary/secondary measurements (see figures 7-5-1 and 7-5-2 through 7-5-11C).

b. Turn at Fix Section 2.

i. Apply the standard **OCS** slope, (or the assigned **CG** associated slope) beginning at the **AB** line at the inbound-segment end **OCS** height.

STEP 1: Measure and apply the **OCS** along the do from the **AB** line (parallel to track) to **LL'**, the shortest primary distance to the obstacle (single and multiple segments). See figures 7-5-2 through 7-5-13, (skip 7-5-10) for various obstacle measurement examples.

STEP 2: For obstacles located in secondary areas, measure and apply the **OCS** along the do from the **TIA** boundary to the primary boundary abeam the obstacle, then the **12:1** slope along the shortest distance to the obstacle, (taken perpendicular to the nominal track or in expansion areas, to the primary arc, the primary corner-cutter, corner apex, or other appropriate primary boundary).

ii. Where an obstacle requires multiple measurements (where an obstacle is equidistant from multiple primary boundary points, or lies along perpendiculars from multiple primary boundary points, etc.), apply the most adverse result from each of the combined primary/secondary measurements (see figures 7-5-6 through 7-5-8). Additional obstacle measurements examples appear in figures 7-5-1 through 7-5-11C.

7.5.10. Turning MA (Second Turn).

7.5.11. DF-TF Turn (Second Turn, following turn-at-altitude).

Turns at the **DF** path terminator fix will be **FB** or **FO** to a **TF** leg. In either case, the outer boundary provides **FO** protection, and the inner boundary provides **FB** protection. Maximum turn angle is 90 degrees within 0.03 degrees (applicable to both tracks within the **DF** segment). This application provides that construction under chapter 1, or this chapter will apply, including cases where the inside and outside turn construction differs.

a. DF-TF (FB) Turn.

i. Inside DF-TF (FB) construction.

CASE 1: Full-width inside secondary exists at the early-turn point (LL').

STEP 1: Construct a baseline (LL') perpendicular to the inbound track nearer the turn-side boundary at distance $D_{earlyTP}$ (calculator 5-7) prior to the fix.

STEP 2: Apply paragraph 7.1.17 criteria.

CASE 2: Less than full-width inside secondary exists at (LL').

STEP 1: Apply paragraph 7.5 .8.c criteria.

ii. Outside **DF-TF (FB)** construction.

CASE 1: Full width outside secondary exists at the early turn point (L'L").

STEP 1: Construct a baseline (L'L") perpendicular to the inbound track nearer the non-turn side boundary at distance $D_{earlyTP}$ (calculator 5-7) prior to the fix.

STEP 2: Apply paragraph 7.1.17 criteria (see figures 7-5-6 through 7-5-8).

CASE 2: Less than full-width outside secondary exists at (L'L").

STEP 1: Apply paragraph 7.5 .8.d criteria.

b. DF-TF (FO) Turn.

i. Inside DF-TF (FO) Turn Construction.

STEP 1: Construct a baseline (LL') perpendicular to the inbound track nearer the turn-side boundary at distance ATT prior to the fix (see figure 7-5-9).

Note: Where half-turn-angle construction is specified, apply a line splaying at the larger of half-turn-angle or 15 degrees relative to the outbound track.

CASE 1: No inside secondary area exists at LL'.

STEP 1: Create the OEA early-turn protection by constructing a line, splaying at the larger of one-half (½) the turn angle, or 15 degrees relative to the outbound track, from the intersection of LL' and the inbound segment inner primary boundary to connect with the outbound TF segment boundaries.

The TF secondary area begins at the intersection of this diagonal line and the outbound segment boundary.

CASE 2: Partial width inside secondary area exists at LL'.

STEP 1: Create the OEA early-turn primary area protection by constructing a line, splaying at the larger of one-half (½) the turn angle, or 15 degrees relative to the outbound track, from the intersection of LL' and the inbound segment inner primary boundary to connect with the TF segment primary boundary.

STEP 2: Create the OEA early-turn secondary protection by constructing a line, splaying at the larger of one-half (½) the turn angle, or 15 degrees relative to the outbound track, from the intersection of LL' and the inbound segment inner boundary to connect with the TF segment boundary.

CASE 3: Full-width inside secondary area exists at **LL'.**

STEP 1: Apply chapter 1 criteria (see figure 7-5-9).

ii. Outside DF-TF (FO) Turn Construction.

STEP 1: Construct the late-turn baseline for each inbound track, (PP') for the track nearer the inside-turn boundary, and (P'P'') for the outer track at distance (ATT + rr) beyond the fix, perpendicular to the appropriate inbound track (see figure 7-5-9).
Note: A DF-TFFO turn is limited to 90 degrees (both inbound tracks) and should require no more than one WS per baseline. Construct the outside track WS (WS1) on base line P'P''), then construct WS2 on baseline PP'.

STEP 2: Apply WS construction, see paragraph 7.5 .6.a(2) for necessary data, and paragraph 7.5 .13 for WS construction (see figure 7-5-9).

7.5.12. TF-TF Turn (Second Turn, following turn-at-fix).

Turns at the TF path terminator fix will be FB or FO to a TF leg. In either case, the outer boundary provides FO protection, and the inner boundary provides FB protection. Maximum turn angle is 90 degrees within 0.03 degrees. This application provides that construction under chapter 1, or this chapter will apply, including cases where the inside and outside turn construction differs.

a. TF-TF (FB) Turn.

i. Inside TF-TF (FB) construction.

STEP 1: Apply paragraph 7.1.10 criteria.

ii. Outside TF-TF (FB) construction.

STEP 1: Apply paragraph 7.1.9 criteria.

b. TF-TF (FO) Turn.

i. Inside TF-TF (FO) Turn Construction.

STEP 1: Apply paragraph 7.1.10 criteria.

ii. Outside TF-TF (FO) Turn Construction.

STEP 1: Apply paragraph 7.1.9 criteria.

7.5.13. Wind Spiral Cases.

a. WS construction applies to turn-at-an-altitude, turn-at-a-fix (FO) for the first MA turn, and DF-TF (FO) for the second turn. The late-turn line P' designator is typically placed where the baselines cross. Where baseline extension is required, mark each baseline inner end with P'.

b. Each WS has several connection options along its boundary. The chosen connection/s must provide the most reasonably conservative, (larger area) track and protection areas (see figures 7-5-14A/B/C for examples).

i. A 15-degree or greater* splay line to join outbound segment outer boundaries, from:

- WS/direct-to-fix tangent point
- WS to WS tangent line origin
- WS to WS tangent line end
- WS/outbound segment parallel point (DF segment NA)

ii. A tangent line to join the next WS.

iii. A tangent line direct to the next fix (DF segment).

iv. A tangent line, converging at 30 degrees to the segment track (TF segment).

***Note:** See paragraph 7.5 .14.a and 7.5 .14.b for alternate connection details.

v. Outbound segment type and turn magnitude are primary factors in WS application. Refer to table 7-5-2 for basic application differences.

Table 7-5-2. MA First Turn Wind Spiral Application Comparison

	Turn-At-Fix (FO)	Turn-At-Altitude
WS1 Baseline (PP’)	Fix + ATT + rr	TIA + rr
WS2 Baseline (PP’)	Fix + ATT + rr	TIA + rr
WS Number	1 or 2	1, 2, or 3*
Final WS Connection (Tangent line)	30 degrees to outbound track	Direct-to-Fix

NOTE: * Where a required turn exceeds that served by three wind spirals, consider adding fixes to avoid prohibitively large protection areas resulting from further wind spiral application.

c. Turn-at-Fix (FO) and Turn-at-Altitude WS Comparison.

i. Three cases for outer-boundary wind spirals commonly exist:

CASE 1: Small angle turns use one wind spiral (WS1);

CASE 2: Turns near/exceeding 90 degrees ~ use a second wind spiral (WS2); and

CASE 3: Turns near/exceeding 180 degrees ~ use a third wind spiral (WS3).

ii. Turn-at-Altitude WS application concludes with a line tangent to the final WS direct to the next fix.

iii. Turn-at-Fix (FO) WS application concludes with a line tangent to the final WS converging at a 30-degree angle to the outbound segment nominal track. The intersection of this line with the nominal track establishes the earliest maneuvering point for the next fix. The minimum segment length is the greater of:

- The minimum length calculated using calculators 1-5 and 1-10; or,
- The distance from previous fix to the intersection of the 30-degree converging outer boundary line extension and the nominal track, plus DTA and ATT [see paragraph 7. 5.8.c].

iv. Second MA Turn DF-TF Turn-at-Fix (FO) WS application concludes with a line tangent to the final WS converging at a 30-degree angle to the outbound segment nominal track. This construction requires two WS baselines, one for each inbound track. Each late turn baseline is located (ATT + rr) beyond the fix, oriented perpendicular to the specific track. The baseline for the inbound track nearer the inside-turn boundary is designated PP’, the baseline associated with the outside-turn track is designated P'P''. For convenience P' is often placed at the intersection of the two baselines, but a copy properly goes with each baseline inner end where baseline extensions are required.

7.5.14. First MA Turn WS Construction.

Find late-turn point distance (D_{lateTP}) using calculator 5-8.

Calculator 5-8. Late-Turn Point Distance

$$D_{LateTP} = ATT + rr$$

Where

rr = delay/roll-in calculator 1-4

a. **CASE 1:** Small angle turn using 1 WS.

STEP 1: Construct the WS1 baseline, (PP') perpendicular to the straight missed approach track at the late-turn-point (see table 7-5-2 for line PP' location, see figures 7-5-3 and 7-5-12).

STEP 2: Locate the wind spiral center on PP' at distance R (no-wind turn radius, using calculator 5-3; see figure 7-5-2) from the intersection of PP' and the inbound-segment outer-boundary extension (see figures 7-5-4 and 7-5-12).

STEP 3: Construct WS1 from this outer-boundary point in the direction of turn until tangent to the WS/Segment connecting line from table 7-5-2 (see figures 7-5-4 and 7-5-12).

CASE 1-1: Turn-altitude (WS1 ends when tangent to a line direct to fix)

STEP 1: Construct the OEA outer primary and secondary boundary lines parallel to this track (1-2-2-1 segment width) (see figure 7-5-3).

STEP 2: Construct a line from the WS1 tangent point, splaying at 15 degrees from the WS1-to-fix track until it intersects the parallel boundary lines or reaches the segment end (see figures 7-5-2 through 7-5-6).

Note: Consider 'full-width protection at the fix' to exist where the splay line is tangent to a full-width- radius- circle about the fix.

STEP 2alt-1: Where **STEP 2** construction provides less than full-width protection at the DF fix, construct the OEA outer boundary with a line splaying from the WS1/direct-to-fix tangent point at 15 degrees relative to the direct-to- fix line, (or greater where required to provide full-width protection at the DF fix), until it intersects the parallel boundary lines (not later than tangent/tangent- extension to the full-width-arc about the fix), and provides full-width protection at or before the DF fix. DF secondary areas begin/exist only where full width primary exists (see figures 7-5-14A and 7-5-14B).

Note: Where excessive splay (dependent upon various conditions but generally in the 35-40 degree range), consider lengthening the segment, restricting the speed, category, etc. to avoid protection and/or construction difficulties.

CASE 1-2: Turn-at-Fix (FO) (WS1 ends when tangent to a 30-degree line converging to nominal track).

STEP 1: Construct the OEA outer boundary line using WS1 and the tangent 30-degree converging line until it crosses the outbound segment boundaries. See figure 7-5-12.

STEP 1a: Where WS1 lies within the outbound segment primary boundary, construct the OEA boundary using WS1 and a line (from the point WS1 is parallel to the outbound segment nominal track), splaying at 15 degrees relative to the outbound segment nominal track until it intersects the outbound segment boundary lines.

STEP 1b: Where WS1 lies within the outbound segment secondary boundary, construct the OEA boundary using WS1 and a line (from the point WS1 is parallel to the outbound segment nominal track), splaying at 15 degrees relative to the outbound segment nominal track until it intersects the outbound segment boundary line. Continue WS1 and the tangent 30-degree converging line to establish the inner primary/secondary boundary.

b. **CASE 2:** Larger turn using more than 1 WS. For turns nearing or greater than 90 degrees, WS2 may be necessary (see figures 7-5-4 and 7-5-13).

STEP 1: To determine WS2 necessity, locate its center on baseline PP', at distance R from the inbound-segment inner-boundary extension.

STEP 2: Construct WS2 from this inner-boundary point in the direction of turn until tangent to the WS/Segment connecting line from table 7- 5-2 (see figure 7-5-13).

STEP 3: Where WS2 intersects WS1 construction, (including the connecting and expansion lines where appropriate), include WS2 in the OEA construction. Otherwise revert to the single WS construction.

STEP 3a: Connect WS1 and WS2 with a line tangent to both (see figures 7-5-4 and 7-5-13).

Note: The WS1/ WS2 tangent line should parallel a line between the WS center points.

CASE 2-1: Turn-at-Altitude: (WS2 ends when tangent to a line direct-to-fix)

STEP 1: Construct the OEA outer primary and secondary boundary lines parallel to this track (1-2-2-1 segment width).

STEP 2: Construct a line from the WS2 tangent point, splaying at 15 degrees from the WS2-to-fix track until it intersects the parallel boundary lines or reaches the segment end (see figure 7-5-4).

Note: Consider 'full-width protection at the fix' exists where the splay line is tangent to a full-width- radius- circle about the fix.

STEP 2alt-1: Where STEP 2 construction provides less than full-width protection at the DF fix, construct the OEA outer boundary with a line splaying from the WS2/direct-to-fix tangent point at 15 degrees relative to the direct-to- fix line, (or greater where required to provide full-width protection at the DF fix), until it intersects the parallel boundary lines (not later than tangent/tangent- extension to the full-width-arc about the fix), and provides full-width protection at or before the DF fix. Where the turn angle is ≤105 degrees, or the divergence angle between the WS/WS tangent line and the direct-to-fix line is ≤15 degrees, apply the splay line from the WS1/WS2 tangent line origin. DF secondary areas begin/exist only where full width primary exists (see figures 7-5-14A and 7-5-14C).

Note: Where excessive splay (dependent upon various conditions but generally in the 35-40 degrees range), consider using an earlier splay origin point, lengthening the segment, restricting the speed, category, etc. to avoid protection or construction difficulties (see paragraph 7.5 .13 for origin points).

CASE 2-2: Turn-at-Fix (FO): (WS2 ends when tangent to a 30-degree line converging to nominal track).

STEP 1: Construct the OEA outer boundary line using WS2 and the 30-degree converging line until it crosses the outbound segment boundaries (see figure 7-5-13).

STEP 1a: Where WS2 lies within the outbound segment primary boundary, construct the OEA boundary using WS1, WS2 and a line (from the point WS1 or WS2 is parallel to the outbound segment nominal track, the more conservative), splaying at 15 degrees relative to the outbound segment nominal track until it intersects the outbound segment boundary lines.

STEP 1b: Where WS2 lies within the outbound segment secondary boundary, construct the OEA boundary using WS1, WS2 and a line (from the point where WS2 is parallel to the outbound segment nominal track), splaying at 15 degrees relative to the outbound segment nominal track until it intersects the outbound segment boundary line. Continue WS2 and the tangent 30-degree converging line to establish the inner primary/secondary boundary.

c. **CASE 3: Larger turn using more than 2 WSs. (Not applicable to Turn- at-Fix due to 90-degree turn limit).** For turns nearing or greater than 180 degrees ~ (such as a missed approach to a holding fix at the IF),

STEP 1: Construct the WS3 baseline perpendicular to the straight missed approach track along the CD line-extended toward the turn side (see figure 7-5-5).

STEP 2: To determine WS3 necessity, locate its center on the WS3 baseline at distance R from point C (see figure 7-5-5).

STEP 3: Construct WS3 from point C in the direction of turn until tangent to the WS/Segment connecting line from table 7-5-2 (see figure 7-5-5).

STEP 4: Where WS3 intersects WS2 construction, include WS3 in the OEA construction. Otherwise revert to the dual WS construction (see figure 7-5-5).

STEP 5: Connect WS2 and WS3 with a line tangent to both (see figures 7-5-4 and 5-5).

Note: The WS2 & WS3 tangent line should parallel a line between the WS center points.

CASE 3-1: Turn-at-Altitude: (WS3 ends when tangent to a line direct to fix)

STEP 1: Construct the OEA outer primary and secondary boundary lines parallel to this track (1-2-2-1 segment width) (see figure 7-5-5).

STEP 2: Construct a line from the WS3 tangent point, splaying at 15 degrees from the WS3-to-fix track until it intersects the parallel boundary lines or reaches the segment end (see figure 7-5-5).

7.5.15. Outside Turn Secondary Area. Outbound segment secondary areas following wind spirals begin where either the 30-degree converging line crosses the secondary and primary boundaries from outside the segment, or the 15-degree splay line crosses the primary boundary from inside the segment.

7.5.16. Second MA Turn WS Construction (DF-TF FO).

To accommodate the two inbound tracks in the DF leg, the second MA turn DF-TF (FO) construction uses two WS baselines, PP' and P'P''.

Note: Apply table 7-5-2 PP' location information for each baseline (calculator is identical).

a. **CASE 1:** Small angle turn using 1 WS for each inbound DF track.

STEP 1: Construct the WS1 baseline, (P'P'') perpendicular to the DF track nearer the outside of the DF-TF turn, at the late-turn-point. See table 7-5-2 for line PP' location.

STEP 1a: Construct the WS2 baseline, (PP') perpendicular to the DF track nearer the inside of the DF-TF turn, at the late-turn-point. See table 7-5-2 for line PP' location.

STEP 2: Locate the WS1 center on P'P'' at distance R (no-wind turn radius, using calculator 5-3; see figure 7-5-2) from the intersection of P'P'' and the inbound segment outer-boundary extension.

STEP 2a: Locate the WS2 center on PP' at distance R (no-wind turn radius, using calculator 5-3; see figure 7-5-9) from the intersection of PP' and the inbound segment inner-boundary extension.

STEP 3: Construct WS1 from this outer boundary point in the direction of turn until tangent to the WS/Segment connecting line from table 7-5-2.

STEP 3a: Construct WS2 from this inner boundary point in the direction of turn until tangent to the WS/Segment connecting line from table 7-5-2.

STEP 4: Where WS2 intersects WS1 construction, include WS2 in the OEA construction, and connect WS1 to WS2 with a tangent line. Otherwise revert to the single WS construction.

CASE 1-1: WS1 and/or WS2 lie outside the outbound segment boundary.
STEP 1: Construct the OEA outer boundary using WS1 and/or WS2 and the tangent 30-degree converging line until it crosses the outbound segment boundaries (see figure 7-5-9).

CASE 1-2: WS1 and WS2 lie inside the outbound segment boundary.

STEP 1: Where WS1 and/or WS2 lie inside the outbound segment primary boundary, construct the OEA outer boundary using WS1 and/or WS2 and a line (from the point WS1 or WS2 is parallel to the outbound segment nominal track), splaying at 15 degrees relative to the outbound segment nominal track until it intersects the outbound segment boundary lines.

STEP 1a: Where WS1 and/or WS2 lie inside the outbound segment secondary boundary, construct the OEA outer boundary using WS1 and/or WS2 and a line (from the point WS1 or WS2 is parallel to the outbound segment nominal track), splaying at 15 degrees relative to the outbound segment nominal track until it intersects the outbound segment boundary line. Continue the final WS and 30-degree converging line to establish the primary/secondary boundary.

7.5.17. MA Climb Gradient.

Where the standard OCS slope is penetrated and the lowest HATh (final segment evaluation) is required, specify a missed approach CG to clear the penetrating obstruction. MA starting ROC is 100 ft for NVGP calculator 4-25 output for LPV, or table 7-3-2 values for other Vertically-Guided-Procedures, plus appropriate Volume 1, chapter 3 ROC adjustments. ROC for a sloping OCS applies (48 feet per NM), the distance is measured parallel to the missed approach track to TIA end (Turn-at-Altitude), or early-turn point (Turn-at-Fix), then shortest primary distance to the next fix. Apply fix-to-fix distance for subsequent segments. Where a part-time altimeter is in use, consider the aircraft SOC altitude to be the MDA associated with the local altimeter (ensures adequate CG is applied).

STEP 1: Calculate the ROC, the altitude at which the ROC for the obstacle is achieved, and the required CG (ft/NM) using calculator 5-9. See calculator 1-21 for MA Slope calculations.

STEP 2: Apply the CG to:

- The altitude which provides appropriate ROC, or
- The point/altitude where the subsequent standard OCS slope clears all obstacles.

STEP 2a: Where a RASS adjustment is applicable for climb-to-altitude operations (prior to turn, terminate CG, etc.), apply the CG associated with the lower MDA/DA (calculator 5-9). To establish the RASS-based climb-to-altitude, add the difference between the Local altimeter-based MDA and the RASS-based MDA to the climb-to-altitude and round to the next higher 100-ft increment (see Volume 1, chapter 3 for further details).

Calculator 5-9. ROC/CG/Minimum Altitude/OCS

$$(1)\ ROC_{obs} = ROC_{start} + 48 \times d$$

$$(2)\ ALt_{min} = O_{eLev} + ROC_{obs}$$

$$(3)\ CG = \frac{r}{d} \times In\left(\frac{r+ALt_{min}}{r+Aircraft_{SOC}}\right)$$

Where

ROC_{start} = *SOC ROC (table 7-3-2 value) or (100 ft for NVGP)*
d = distance (NM) CG origin (SOC) to Obstacle
O_{elev} = *Obstacle Elevation (MSL)*
$Aircraft_{SOC}$ = *aircraft altitude (MSL) at CG origin*

Figure 7-5-1. Straight Missed Approach (Legs with Specified Tracks)

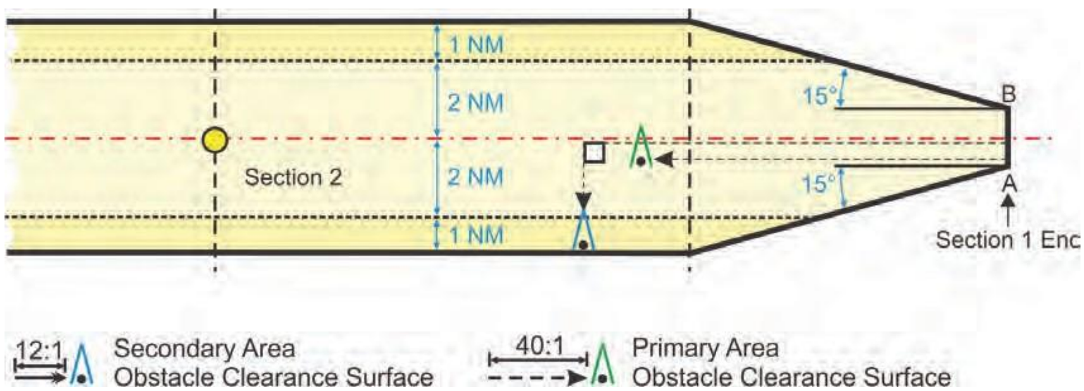


**Figure 7-5-2. Turn at Altitude –
Direct to Waypoint Small Angle Turn**

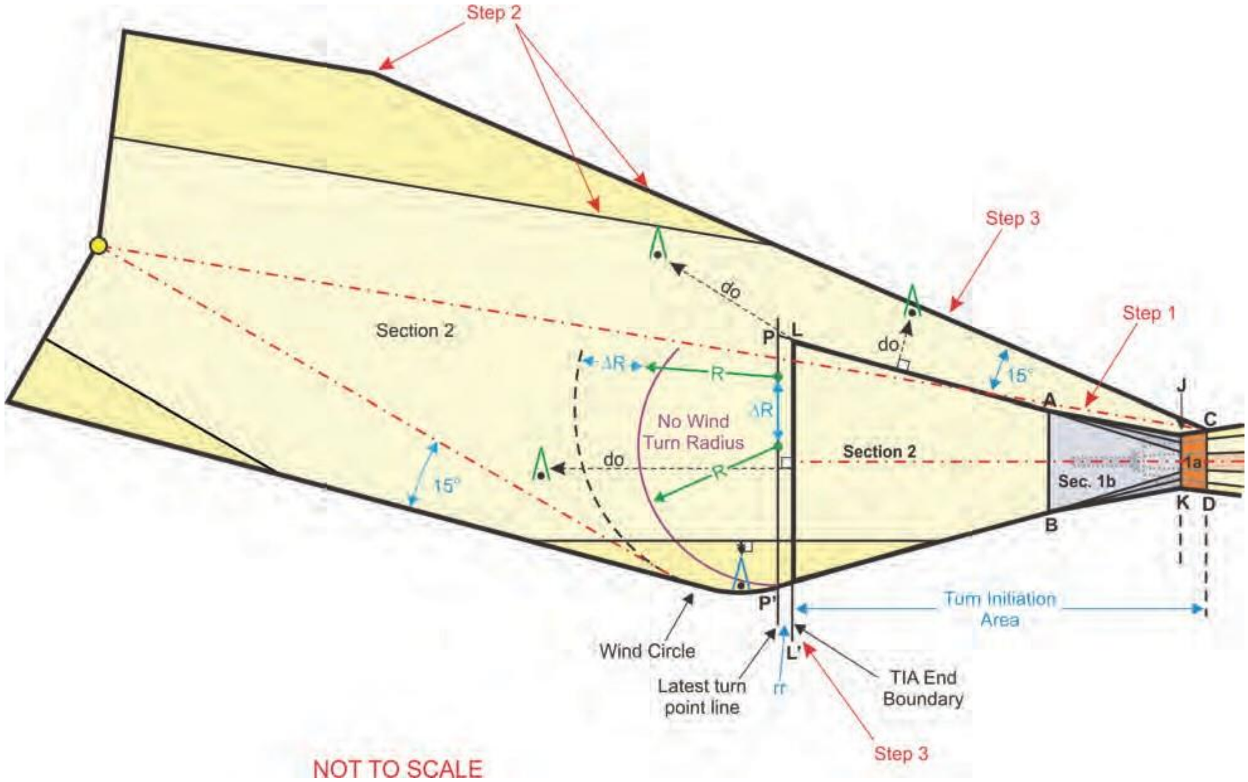


Figure 7-5-3. Turn at Altitude, TIA must Extend to the End of Section 1B

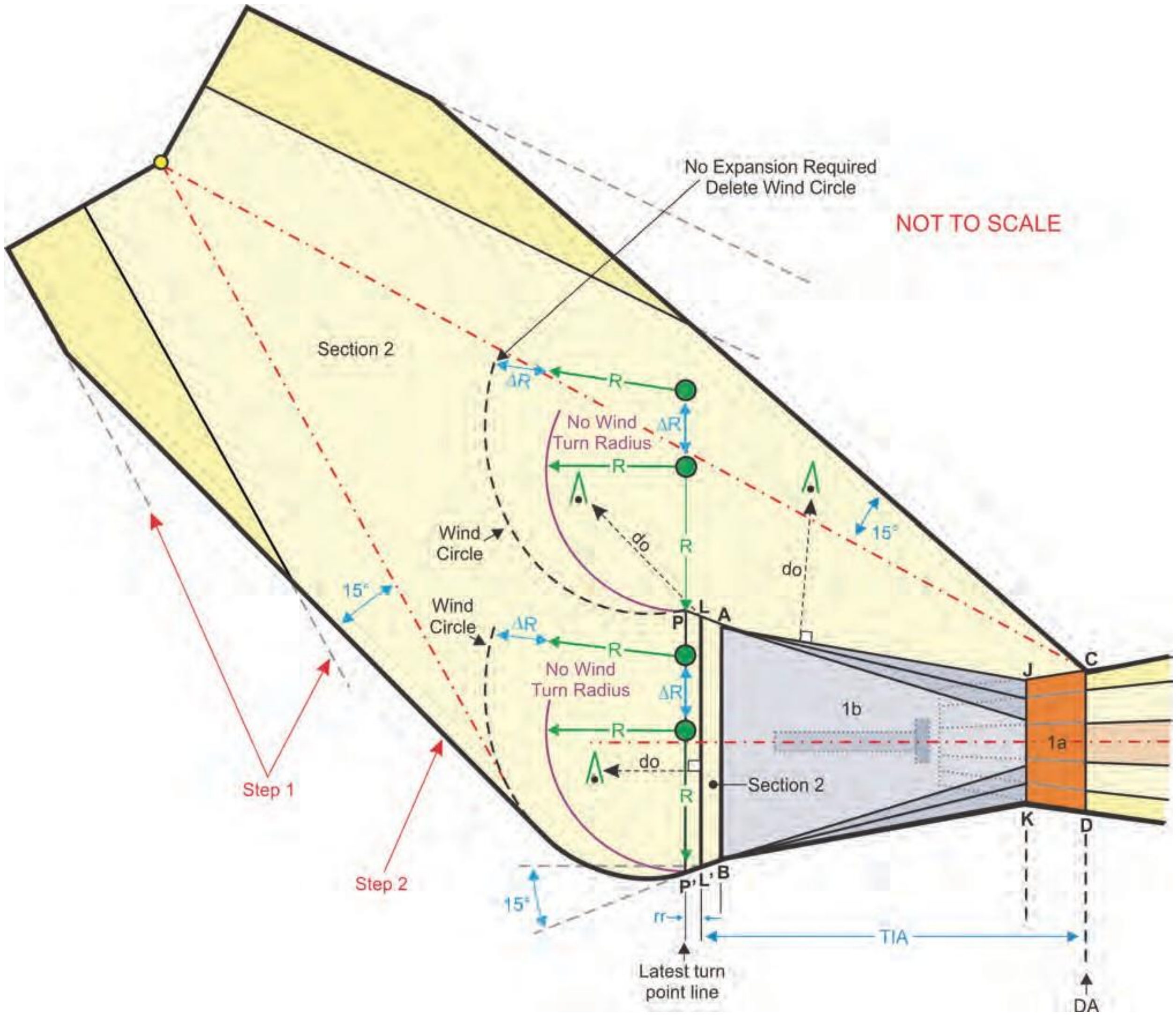


Figure 7-5-4. Turn at Altitude (Minimum Straight Segment)

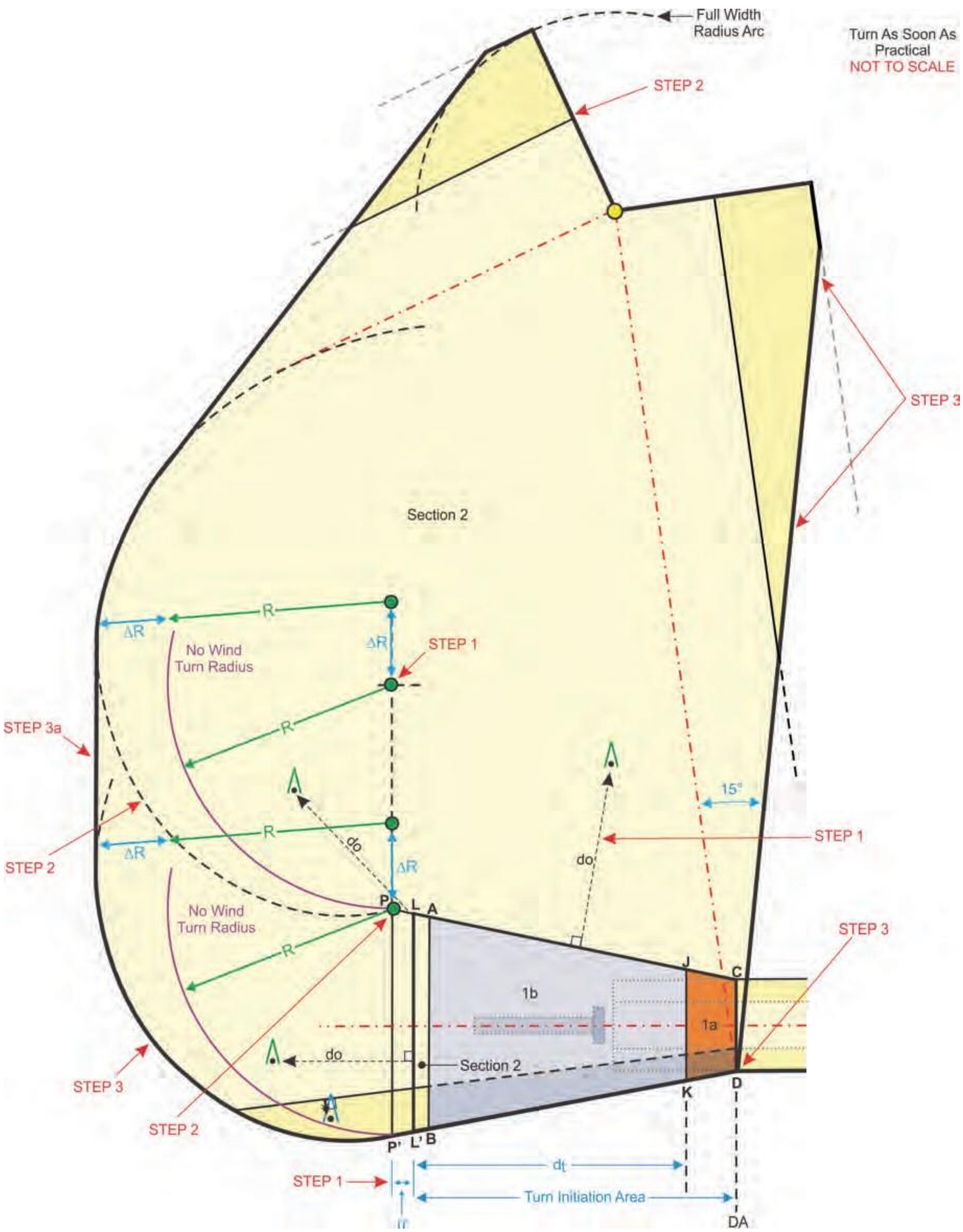


Figure 7-5-5. Turn at Altitude ≥ 180 degrees

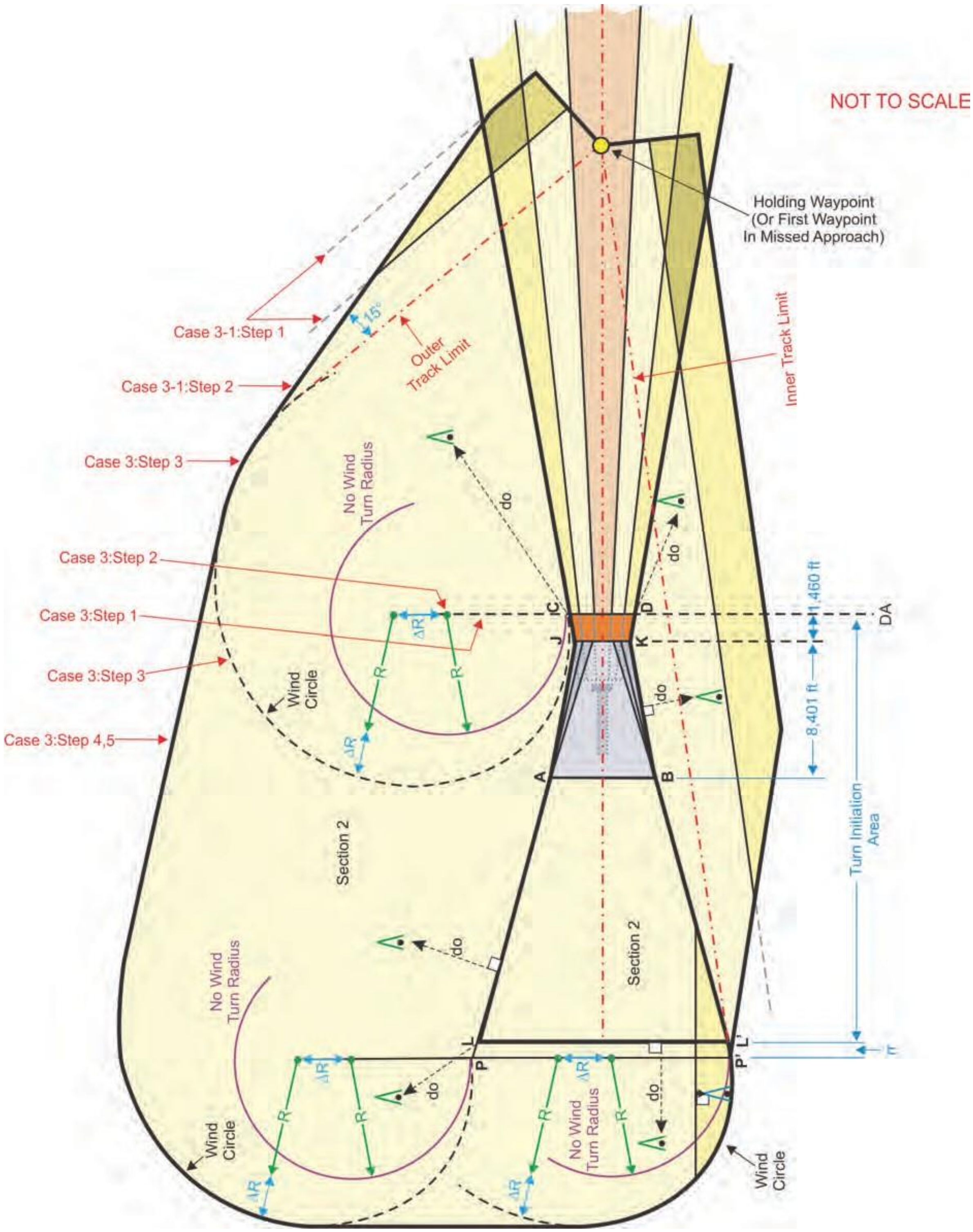


Figure 7-5-6. FB DF-TF Turn Following Turn at Altitude

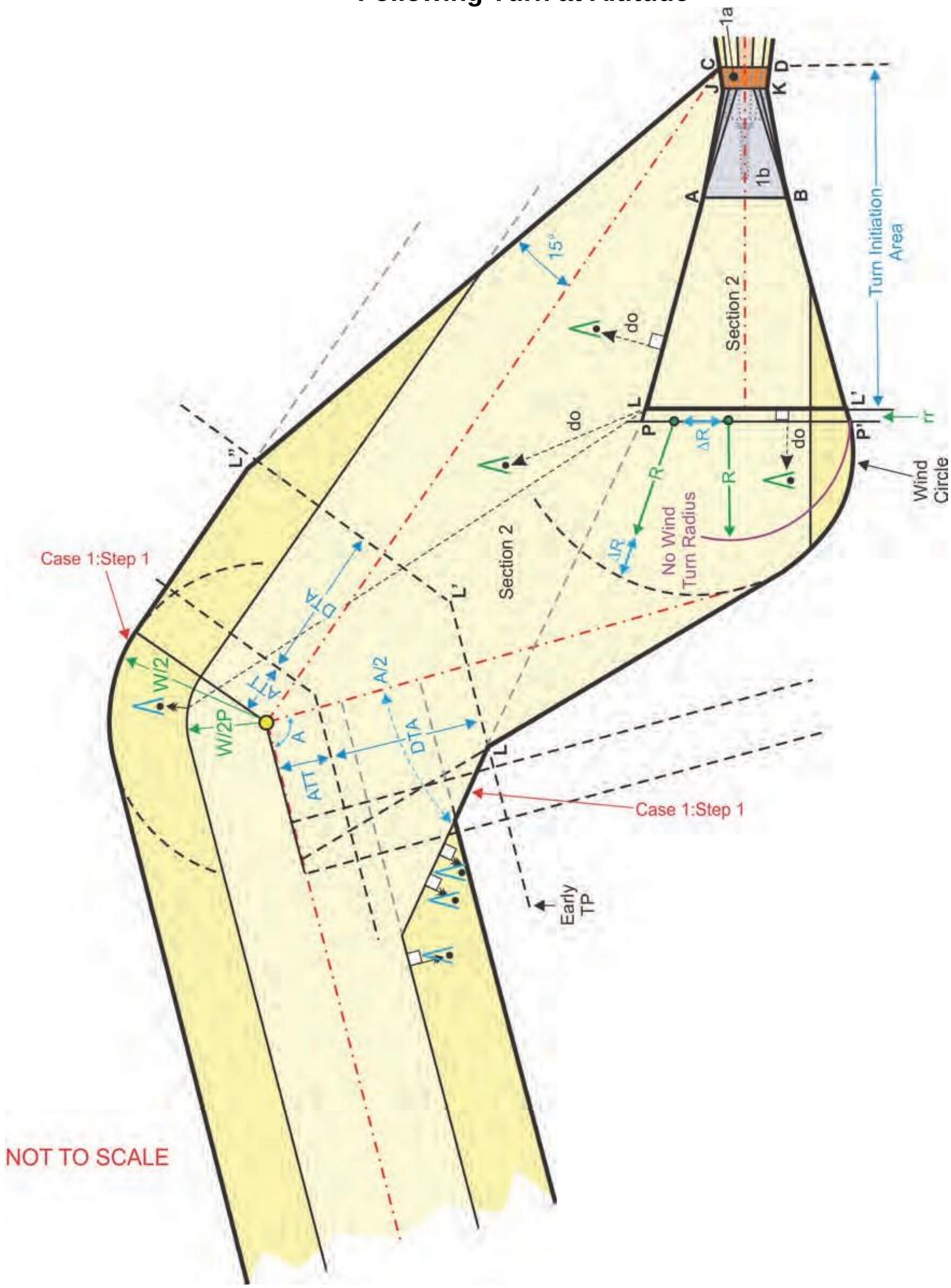
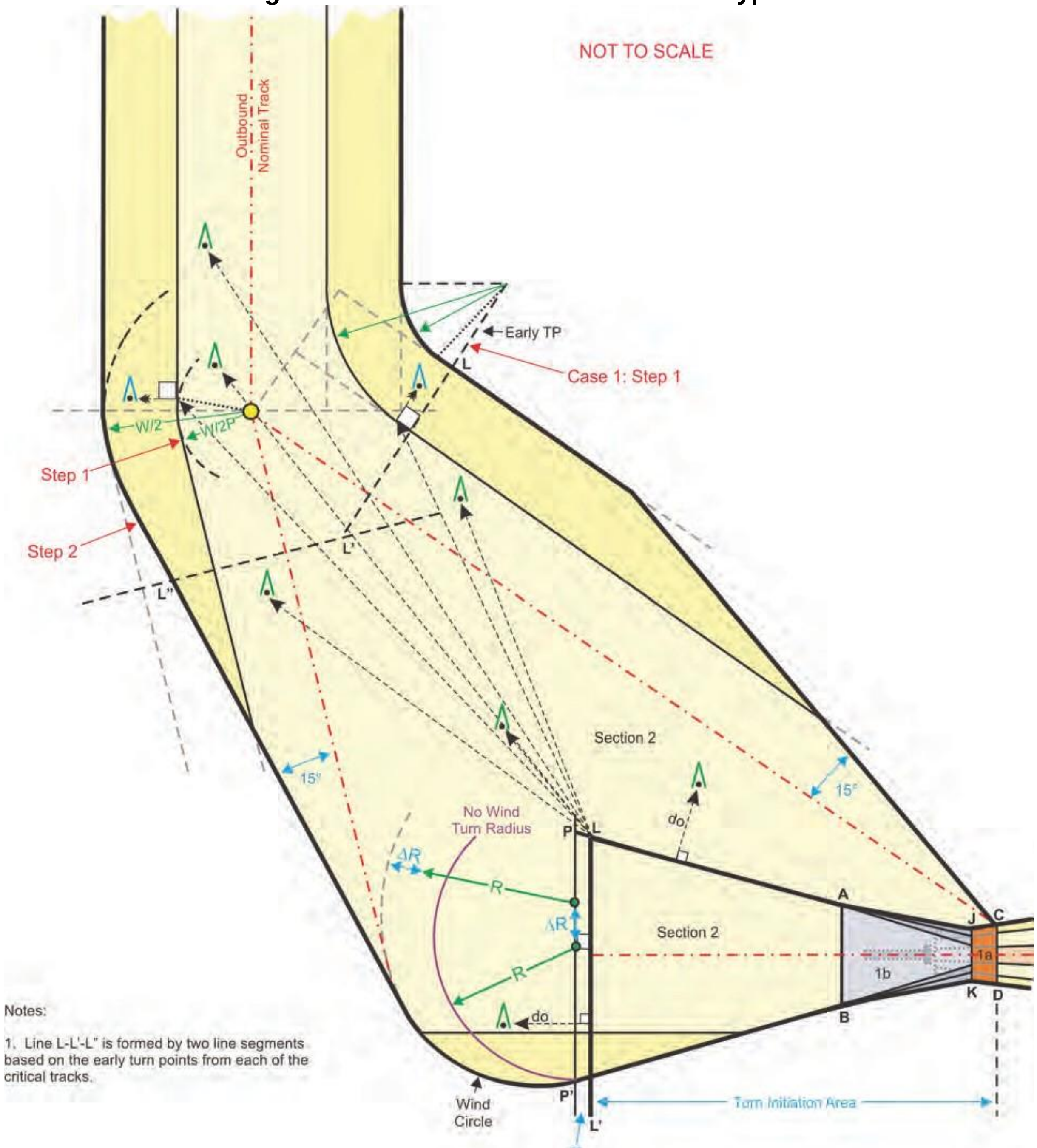


Figure 7-5-7. Turn at Altitude to FB Waypoint



Notes:

1. Line L-L'-L" is formed by two line segments based on the early turn points from each of the critical tracks.

Figure 7-5-8. Maximum Turn (FB) Following Turn at Altitude

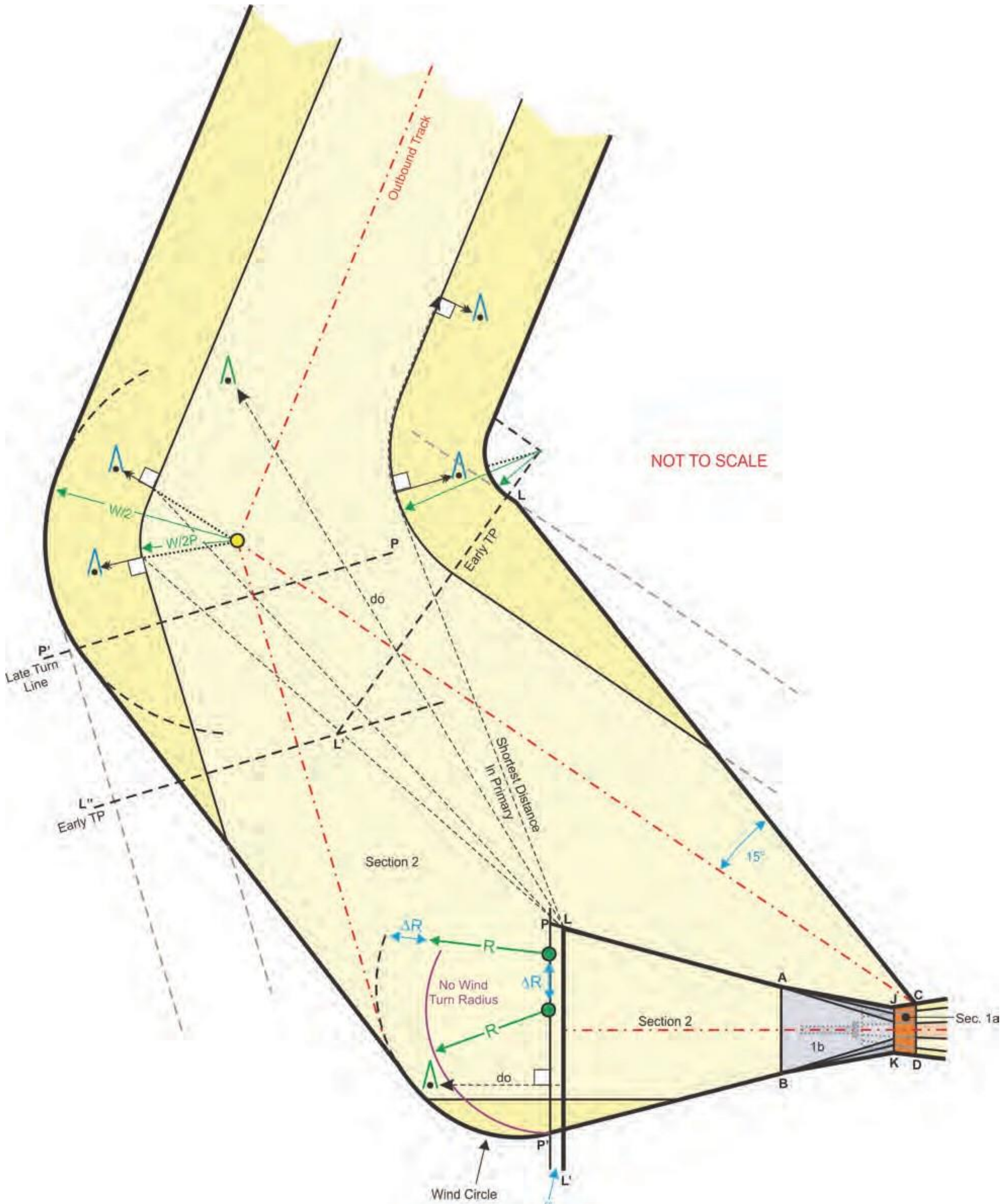


Figure 7-5-9. Turn at Altitude to a FO Waypoint

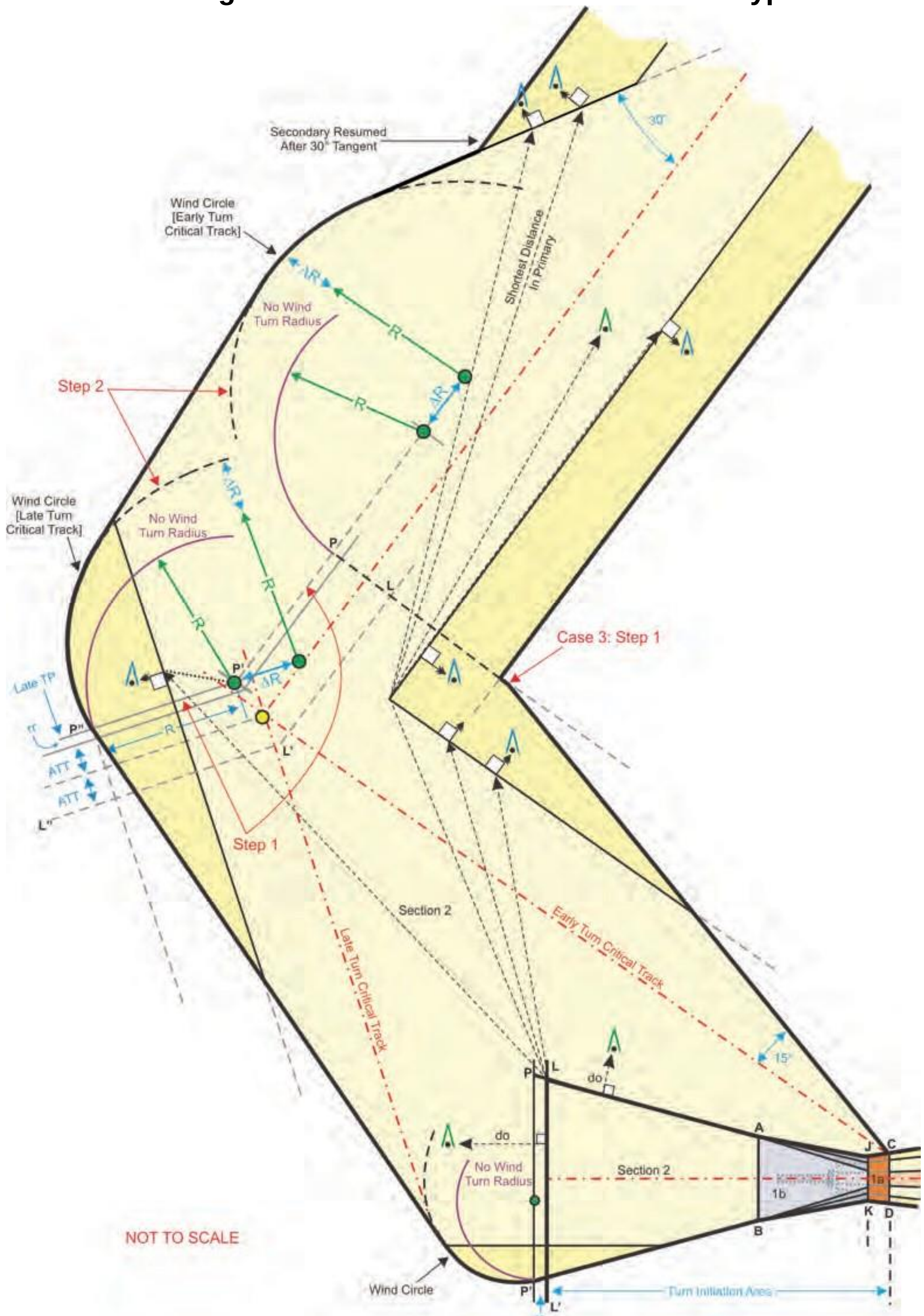
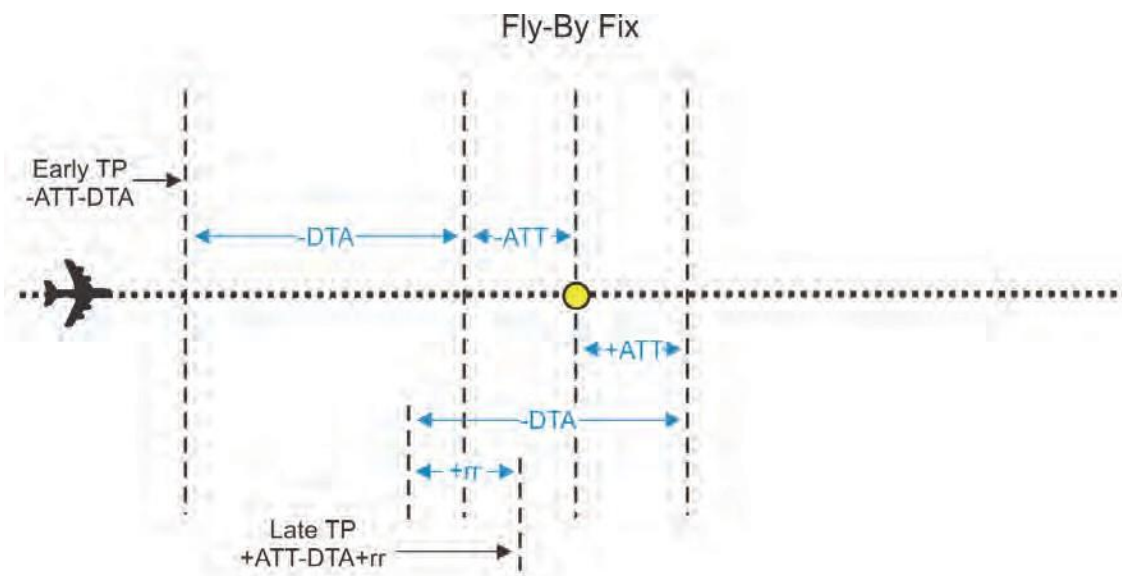


Figure 7-5-10. FO/FB Fix Diagrams



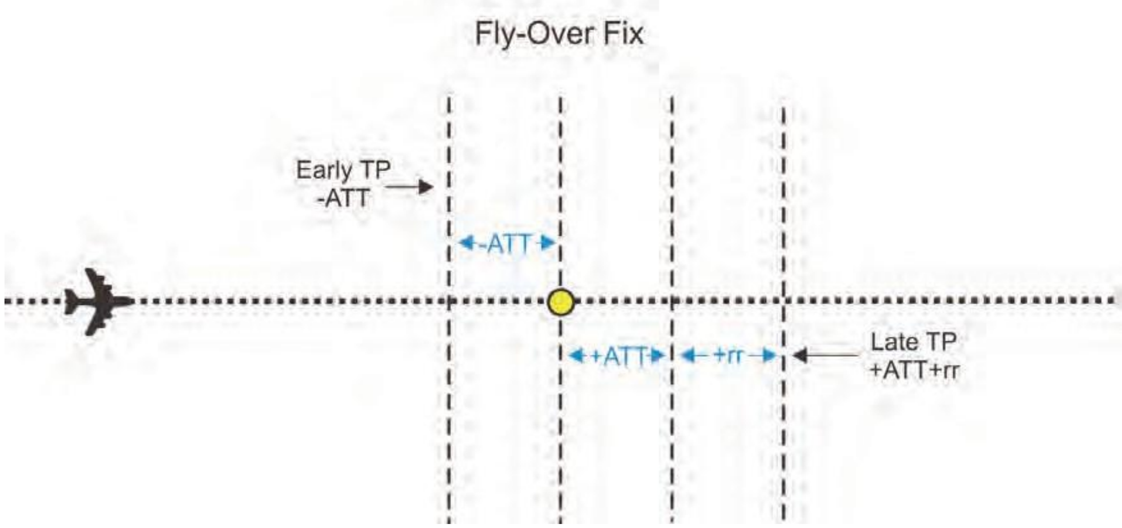


Figure 7-5-11A. Turn at Waypoint (FB)

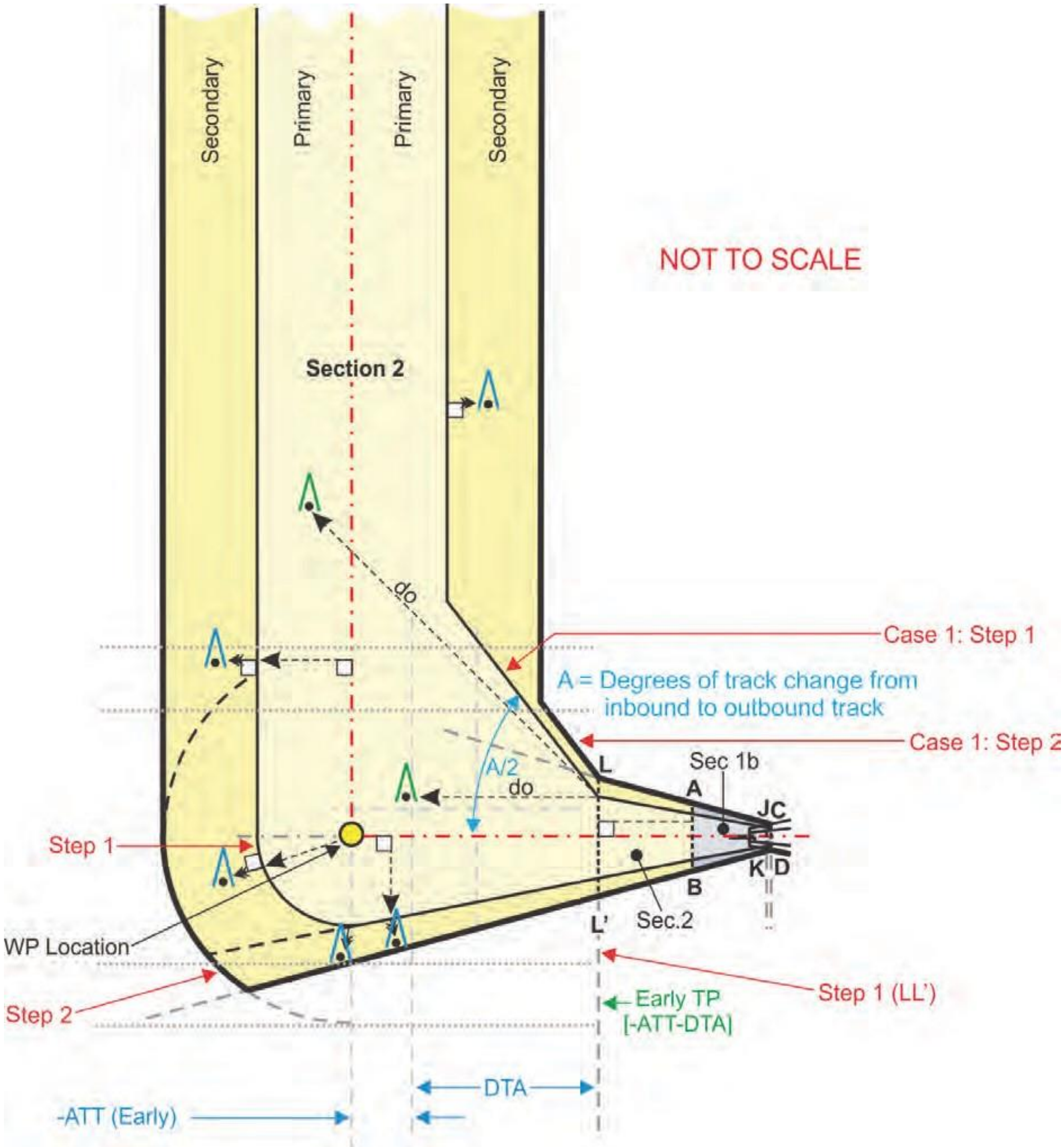


Figure 7-5-11B. Turn at Waypoint (FB)

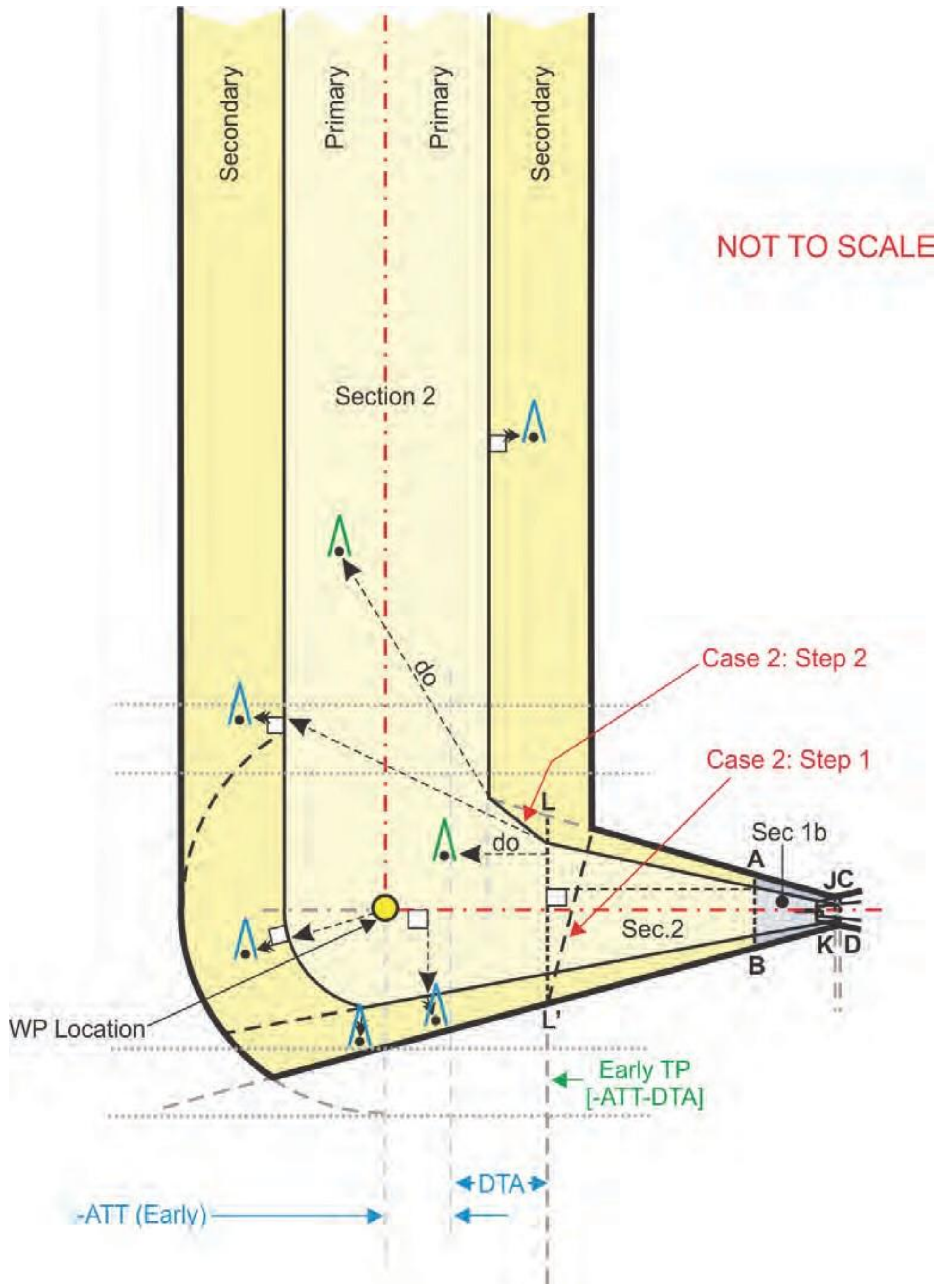


Figure 7-5-11C. Turn at Waypoint (FB)

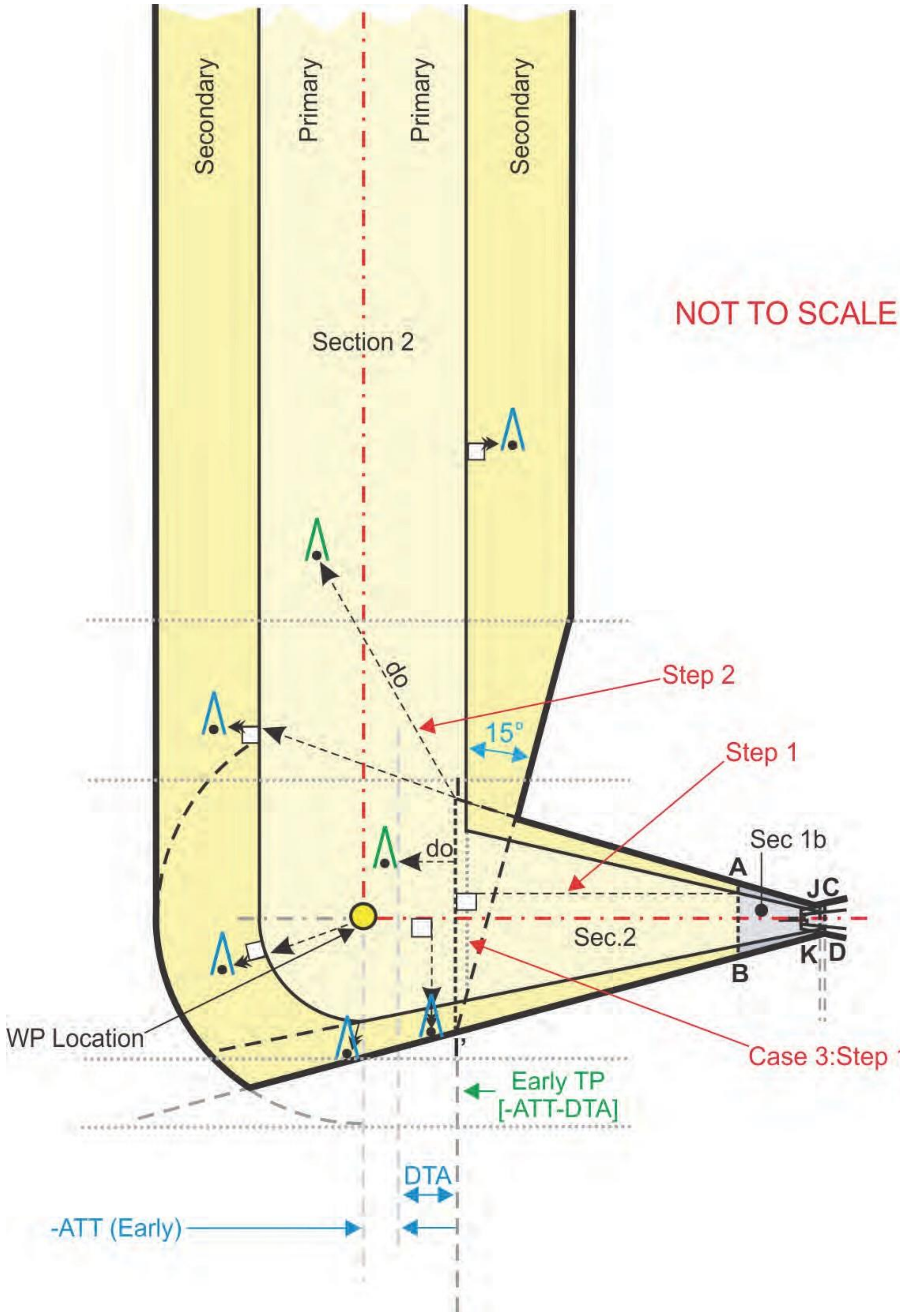


Figure 7-5-12. Turn at Waypoint (FO), < 75°

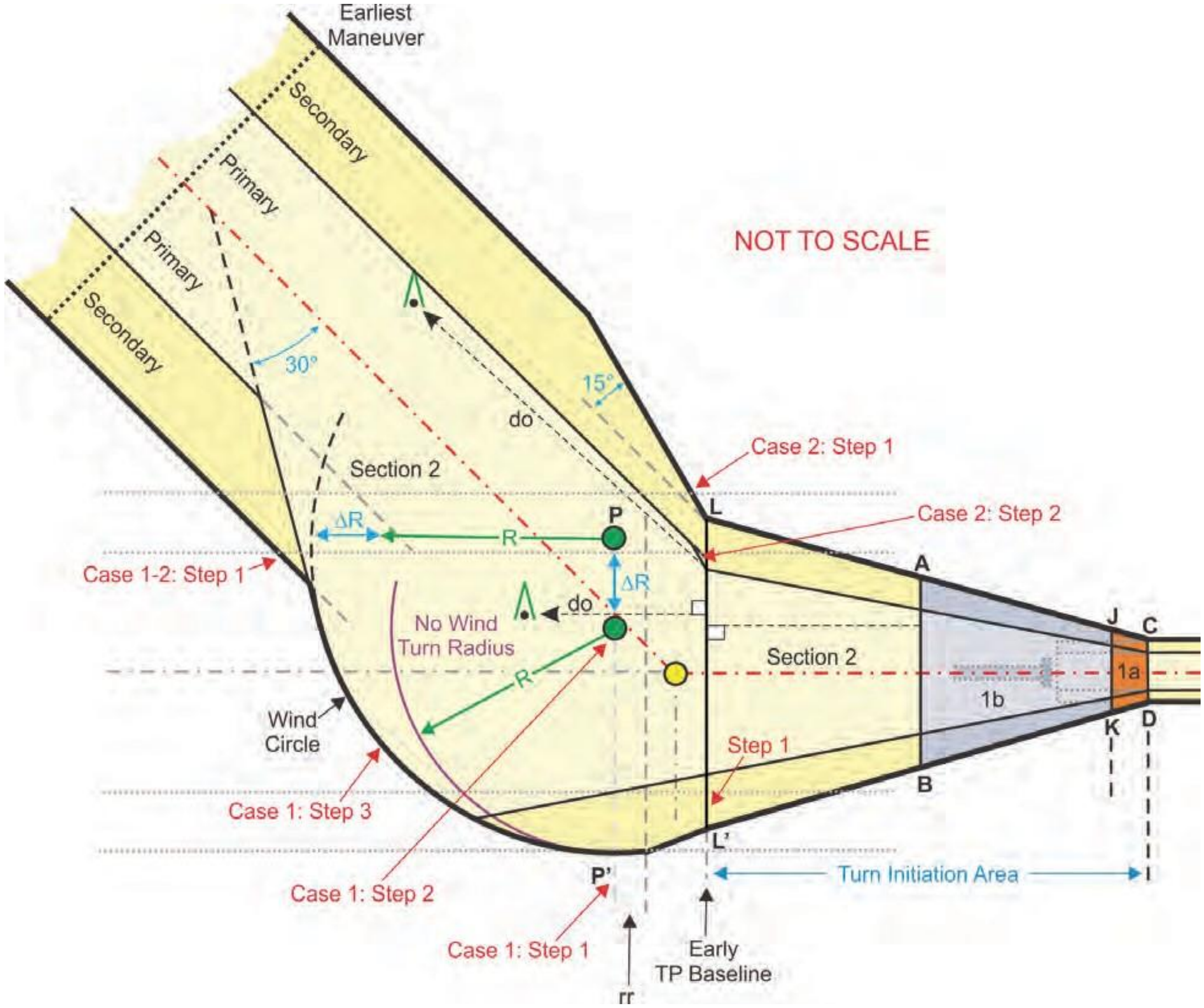


Figure 7-5-13. Turn at Waypoint (FO), 90°

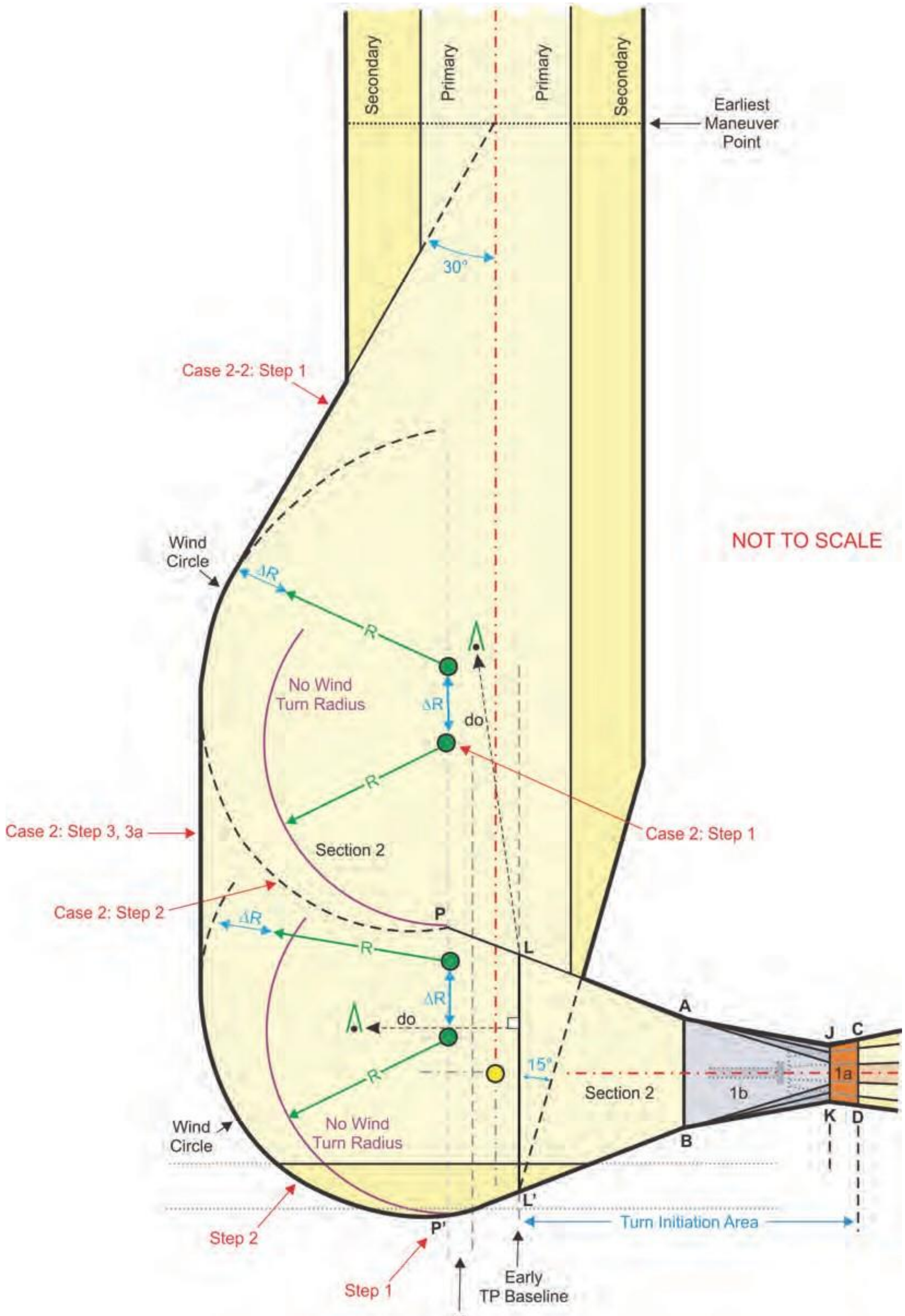


Figure 7-5-14A. WS Outer Boundary Connections

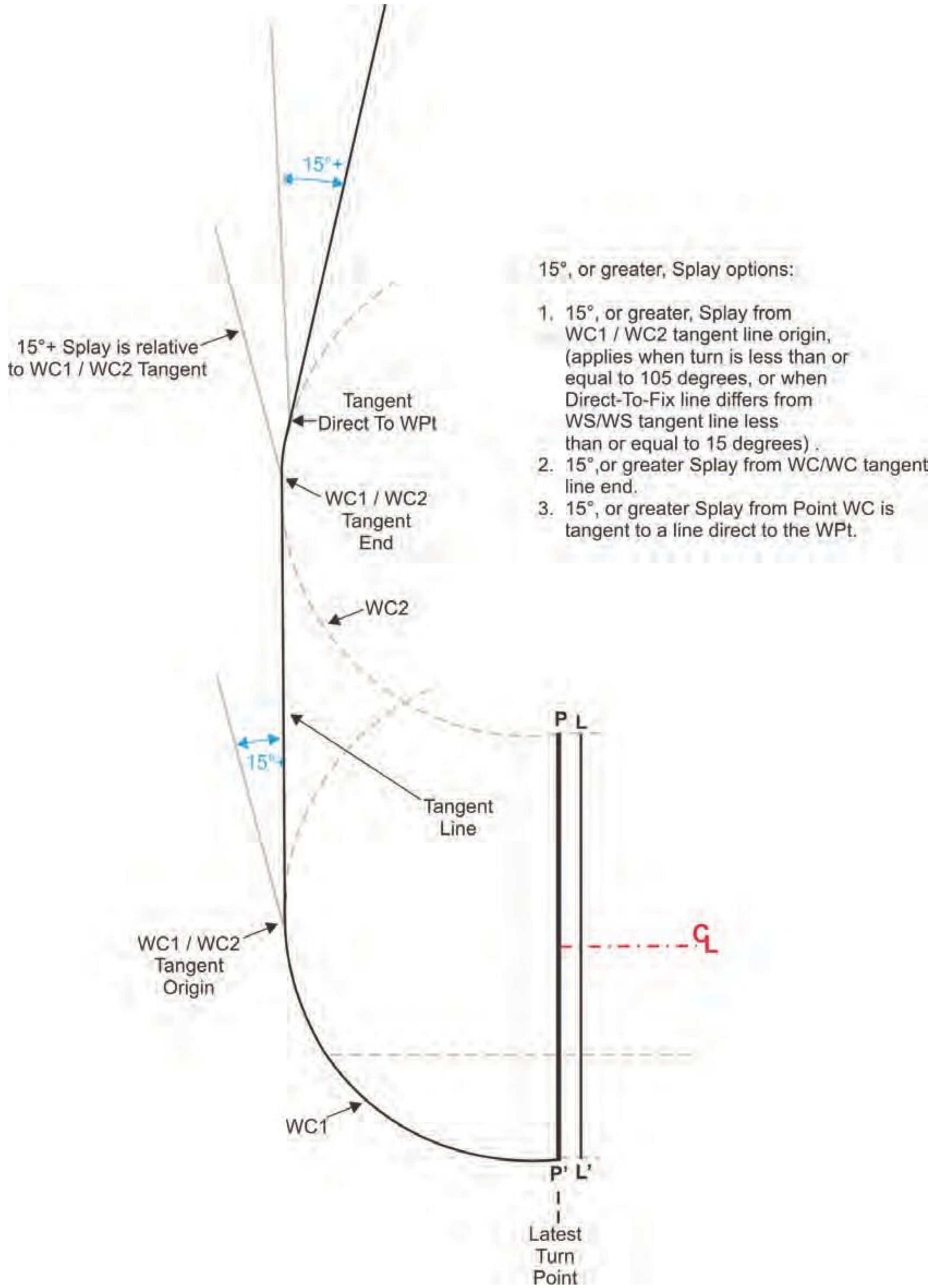


Figure 7-5-14B. WS1 Outer Boundary Connection

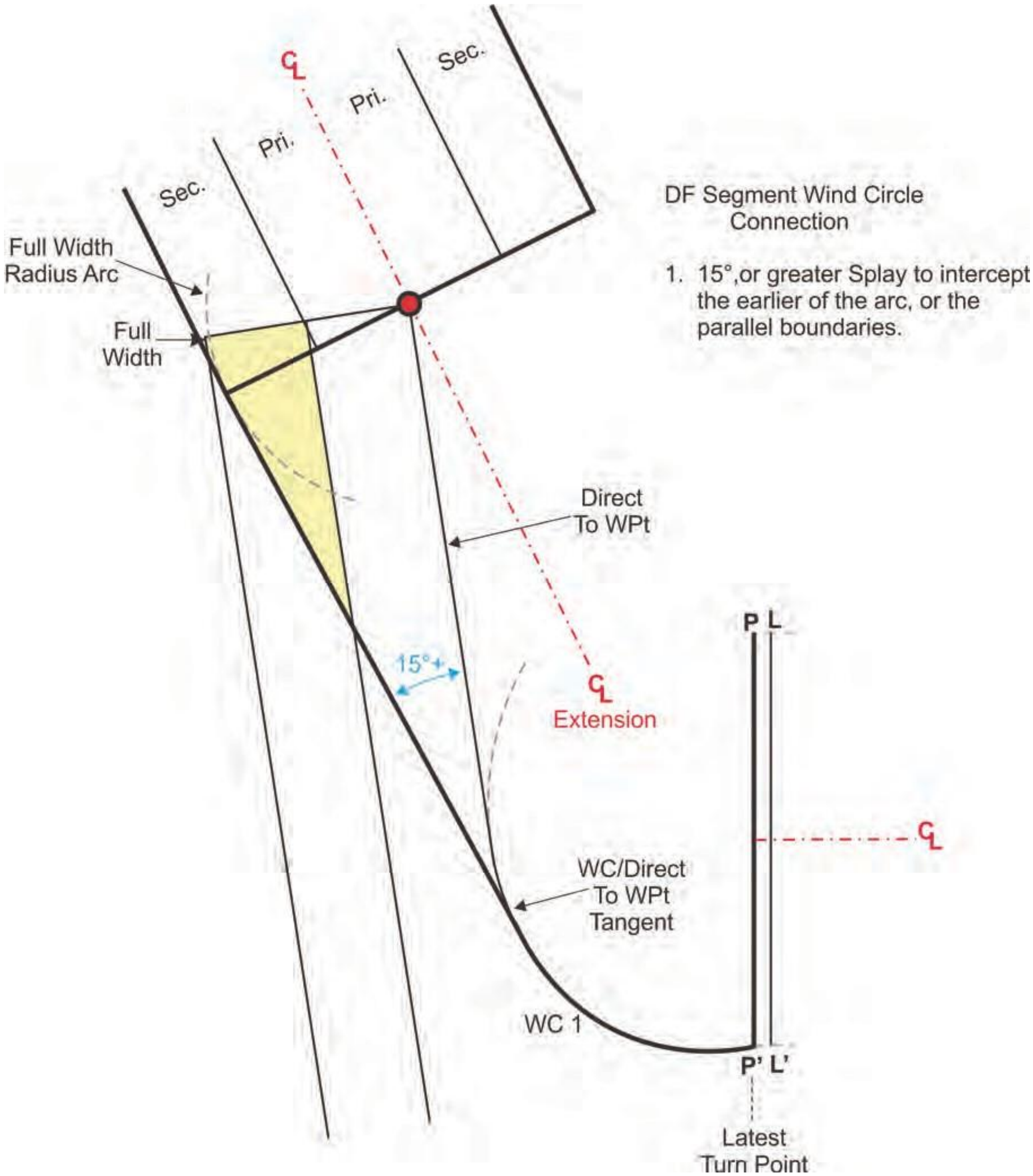
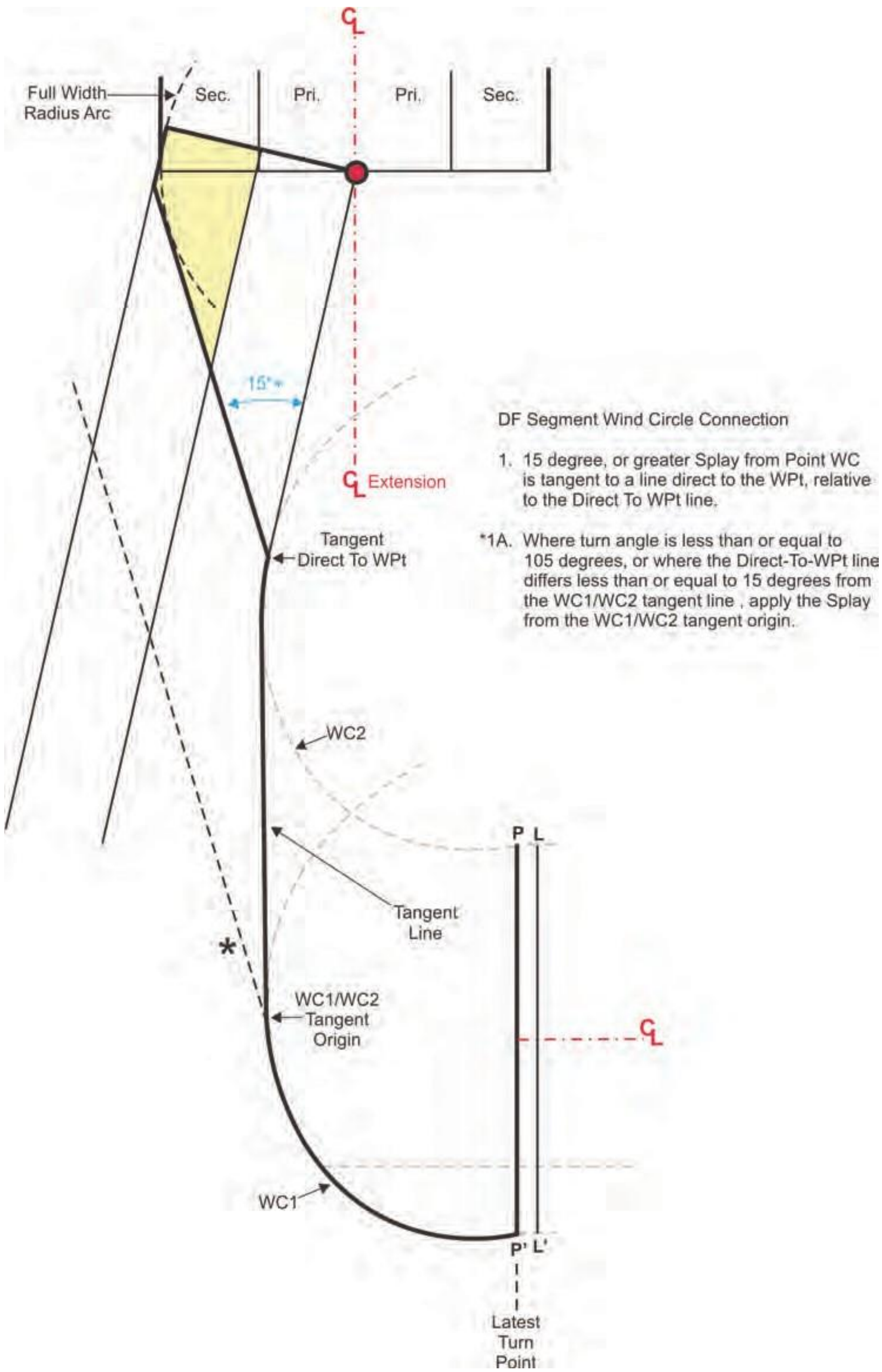


Figure 7-5-14C. WS Outer Boundary Connection (Multiple)



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VOLUME 2: PERFORMANCE BASED NAVIGATION (PBN)

CHAPTER 8: STANDARD FOR HELICOPTER AREA NAVIGATION (RNAV)

SECTION 1: GENERAL INFORMATION

8.1. General Information.

8.1.1. Purpose

This Performance Based Navigation (PBN) chapter contains criteria for the formulation, review, approval and publication of area navigation (RNAV) instrument procedures based on Global Navigation Satellite System (GNSS) navigation for helicopter. The criteria were developed by United States Federal Aviation Administration's (FAA).

8.1.2. General

a. This criteria assumes the use of Global Navigation Satellite System (GNSS) receivers approved for approach operations in accordance with the applicable Technical Standard Order (TSO) or equivalent criteria.

b. Unless otherwise specified, TP308/GPH209 procedures applies. Heliport design must meet the requirements contained in Canadian Aviation Regulations Heliport Standards 325. Obstacle clearance area dimensions are based on 90 knots indicated airspeed (KIAS) maximum in both the initial and intermediate segments and 90 KIAS or 70 KIAS maximum in both the final and the missed approach segments.

Note: The missed approach airspeed limitation applies until the aircraft is established on the inbound course to the missed approach clearance limit. Speed must be depicted if 70 KIAS used for final or MA segment.

c. Apply the hold construction methods and obstacle clearance requirements of Volume 1, Chapter 18. Use pattern 4 for all helicopter holding (including climb-in-hold) up to and including 10 000 ft.

8.1.3. **Background**. The analysis of Global Positioning System/Wide Area Augmentation System (GPS/WAAS) navigation flight test data provides the basis for these criteria. A significant difference exists between approach procedures to runways and approach procedures to heliports. Approaches to runways terminate in relatively obstacle-free environments. Approaches to heliports commonly terminate in areas of dense population and large buildings. Speed limitations incorporated in these criteria provide the smallest obstacle clearance areas, the shortest segment lengths, and the lowest ceiling and visibility minimums. The graphic illustrations in this document are not to scale.

8.1.4. Definitions

8.1.5. Approach Procedure Types using RNAV (GNSS).

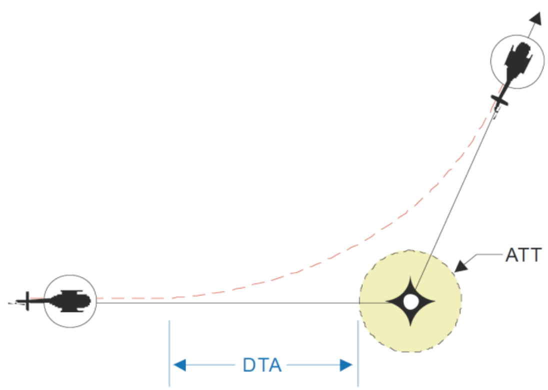
a. IFR to an IFR Heliport. An IFR approach to a heliport that meets the applicable regulations and helicopter standard detailed in CARs 305 and 325.

b. Point-in-Space (PinS) Approach (Proceed VFR). An IFR PinS Approach to one or more heliports or a geographical area associated with a specific heliport. The phrase “Proceed VFR” is charted on the procedure for the VFR segment following the MAP.

c. IFR to a Runway. An IFR helicopter approach procedure to a runway.

8.1.6. Distance of Turn Anticipation (DTA). DTA represents the maximum distance prior to a fly-by-fix that a helicopter is expected to start a turn to intercept the course of the next segment. The along-track tolerance (ATT) value, associated with a fix, is added to the DTA value when DTA is applied (see figure 8-1-1 and formula 2-6).

Figure 8-1-1. Distance of Turn Anticipation (DTA)



DTA = Radius x tan (degrees of turn ÷ 2)

8.1.7. **Fly-By Waypoint (WP).** A ✧ fly-by WP is a waypoint where a turn is initiated prior to reaching it (✧).

8.1.8. **Fly-Over Waypoint (WP).** A ⊕ fly-over WP is a waypoint over which an aircraft is expected to fly before one turn is initiated.

8.1.9. **Final Approach and Takeoff Area (FATO).** A defined area over which the final phase of a helicopter approach manoeuvre to hover or land is completed and from which the take-off manoeuvre is commenced. The guidance for a FATO is published in the regulations and standards detailed in CARs 305 and 325.

8.1.10. **Fictitious Helipoint (FHP).** The FHP is located 2,600 ft beyond the MAP and 9,023 ft in front of the flight path alignment point (FPAP). It is used to establish the approach course width for the WAAS.

8.1.11. **Flight Path Alignment Point (FPAP).** The FPAP is a 3-dimensional (3D) point defined by World Geodetic System of 1984/North American Datum of 1983 (WGS-84/NAD-83) latitude, longitude, mean sea level (MSL) elevation, and WGS-84 Geoid height. The FPAP is used in conjunction with the FHP and the geometric center of the WGS-84 ellipsoid to define the final approach azimuth [localizer performance with vertical guidance (LPV) glidepaths vertical plane, where used) associated with a localizer performance (LP) or LPV final course.

8.1.12. **Flight Technical Error (FTE).** FTE is the measure of the pilot or autopilot's ability to control an aircraft so that it's indicated position matches the desired position.

8.1.13. **Global Navigation Satellite System (GNSS) Azimuth Reference Point (GARP).** A calculated point 1,000 ft beyond the FPAP lying on an extension of a geodesic line from the landing threshold point/fictitious threshold point (LTP/FTP) through the FPAP. This point is used by the airborne system as the origin of the lateral guidance sector. It may be considered as the origin of an imaginary localizer antenna.

8.1.14. **Geoid Height (GH).** The GH is the height of the Geoid relative to the WGS-84 ellipsoid. It is a positive value when the Geoid is above the WGS-84 ellipsoid and negative when it is below. The value is used to convert a mean sea level (MSL) elevation to an ellipsoidal or geodetic height - the height above ellipsoid (HAE).

Note: The Geoid is an imaginary surface within or around the earth that is everywhere normal to the direction of gravity and coincides with MSL in the oceans. It is the reference surface for MSL heights.

8.1.15. **Height Above Landing Area Elevation (HAL).** The HAL is the height of the minimum descent altitude (MDA) above helipoint elevation.

8.1.16. **Height Above Surface (HAS).** HAS is the height of the MDA above the highest terrain/surface within a 5,200-ft radius of the MAP in the PinS Approach procedure.

8.1.17. **Helipoint Crossing Height (HCH).** The HCH is the height of the vertical guidance path above the heliport elevation at the helipoint.

8.1.18. **Helipoint.** The helipoint is the aiming point for the visual segment and is normally centered in the touchdown and lift-off area (TLOF). The TLOF is normally centered in the FATO.

8.1.19. **Heliport.** An area of land, water, or structure used or intended to be used for helicopter landings and takeoffs and includes associated buildings and facilities. IFR and VFR heliports are described in the regulations and standards detailed in CARs 305 and 325.

8.1.20. **Heliport Elevation (HE).** For heliports without a precision approach, the heliport elevation is the highest point of the FATO expressed as the distance above mean sea level (MSL).

8.1.21. **Heliport Geometric Centre (HGC).** The geographic position of the helipoint, measured at the center of the FATO or the central point of multiple FATOs, expressed as (WGS-84/NAD-83) latitude and longitude to the nearest hundredth of a second. The HGC elevation is equal to the heliport elevation.

8.1.22. **Initial Departure Fix (IDF).** The first fix on a PinS Approach departure procedure where application of IFR obstruction protection and air traffic separation standards are provided.

8.1.23. **IFR Heliports**. For the purpose of this publication, consider IFR Heliport to mean instrument heliport, where an instrument approach is conducted to an instrument FATO in accordance with the applicable regulations and heliport standards detailed in CARs 305 and 325.

8.1.24. **IFR Runway**. For the purpose of this publication, consider IFR Runway to mean instrument runway, in accordance with CARs 325 and TP308/GPH209 Annex A.

8.1.25. **Landing and Takeoff Site.** The area of intended landing and takeoff. It can be a heliport, or other point of landing designated for a PinS Approach.

8.1.26. **Landing Threshold Point.** The LTP is a 3D point at the intersection of the runway centerline and the runway threshold (RWT). WGS-84/NAD-83 latitude, longitude, MSL elevation, and geoid height define it. It is used in conjunction with the FPAP and the geometric center of the WGS-84 ellipsoid to define the vertical plane of an RNAV final approach course.

8.1.27. **Proceed VFR.** For PinS Approach procedures, this phase requires the pilot to proceed from the MAP to the selected landing area in VMC conditions. The pilot is responsible for obstacle and terrain avoidance from the MAP to the landing site. A missed approach procedure is not provided between the MAP and the landing site. The landing site is not required to be in sight from the MAP.

8.1.28. **Reference Datum Point (RDP).** The RDP is a 3D point defined by the LTP or FTP latitude/longitude position, MSL elevation, and a threshold crossing height (TCH) value. The RDP is in the vertical plane associated with the final approach course and is used to relate the glidepath angle of the final approach track to the landing runway.

8.1.29. **Touchdown and Lift-Off Area (TLOF).** A TLOF is a load bearing, generally paved area, normally centered in the FATO, on which the helicopter lands or takes off (see CARs Standard 325-Heliports).

8.1.30. **VFR Heliports**. For the purpose of this publication, consider VFR Heliport to mean non-instrument heliport, where a PinS Approach is conducted to a non-instrument FATO by proceeding VFR from the MAP to the heliport in accordance with the applicable regulations and heliport standards detailed in CARs 305 and 325.

8.1.31. **VFR Runway**. For the purpose of this publication, consider IFR Runway to mean non-instrument runway, in accordance with CARs 325 and TP308/GPH209 Annex A.

8.1.32. **Minimum instrument meteorological condition airspeed ($\mathbf{V_{mini}}$). $\mathbf{V_{mini}}$** means instrument flight minimum speed, utilized in complying with minimum limit speed requirements for instrument flight. This is the certified minimum airspeed that a specific helicopter is approved to enter instrument meteorological flight conditions.

8.1.33. **Visual Segment Descent Angle (VSDA).** The angle of descent in the visual segment. Visual Segment Descent Angle (VSDA). The VSDA is a developer-specified angle extending from a point 5 to 20 ft directly above the helipoint to the MDA. The VSDA must cross the MDA between the helipoint and the MAP. The maximum VSDA is 7.5 degrees, optimum is 6.0 degrees, VSDA angles higher than 7.5 degrees require Flight Standards Service approval. (see figure 4-10).

8.1.34. **Visual Segment Reference Line (VSRL).** A line perpendicular to the final course at a distance of 75 ft (22.9 m) from the helipoint for heliports with instrument procedures

8.1.35. **Wide Area Augmentation System (WAAS) Localizer Performance (LP).** The LP approach applies lateral-only WAAS guidance (and reduced OEA) within the FAS to a PinS Approach.

8.1.36. **Information Update.** Recommendations concerning changes or additions should be provided to one of the following:

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SECTION 2: BASIC CRITERIA INFORMATION

8.2. Basic Criteria Information.

8.2.1. Data Resolution

Perform calculations using an accuracy of at least 15 significant digits; i.e., floating point numbers must be stored using at least 64 bits. Unless otherwise noted, do not round intermediate results. Round only the final result of calculations for documentation purposes. Required accuracy tolerance is 1 centimeter for distance and 0.002 arc-second for angles. The following list specifies the minimum accuracy standard for documenting data expressed numerically. This standard applies to the documentation of final results only; e.g., a calculated adjusted glide path angle of 3.04178 degrees is documented as 3.05 degrees. The standard does not apply to the use of variable values during calculation. Use the most accurate data available for variable values.

8.2.2. Documentation Accuracy

a. WGS-84 latitudes and longitudes to the nearest one hundredth (0.01) arc second; [nearest five ten thousandth (0.0005) arc second for Final Approach Segment (FAS) data block entries];

b. Flight Path Alignment Point (FPAP) mean sea level (MSL) elevation to the nearest foot;

c. FPAP height above ellipsoid (HAE) to the nearest tenth (0.1) meter;

d. Landing Threshold Point (LTP) mean sea level (MSL) elevation to the nearest foot;

e. LTP height above ellipsoid (HAE) to the nearest tenth (0.1) meter;

f. Glidepath angle to the next higher one hundredth (0.01) degree;

g. Courses to the nearest one hundredth (0.01) degree;

h. Course width at threshold to the nearest quarter (0.25) meter; and

i. Distances to the nearest hundredth (0.01) unit [except for “length of offset” entry in Final Approach Segment (FAS) data block which is to the nearest 8 meter value].

8.2.3. **Mathematics Convention**. Most formulas in this chapter 8 as depicted are written for degree calculation.

Note: The value ft-per-NM (fpnm) value for 1 NM was previously defined as 6,076.11548 ft. For the purposes of RNAV criteria, 1 NM is defined as the result of the following calculation:

$$\boldsymbol{fpnm} = \frac{\mathbf{1852}}{\mathbf{0.3048}}$$

8.2.4. Conversions:

- Degree measure to radian measure:
  $radians = degrees \times \frac{\pi}{180}$

- Radian measure to degree measure:
  $degrees = radians \times \frac{180}{\pi}$

- Feet to meters:
  $meters = feet \times 0.3048$

- Meters to feet:
  $feet = \frac{meters}{0.3048}$

- Feet to Nautical Miles (NM):
  $NM = feet \times \frac{0.3048}{1852}$

- NM to feet:
  $feet = NM \times \frac{1852}{0.3048}$

- NM to meters:
  $meters = NM \times 1852$

- Meters to NM:
  $NM = \frac{meters}{1852}$

- Temperature Celsius to Fahrenheit:
  $T_{Fahrenheit} = 1.8 \times T_{Celcius} + 32$

- Temperature Fahrenheit to Celsius:
  $T_{Celcius} = \frac{T_{Fahrenheit} - 32}{1.8}$

8.2.5. **Definition of Mathematical Constants**

a. “e” The constant “e” is the base of the natural logarithm and is sometimes known as Napier’s constant, although its symbol (e) honors Euler. With the possible exception of π, “e” is the most important constant in mathematics since it appears in myriad mathematical contexts involving limits and derivatives. Its value is approximately: e = 2.71828182845904523536028747135266249775 7...

b. “r” The TERPS constant for the mean radius of the earth for spherical calculations in feet. r = 20890537

8.2.6. **Operation Precedence (Order of Operations)**

a. First: Grouping Symbols: parentheses, brackets, braces, fraction bars, etc.

b. Second: Functions: Tangent, sine, cosine, arcsine, and other defined functions.

c. Third: Exponentiations: Powers and roots.

d. Fourth: Multiplication and Division: Products and quotients.

e. Fifth: Addition and subtraction: Sums and differences.

Note 1 (on calculator usage): Most calculators are programmed with standard mathematical rules of precedence.

Note 2 (on calculator usage): When possible, let the calculator maintain all of the available digits of a number in memory rather than re-entering a rounded number. For highest accuracy from a calculator, any rounding that is necessary should be done at the latest opportunity.

8.2.7. **Geospatial Standards**

The following standards apply to the evaluation of obstacle and terrain position and elevation data relative to RNAV Obstacle Evaluation Area(s) (OEAs) and Obstacle Clearance Surface(s) (OCSs). Terrain and obstacle data are reported in NAD-83 latitude, longitude, and elevation relative to MSL in Canadian Geodetic Vertical Datum of 1928 (CGVD-28) or Canadian Geodetic Vertical Datum of 2013 (CGVD 2013) vertical datum. Evaluate obstacles using their NAD-83 horizontal position and CGVD-28 and/or CGVD 2013 elevation value compared to the WGS-84 referenced course centerline (along-track and cross-track), OEA boundaries, and OCS elevations as appropriate.

8.2.8. **OEA Construction and Obstacle Evaluation Methodology**

a. Courses, fixes, boundaries (lateral dimension). Construct straight-line courses as a WGS-84 ellipsoid geodesic path. If the course outbound from a fix differs from the course inbound to the fix (courses measured at the fix), then a turn is indicated. Construct parallel and trapezoidal boundary lines as a locus of points measured perpendicular to the geodesic path. (The resulting primary and/or secondary boundary lines do not display a “middle bulge” due to curvature of the ellipsoids surface since they are not geodesic paths.) NAD-83 latitude/longitude positions are acceptable for obstacle, terrain, and airport data evaluation. Determine obstacle lateral positions relative to course centerline/OEA boundaries using ellipsoidal calculations (see Appendix A).

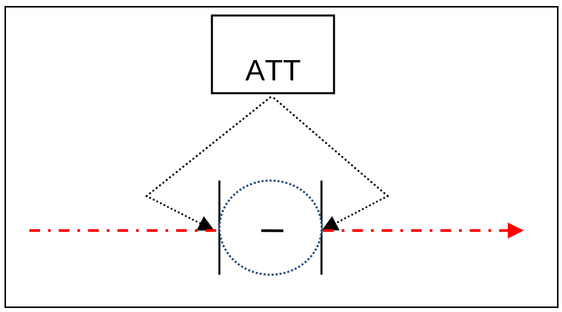
b. Elevations (vertical dimension). Evaluate obstacles, terrain, and airport data using their elevation relative to their orthometric height above the geoid (for our purposes, MSL) referenced to the CGVD-28 and/or CGVD 2013 vertical datum. The elevations of OCSs are determined spherically relative to their origin MSL elevation (CGVD-28 and/or CGVD 2013).

c. Evaluation of Actual and Assumed Obstacles (AAO). Apply the vertical and horizontal accuracy standards in TP308/GPH209 Volume 1 Chapter 2 paragraph 216 for AAO.

8.2.9. **Along Track Tolerance (ATT) Values**

Along Track Tolerance (ATT) is the value used (for segment construction purposes) to quantify position uncertainty of an RNAV fix. The application of ATT can; therefore, be considered "circular;" i.e., the ATT value assigned describes a radius around the plotted position RNAV fix (See Figure 8-2-1 and Table 8-2-1). In order to account for ATT in procedure design, OEAs are constructed and evaluated from the ATT value prior to a segment's initial fix to the ATT value past the segment termination fix. ATT values are not included in minimum segment length calculations.

Figure 8-2-1: Along Track Tolerance (ATT)



Note: Cross-track tolerance (XTT) values were considered in determining minimum segment widths and are not considered further in the segment construction.

Table 8-2-1: ATT Values

RNAV Procedure	Segment	ATT
GNSS	**Enroute** Feeder, initial, Intermediate, Missed Approach (> 30 NM)	**2.0 NM**
	Terminal Feeder, initial, Intermediate, Missed Approach (≤ 30 NM)	**1.0 NM**
	Approach (final)	**0.3 NM**
WAAS* (LPV & LP)	**Approach** (final)	**40 meters**

Note: * Applies to the final segment only. Apply GNSS values to all other segment of the approach procedure. Localizer Performance with Vertical Guidance (LPV) and Localizer Performance (LP).

8.2.10. **Procedure Identification.** GPS and WAAS are considered to be RNAV systems. TP308/GPH209, Volume 5, Chapter 1, Para 105, applies, except:

a. For approaches to a heliport, NAVAID type is considered GNSS (e.g., COPTER RNAV (GNSS) 160°).

b. IFR Approach to an IFR Runway within 30 degrees alignment. Use the abbreviation "RWY" following by the runway number. Example: COPTER RNAV (GNSS) RWY 22).

c. Point-In-Space (PinS) Approach procedures. Use the magnetic bearing of the final approach course. (e.g., COPTER RNAV (GNSS) 270°.

d. Multiple Procedures to the Same Runway. Use TP 308/GPH209 Volume 1, Chapter 1, paragraph 161b.

8.2.11. **Segment Width (General).** Table 8-2-2 lists primary and secondary width values for all segments of an RNAV approach procedure. Where segments cross* a point 30 NM from airport reference point (HGC), segment primary area width increases (expansion) or decreases (taper) at a rate of 30 degrees relative to course to the appropriate width. Secondary area expansion/taper is a straight-line connection from the point the primary area begins expansion/taper to the point the primary area expansion/taper ends. Reference to route width values is often specified as NM values measured from secondary area edge across the primary area to the secondary edge at the other side. For example, route width for segments more than 30 NM from HGC is "1-3-3-1." See figures 8-2-2b and 8-2-2c. For distances ≤ 30 NM, the width is "0.5-1.5-1.5-0.5." See table 8-2-2 and figure 8-2-2a.

Table 8-2-2: RNAV Linear Segment Width (NM) Values

Segment		Primary Area Half-Width (p)	Secondary Area (s)
En Route, Feeder, Initial & Missed Approach	> 30 NM from HGC	± 3.00	1.00
		1-3-3-1	
Feeder, Initial, Missed Approach	≤ 30 NM from HGC	± 1.50	0.5
		0.5-1.5-1.5-0.5	
Intermediate		Continues initial segment width until 2 NM prior to PFAF. Then tapers uniformly to final segment width.	Continues initial segment width until 2 NM prior to PFAF. Then tapers to final segment width.

***Note:** Feeder segment width is 1-3-3-1 at all distances greater than 30 NM from HGC. A segment designed to cross within 30 NM of the HGC more than once does not taper in width until the 30 NM limit is crossed for approach and landing; i.e., crosses the limit for the last time before landing. A missed approach segment designed to cross a point 30 NM of the HGC more than once expands when it crosses the boundary the first time and remains expanded.

Figure 8-2-2a: Segment Width Variables

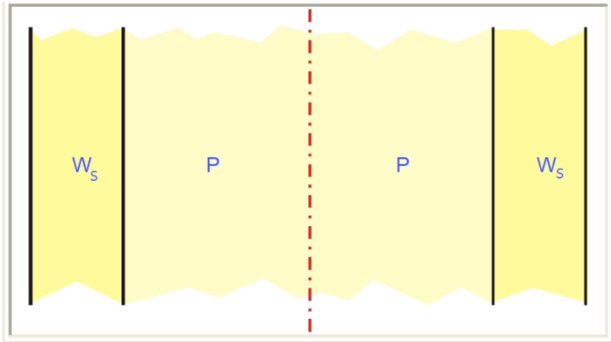


Figure 8-2-2b: Enroute/Feeder/Initial Segment Cross Section (> 30 NM)

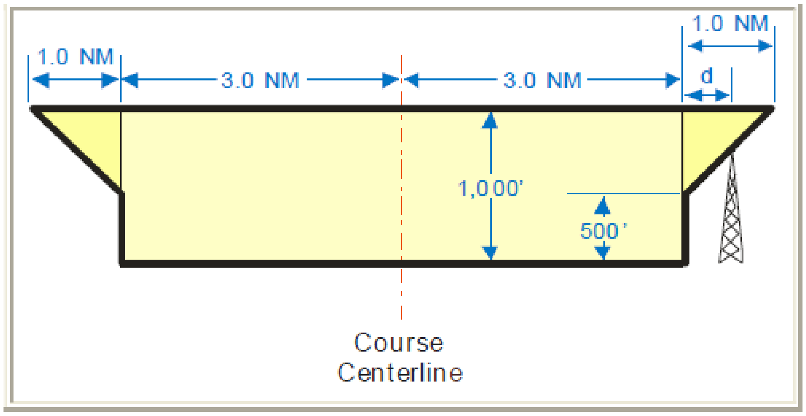
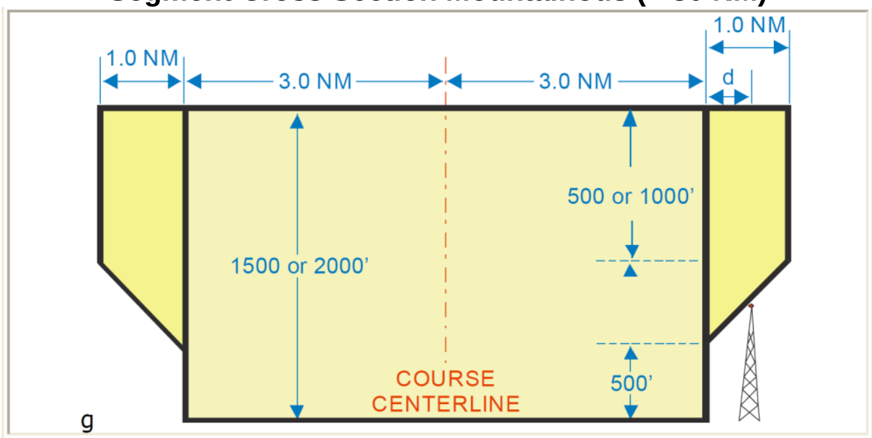


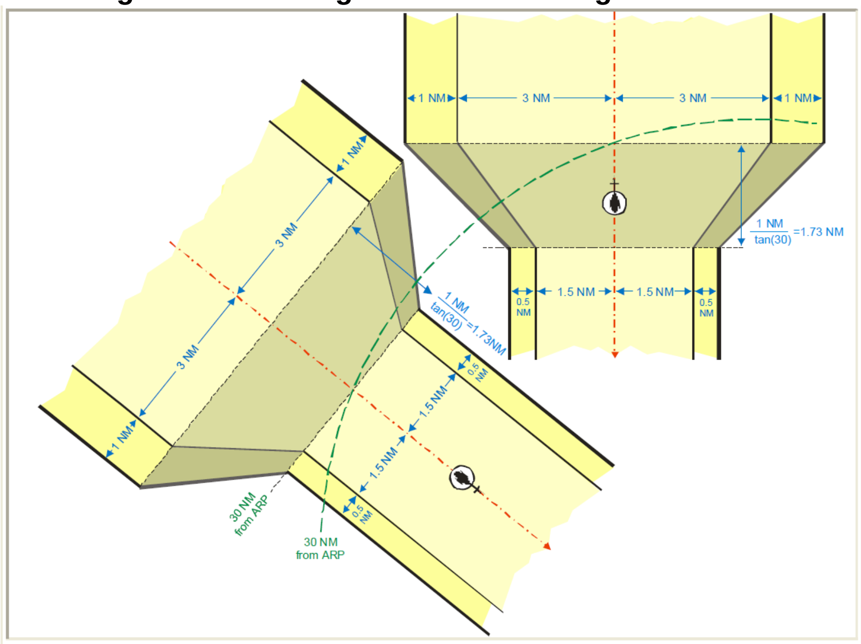
Figure 8-2-2c: Enroute/Feeder/Initial Segment Cross Section Mountainous (> 30 NM)



a. Width Changes at 30 NM from HGC /ARP

1. Width Changes at 30 NM from HGC (non-RF). Receiver sensitivity changes at 30 NM from HGC. From the point the designed course crosses 30 NM from HGC, the primary OEA can taper inward at a rate of 30 degrees relative to course from ± 3 NM to ± 1.5 NM. The secondary area tapers from a 1 NM width when the 30 NM point is crossed to a 0.5 NM width abeam the point the primary area reaches the ± 1.5 NM width. The total along-track distance required to complete the taper is approximately 2.598 NM (15,786.211 ft). Segment width tapers regardless of fix location within the tapering section unless a turn is associated with the fix. Delay OEA taper until the turn is complete and normal OEA turn construction is possible (see figure 8-2-3a).

Figure 8-2-3a: Segment Width Changes at 30 NM



2. Width Changes at 30 NM from HGC /ARP (RF). When the approach segment crosses the point 30 NM from airport reference point in an RF leg, construct the leg beginning at a width of 1-3-3-1 prior to the 30 NM point and taper to 0.5-1.5-1.5-0.5 NM width inside the 30 NM point. Calculate the perpendicular distance ($B_{primary}$, $B_{secondary}$) from the RF segment track centerline to primary and secondary boundaries at any along-track distance (specified as degrees of RF arc "α") from the point the track crosses the 30 NM point using formula 2-1 (see figure 8-2-3b, apply formula 2-3c to find the RF arc radius).

Formula 2-1: RF Segment Taper Width

$$D = \frac{P_{HW > 30} - P_{HW \leq 30}}{\tan(30°)}$$

$$D = \frac{3 - 1.5}{\tan(30°)}$$

$$\alpha = \frac{180 \cdot D}{\pi \cdot R}$$

Calculates degrees of arc (α) to complete taper

$$B_{primary} = P_{HW > 30} - P_{HW \leq 30} \cdot \frac{\phi \cdot \pi \cdot R}{180 \cdot D}$$

$$B_{primary} = 3 - 1.5 \cdot \frac{\phi \cdot \pi \cdot R}{180 \cdot D}$$

$$B_{secondary} = S_{HW > 30} - S_{HW \leq 30} \cdot \frac{\phi \cdot \pi \cdot R}{180 \cdot D}$$

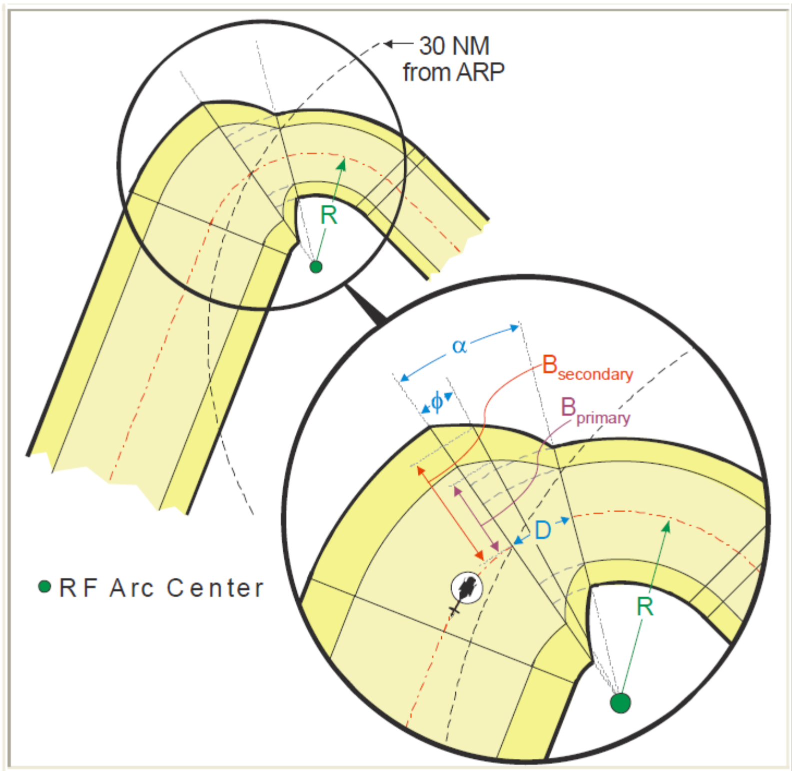
$$B_{secondary} = 4 - 2 \cdot \frac{\phi \cdot \pi \cdot R}{180 \cdot D}$$

Where:

$D =$ taper distance
$R =$ RF leg radius
$\phi =$ degrees of arc (RF track)
$P_{HW > 30} =$ Primary Half Width outside 30 NM
$P_{HW \leq 30} =$ Primary Half Width at or inside 30 NM
$S_{HW > 30} =$ Secondary Half Width outside 30 NM
$S_{HW \leq 30} =$ Secondary Half Width at or inside 30 NM
$B =$ taper width from centerline

Note: “D & R” units will be in NM.

Figure 8-2-3b: Segment Width Changes in RF Leg



8.2.12. **Calculating the Turn Radius (R).** The design turn radius value is based on four variables: indicated airspeed, assumed tailwind, altitude, and bank angle. Calculate R using formula 2-3c. Apply the indicated airspeed from table 8-2-3 for the highest speed helicopter category that will be published on the approach procedure. Apply the highest expected turn altitude value. Apply the appropriate bank angle from table 8-2-4 and formula 2-2 to determine the vertical path altitude (VP_{alt}).

Formula 2-2: Vertical Path Altitude (VP_{alt})

$$\mathbf{VP_{alt}} = \mathbf{e}^{\frac{\mathbf{D_Z \cdot tan(\theta)}}{\mathbf{r}}} \cdot (\mathbf{r} + \mathbf{PFAF_{alt}}) - \mathbf{r}$$

Where:

$PFAF_{alt}$ = Designed PFAF MSL altitude

θ = glidepath angle

D_Z = distance (ft) from PFAF to fix

Note: If D_Z is a NM value, convert to feet by multiplying NM by 1852/0.3048

Note: Determine the highest altitude within a turn by:

- For approach, calculate the vertical path altitude (VP_{alt}) by projecting a 3-degree vertical path from the PFAF along the designed nominal flight track to the turn fix.

- For missed approach highest altitude in a turn, apply (a) or (b), and (c).

  a. Turn-At-A-Fix, project a vertical path along the nominal flight track from the SOC point and altitude to the turn fix, that rises at a rate of 400 ft/NM (Helicopter) or a higher rate if a steeper climb gradient is specified. Compare the vertical path altitude at the fix to the minimum published fix altitude, apply the higher of the two; or

  b. Turn-At-An-Altitude, apply the climb-to-altitude; and

  c. Plus an additive, (Turn-At-A-Fix (FO) and Turn-At-An-Altitude) based on a continuous climb of 400 ft per 12 degrees of turn [ϕ*400/12], where ϕ is degrees of turn). The turn altitude must not be higher than the published missed approach altitude.

- Helicopter example: 900 ft would be added for a turn of 27 degrees, 767 ft would be added for 23 degrees, 333 ft for 10 degrees of turn.

Step 1: Determine the true airspeed **(V_{KTAS})** for the turn using formula 2-3a. Locate and use the appropriate knots indicated airspeed **(V_{KIAS})** from table 8-2-3. Use the highest altitude within the turn.

Formula 2-3a: True Airspeed (V_{KTAS})

$$V_{KTAS} = \frac{V_{KIAS} \cdot 171233 \cdot \sqrt{(288+15) - 0.00198 \cdot alt}}{(288 - 0.00198 \cdot alt)^{2.628}}$$

where alt = aircraft MSL elevation
V_{KIAS} = knots indicated airspeed

(V_{KIAS}*171233*((288+15)-0.00198*alt)^0.5)/(288-0.00198*alt)^2.628

Table 8-2-3. Helicopter Indicated Airspeeds (Knots)

Segment	Indicated Airspeed	
	Civil	Military
Feeder, Initial, Intermediate	140	140
Final, Missed Approach	70	90

Step 2: Calculate the appropriate tailwind component (V_{KTW}) using formula 2-3b for the highest altitude within the turn. EXCEPTION: If the MSL altitude is 2,000 ft or less above airport elevation, use 30 knots.

Formula 2-3b: Tailwind (V_{KTW})

$$V_{KTW} = 0.00198 \cdot alt + 47$$

where alt = highest turn altitude (MSL)

Note: If "alt" is 2,000 or less above airport elevation, then V_{KTW} = 30

0.00198*alt+47

Note: Greater tailwind component values may be used where data indicates higher wind conditions are likely to be encountered. Where a higher value is used, it must be recorded in the procedure documentation.

Step 3: Calculate R using formula 2-3c.

Formula 2-3c. Turn Radius (R)

$$R = \frac{(V_{KTAS} + V_{KTW})^2}{tan(bank_{angle}) \cdot 68625.4}$$

where $bank_{angle}$ = assumed bank angle (normally 11° or 14° for Helicopter)

Note: Use formula 2-8 to verify the required bank angle does not exceed the design bank angle (11 or 14 degrees), see table 8-2-4. R is in nautical miles.

Table 8-2-4: Bank Angles

Knots True Airspeed (KTAS)	< 90	≥ 90
Bank Angle (In degrees)	11.0	14.0

8.2.13. **Turn Construction.** If the outbound course from a fix differs by more than 0.03 degrees from the inbound course to the fix (courses measured at the fix), a turn is indicated.

a. Turns at Fly-Over Fixes (see figures 8-2-4 and 8-2-5).

1) Extension for Turn Delay. Turn construction incorporates a delay in start of turn to account for pilot reaction time and roll-in time (rr). Calculate the extension distance in feet using formula 2-4a (terminal) or formula 2-4b (feeder and enroute).

Formula 2-4a: Reaction & Roll Dist (Terminal)

$$rr = 6 \cdot \frac{\frac{1852}{0.3048}}{3600} \cdot V_{KTAS}$$

$6*1852/0.3048/3600*V_{KTAS}$

Note: 6 second delay. "rr" units will be in ft.

Formula 2-4b: Reaction & Roll Dist (Enroute, Feeder)

$$rr=8 \cdot \frac{\frac{1852}{0.3048}}{3600} \cdot (V_{KTAS} + V_{KTW})$$

$8*(1852/0.3048/3600)*(V_{KTW}+V_{KTAS})$

Note: 8 second delay. "rr" units will be in ft.

Step 1: Determine **R.** See formula 2-3c.

Step 2: Determine **rr**. See formula 2-4a or formula 2-4b.

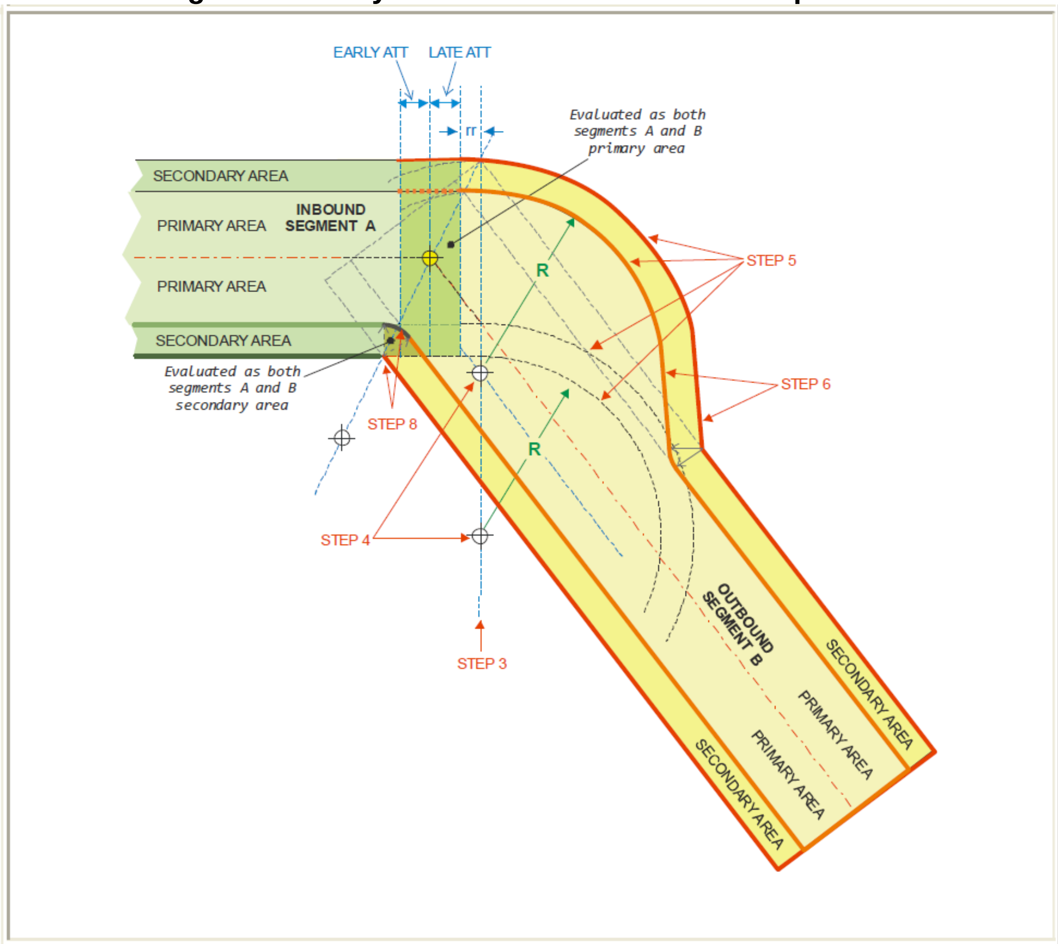
Step 3: Establish the baseline for construction of the turn expansion area as the line perpendicular to the inbound track at a distance past the turn fix equal to **(ATT+rr).**

Step 4: On the baseline, locate the center points for the primary and secondary turn boundaries. The first is located at a distance R from the non-turning side primary boundary. The second is located at a distance R from the turning side secondary boundary (see figures 8-2-4 and 8-2-5).

Step 5: From these center points construct arcs for the primary boundary of radius R. Complete the secondary boundary by constructing additional arcs of radius ($R+W_S$) from the same center points. (W_S=width of the secondary). This is shown in figures 8-2-4 and 8-2-5.

Step 6: The arcs constructed in step 5 are tangent to the outer boundary lines of the inbound segment. Construct lines tangent to the arcs based on the first turn point tapering inward at an angle of 30 degrees relative to the outbound track that joins the arc primary and secondary boundaries. If both the inner and outer arcs lie outside subsequent segment boundary lines, but the resulting tapering line tangent points lie inside the subsequent segment boundary lines, consider the expanded boundary connection points to be the intersection of the arc and the subsequent segment boundary lines. If the arcs from the second turn point are inside the tapering lines as shown in figure 8-2-4, then they are disregarded and the expanded area construction is completed. If not, proceed to step 7.

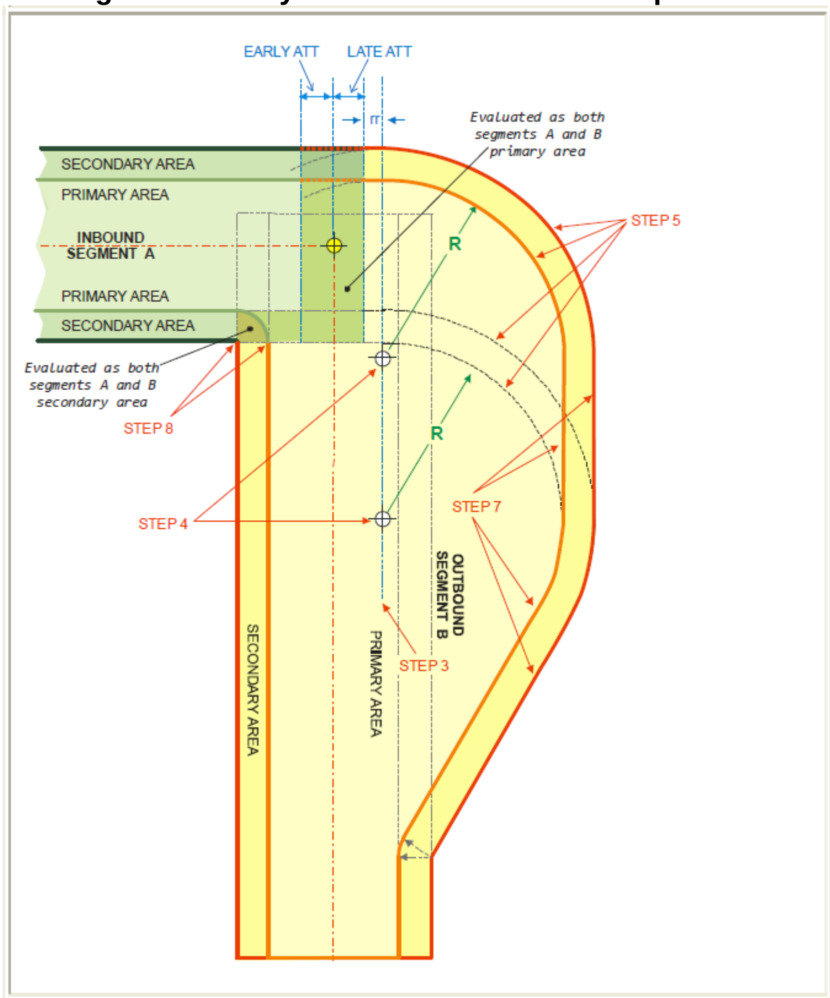
Figure 8-2-4: Fly-Over with No Second Arc Expansion



Step 7: If both the inner and outer arcs lie outside the tapering lines constructed in step 6, connect the respective inner and outer arcs with tangent lines and then construct the tapering lines from the arcs centered on the second center point as shown in figure 8-2-5.

Step 8: The inside turn secondary boundary is the intersection of the preceding and succeeding segment secondary boundaries. The inside turn primary boundary is an arc of secondary-width radius joining the preceding and succeeding segment primary boundaries.

Figure 8-2-5: Fly-Over with Second Arc Expansion



Note: The inbound OEA end (± ATT) is evaluated for both inbound and outbound segments.

2) Minimum length of TF leg following a fly-over turn. The leg length of a TF leg following a fly-over turn must be sufficient to allow the aircraft to return to course centerline. Determine the minimum leg length (L) using Distance of Turn Anticipation **(**DTA) distance from formula 2-5 and formula 2-6.

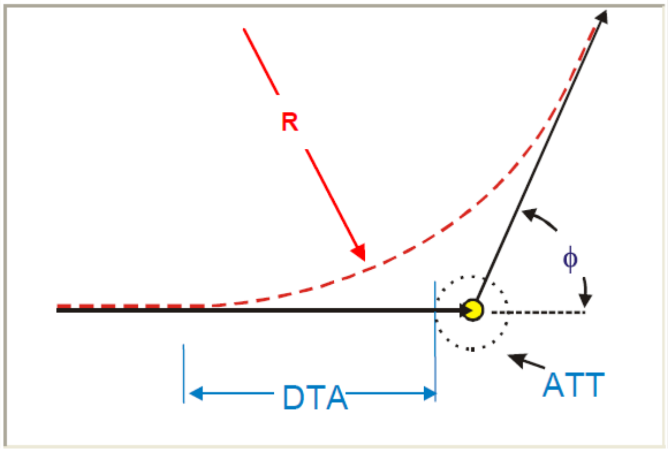
Formula 2-5: Distance of Turn Anticipation (DTA)

$$\mathbf{DTA} = \mathbf{R} \cdot \mathbf{tan}\left(\frac{\phi}{\mathbf{2}}\right)$$

Where:

R = turn radius from formula 2-3c

ϕ = degrees of heading change



Note: “R” units will be in NM.

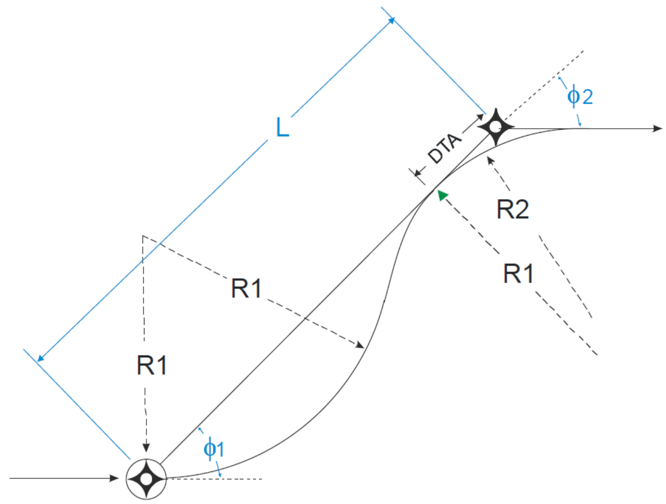
Formula 2-6: TF Leg Minimum Length (L) Following Fly-Over Turn

$$\text{If } \phi_1 < \frac{180}{\pi} \cdot \text{acos}(3^{0.5} - 1), \text{then}$$

$$L = R_1 \cdot \left(\sin(\phi_1) + 2 \cdot \sin\left(\text{acos}\left(\frac{1 + \cos(\phi_1)}{2} \right) \right) \right) + R_2 \cdot \tan\left(\frac{\phi_2}{2}\right), \text{else}$$

$$L = R_1 \cdot \left(sin(\phi_1) + 4 - 3^{0.5} - 3^{0.5} \cdot \cos(\phi_1) \right) + R_2 \cdot \tan\left(\frac{\phi_2}{2}\right)$$

Where:
- R1 = turn radius (NM) at the segment initial fix (formula 2-3c)
- R2 = turn radius (NM) at the segment termination fix (zero if no fly-by turn)
- ϕ1 = turn magnitude at the segment initial fix
- ϕ2 = turn magnitude at the segment termination fix



Note: “L” units will be in NM.

b. **Fly-By Turn.** See figure 8-2-6.

Step 1: Establish a line through the turn fix that bisects the turn angle. Determine Turn Radius (R). See formula 2-3c. Scribe an arc (with origin on bisector line) of radius R tangent to inbound and outbound courses. This is the designed turning flight path.

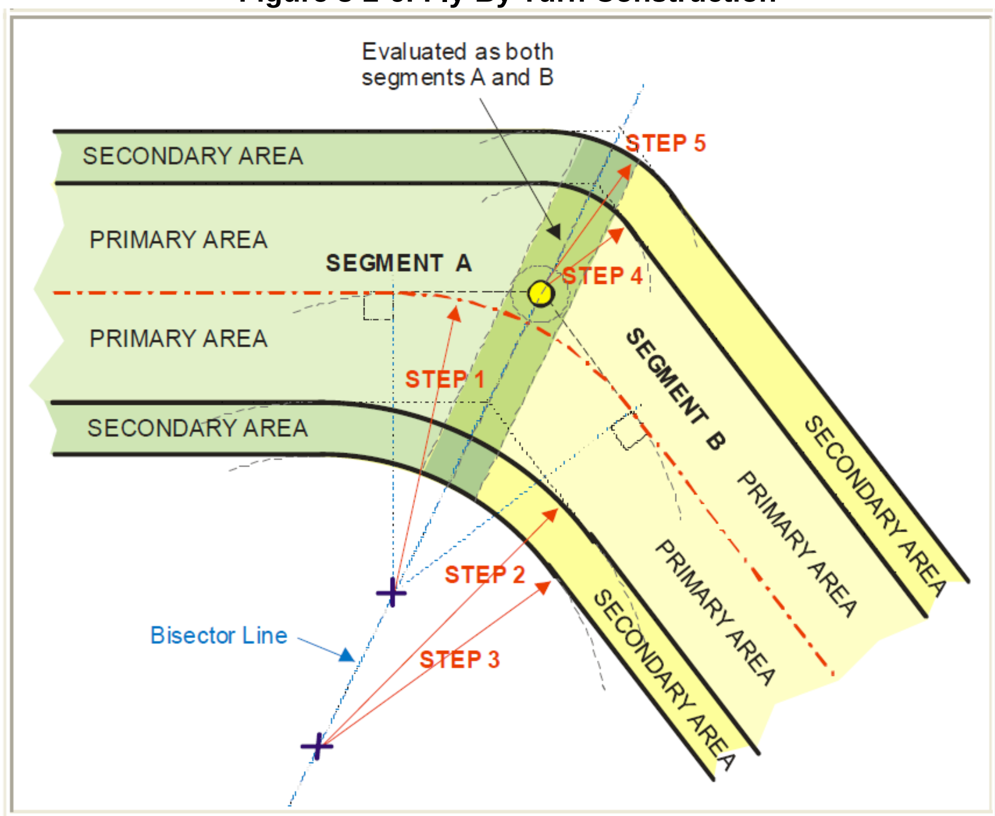
Step 2: Scribe an arc tangent to the inner primary boundaries of the two segment legs with a radius equal to $R + \frac{\text{Primary Area Half-width}}{2}$ (example: half width of 2 NM, the radius would be R+1.0 NM).

Step 3: Scribe an arc that is tangent to the inner secondary boundaries of the two segment legs using the origin and radius from step 2 minus the secondary width.

Step 4: Scribe the primary area outer turning boundary with an arc with a radius equal to the segment half width centered on the turn fix.

Step 5: Scribe the secondary area outer turning boundary with the arc radius from step 4 plus the secondary area width centered on the turn fix.

Figure 8-2-6: Fly-By Turn Construction



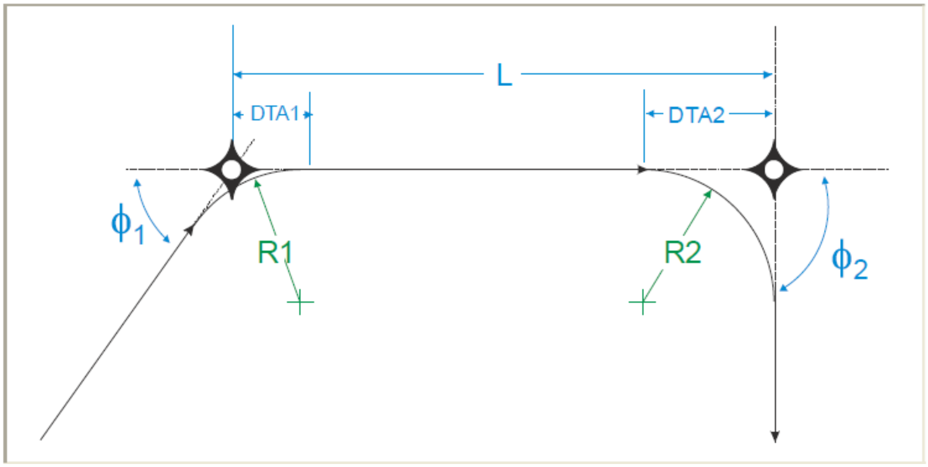
1) Minimum length of track-to-fix (TF) leg following a fly-by turn. Calculate the minimum length for a TF leg following a fly-by turn using formula 2-7.

Formula 2-7: TF Leg Minimum Length (L) Following Fly-by Turn

$$L = R1 \cdot \tan\left(\frac{\phi 1}{2}\right) + R2 \cdot \tan\left(\frac{\phi 2}{2}\right)$$

Where:

R1 = Turn radius at the segment initial fix (formula 2-3c)
R2 = Turn radius at the segment termination (formula 2-3c)
Note: Zero when no turn
ϕ_1 = turn magnitude at the segment initial fix
ϕ_2 = turn magnitude, if any at the segment termination fix



Note: "L" units will be in NM.

c. **Radius-to-Fix (RF) Turn.** Incorporation of an RF segment may limit the number of aircraft served by the procedure. RF legs are used to control the ground track of a turn where obstructions prevent the design of a fly-by or fly-over turn, or to accommodate other operational requirements.* The curved leg begins tangent to the previous segment course at its terminating fix and ends tangent to the next segment course at its beginning fix (see figure 8-2-7). OEA construction limits turn radius to a minimum value equal-to or greater-than the OEA (primary and secondary) half-width. The RF segment OEA boundaries are parallel arcs.

***Note:** RF legs segments are not applicable to the final segment or section 1 of the missed approach segment. RF legs in the intermediate segment must terminate at least 2 NM prior to the PFAF. Where RF legs are used, annotate the procedure (or segment as appropriate) "RF Required."

Step 1: Determine the segment turn radius (R) that is required to fit the geometry of the terrain/airspace. Enter the required radius value into formula 2-8 to verify the resultant bank angle is ≤ 20 degrees (maximum allowable bank angle). Where a bank angle other than standard is used, annotate the value in the remarks section of the appropriate form.

Formula 2-8: Radius-to-Fix (RF) Bank Angle

$$bank_{angle} = atan\left(\frac{(V_{KTAS} + V_{VTW})^2}{R \cdot 68625.4}\right)$$

Where:

V_{KTAS} = value from formula 2-3a

V_{KTW} = value from Order 8260.58, table 1-3

R = required radius

atan((V_{KTAS}+V_{KTW})^2/(R*68625.4))*180/π

Calculate RF segment length using formula 2-9a.

Formula 2-9a: Radius-to-Fix (RF) Segment Length

$$Segment_{length} = \frac{\pi \cdot R \cdot \phi}{180}$$

Where:

R = RF segment radius (answer will be in the units entered)

ϕ = # of degrees of ARC (heading change)

π*R*ϕ/180

Step 2: Turn Center. Locate the turn center at a perpendicular distance R from the preceding and following segments.

Step 3: Flight path. Construct an arc of radius R from the tangent point on the preceding course to the tangent point on the following course.

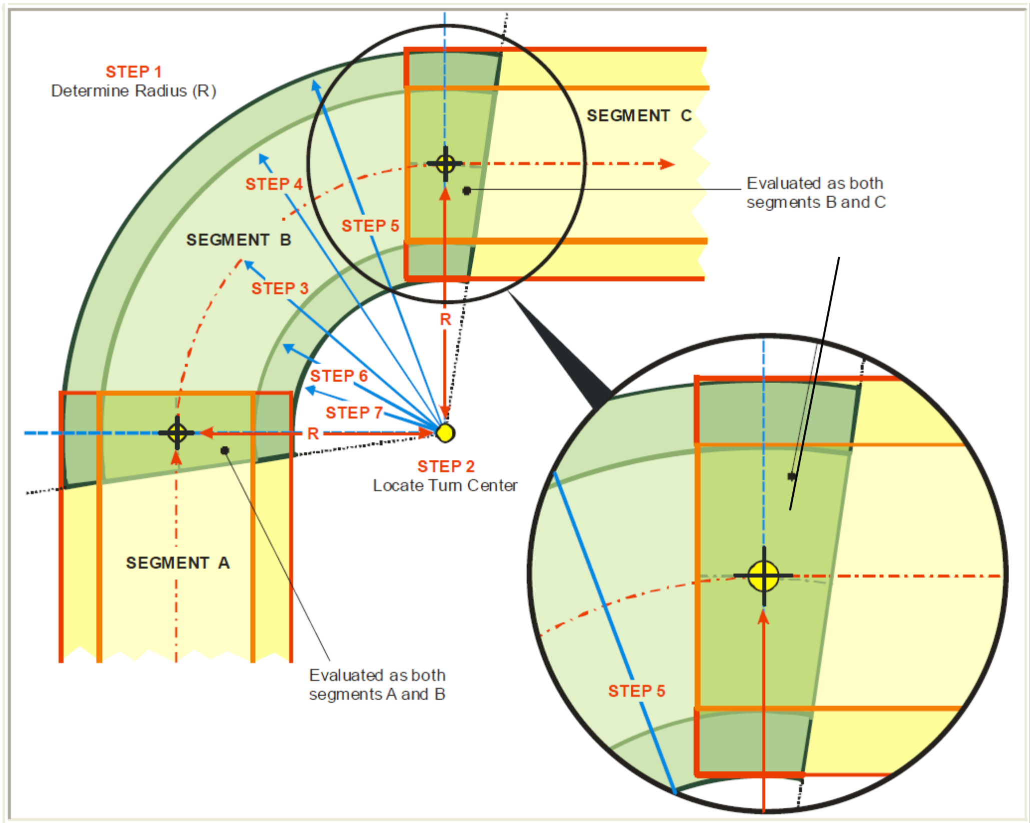
Step 4: Primary area outer boundary. Construct an arc of radius R+Primary area halfwidth from the tangent point on the preceding segment primary area outer boundary to the tangent point on the following course primary area outer boundary.

Step 5: Secondary area outer boundary. Construct an arc of radius R+Primary area halfwidth+ secondary area width from the tangent point on the preceding segment secondary area outer boundary to the tangent point on the following course secondary area outer boundary.

Step 6: Primary area inner boundary. Construct an arc of radius R-Primary area halfwidth from the tangent point on the preceding segment inner primary area boundary to the tangent point on the following course inner primary area boundary.

Step 7: Secondary area inner boundary. Construct an arc of radius R-(Primary area halfwidth + secondary area width) from the tangent point on the preceding segment inner secondary area boundary to the tangent point on the following course inner secondary area boundary.

Figure 8-2-7: Radius-to-Fix (RF) Turn Construction



d. **RNAV TF/VA/VI/CF leg followed by a DF Leg.** Calculate minimum DF segment length using formula 2-9b.

Formula 2-9b: RNAV DF Leg Minimum Length following TF/VA/VI/CF Legs (L)

If $\phi > 30$ then

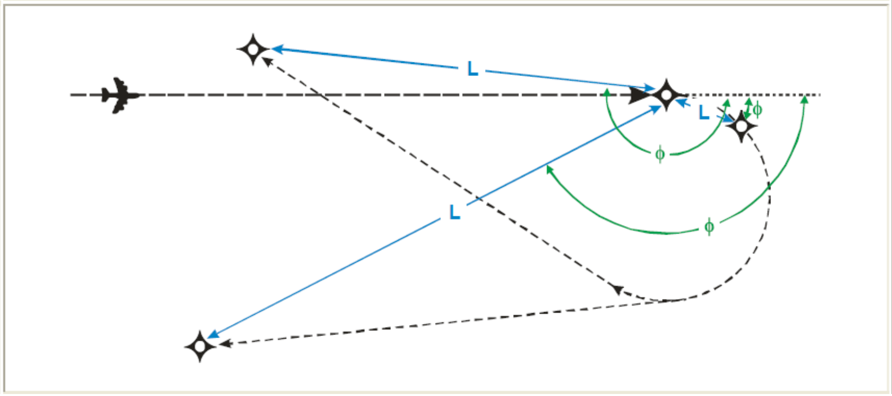
$$L = 4 \cdot R \cdot \left(\sin\left(\frac{\phi + 30}{2}\right)\right)^2, \text{ else}$$

$$L = 2 \cdot R \cdot \sin(\phi)$$

Where:

R = turn radius (NM) at the segment initial fix (formula 2-3c)

ϕ = turn magnitude at the segment initial fix

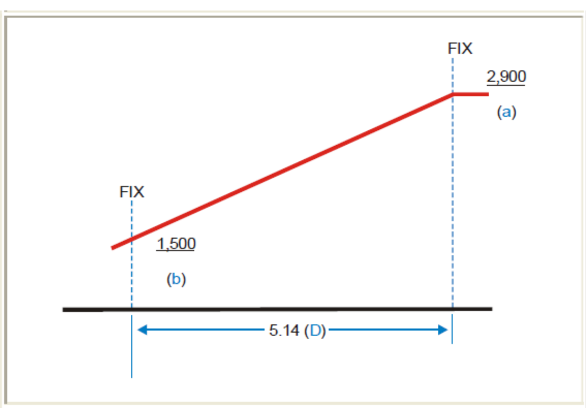


Note: "ϕ" units will be in degrees.

8.2.14. **Helicopter Initial and Intermediate Descent Gradient.** The optimum descent gradient in the initial and intermediate segment is 400 ft/NM (6.58%, 3.77°); maximum is 600 ft/NM (9.87%, 5.64°).

a. **Calculating Descent Gradient (DG).** Determine total altitude lost between the plotted positions of the fixes. Determine the distance (D) in NM. Divide the total altitude lost by D to determine the segment descent gradient using formula 2-10 (see figure 8-2-8).

Figure 8-2-8: Calculating Descent Gradient



Formula 2-10: Descent Gradient (DG)

$$DG = \frac{r \cdot \ln\left(\frac{r + a}{r + b}\right)}{D}$$

Where:

a = beginning altitude

b = ending altitude

D = distance (NM) between fixes

r*ln((r+a)/(r+b))/D

8.2.15. **Feeder Segment.** When the initial approach fix (IAF) is not part of the enroute structure, it may be necessary to designate feeder routes from the enroute structure to the IAF. The feeder segment may contain a sequence of TF segments (and/or RF segments). The maximum course change between TF segments is 90 degrees (70 degrees preferred). Formula 2-3c note applies. Section 2, paragraph 8.2.13 turn construction applies. The feeder segment terminates at the IAF (see section 2, figures 8-2-4, 8-2-5, and 8-2-6 for construction).

a. **Length.** The **minimum** length of a sub-segment is determined under section 2, paragraph 8.2.13.a(2) or 8.2.13.b(1) as appropriate. The **maximum** length of a sub-segment is 50 miles. The total length of the feeder segment should be as short as operationally possible.

b. **Width.** Primary area width is ± 3.0 NM from course centerline; secondary area width is 1.0 NM (1-3-3-1). These widths apply from the feeder segment initial fix to the approach IAF/termination fix.

c. **Obstacle Clearance.** The feeder segment OEA begins at the beginning fix early ATT and ends at the ending fix late ATT. The minimum ROC over areas is 1,000 ft (2,000 ft or 1500 ft as required for mountainous). TP308/GPH209, Volume 1, paragraph 1720 and 1721 applies. The published minimum feeder route altitude must provide at least the minimum ROC value and must not be less than the altitude established at the IAF. (Refer to figures 8-2-2a, 8-2-2b and apply formula 2-12a for standard secondary ROC.) Apply formula 2-12b for designated mountainous area calculations (formulas are applicable for enroute, feeder, and initial).

d. **Descent Gradient, Helicopter (feeder, initial, intermediate segments).** The optimum descent gradient in feeder, initial, and intermediate segments is 400 ft/NM (6.58%, 3.77°); maximum is 600 ft/NM (9.87%, 5.64°). Where higher descent gradients are required, TP308/GPH209, Volume 5, paragraph 110 applies.

e. **Minimum Crossing Altitude (MCA).** Establish an MCA when an obstacle prevents a normal climb to a higher minimum enroute altitude (MEA). The normal climb gradient is shown in table 8-2-5. When a MCA is required, chart the required climb gradient and rate of climb on the procedure.

Table 8-2-5: Normal Helicopter Enroute Climb Gradient

Gradient Level (MSL)	Gradient	OCS Slope
at or below 5,000 ft	300 ft per NM	20.25:1
5,001 ft through 10,000 ft	240 ft per NM	25.3:1

Note: The MCA computation is based on the distance from the nearest fix displacement tolerance line to the obstacle. The computation is rounded to the next higher 100-ft increment (see figure 8-2-9 for an example MCA computation).

f. **Determine MCA.** Apply formula 2-11a, or 2-11b to determine MCA.

Formula 2-11a: MCA Sea Level to 5,000 ft MSL

$$MCA = A - 300 \cdot L$$

Where:

A = "Climb to" MSL Altitude

L = Length of segment (NM)

A-300*L

Formula 2-11b: MCA 5,001 - 10,000 ft MSL

$$MCA = 5000 - 300\left(L - \frac{A-5000}{240}\right)$$

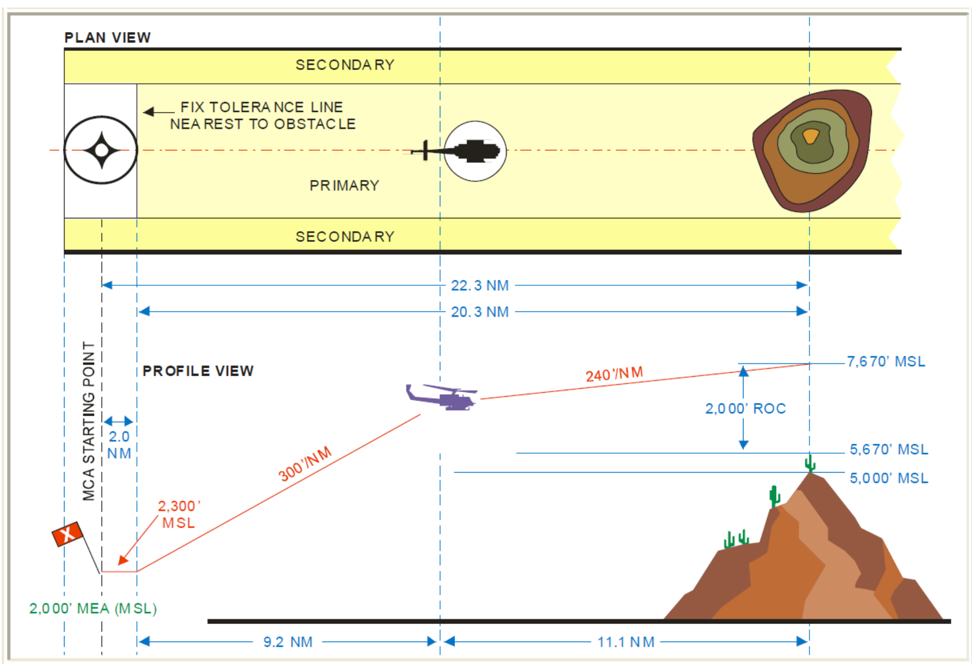
Where:

A = "Climb to" MSL Altitude

L = Length of segment (NM)

5000-300*(L-(A-5000)/240)

Figure 8-2-9: Minimum Crossing Altitude (MCA)



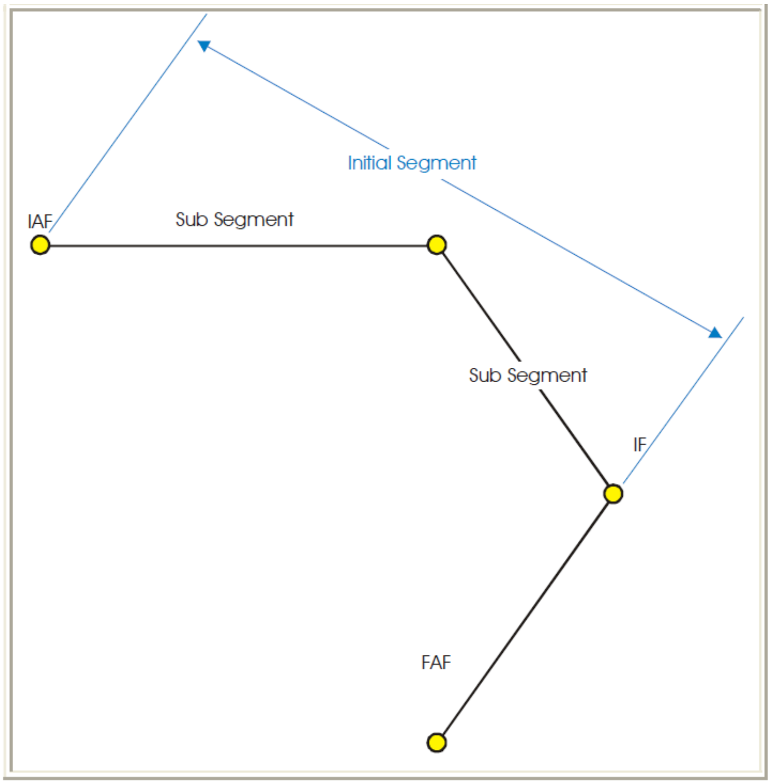
Step 1: Add 1,000 ft ROC (or 2,000/1500 ft as required for mountainous) to MSL height of obstacle.

Step 2: Apply formula 2-11a or 2-11b to determine the MCA.

Terminal Segments

8.2.16. **Initial Segment.** The initial segment begins at the IAF and ends at the intermediate fix (IF). The initial segment may contain sequences of straight sub segments (see figure 8-2-10). Section 2, paragraphs 8.2.16.b, 8.2.16.c, 8.2.16.d, and 8.2.16.e apply to all sub segments individually. The total length of all sub segments must not exceed 50 NM. For descent gradient limits, see Volume 5, paragraph 110.

Figure 8-2-10: Initial Sub Segments



a. **Course Reversal.** The optimum design incorporates either the basic Y or T configuration. This design eliminates the need for a specific course reversal pattern. Where the optimum design cannot be used and a course reversal is required, establish a holding pattern at the initial, or intermediate approach fix. See section 2, paragraph 8.2.16.f(2). The maximum course change at the fix (IAF/IF) is to 90 degrees (70 degrees above FL 190).

b. **Alignment.** Design initial/initial and initial/intermediate TF segment intersections with the smallest amount of course change that is necessary for the procedure. No course change is optimum. Where a course change is necessary, it should normally be limited to 70 degrees or less; 30 degrees or less is preferred. The maximum allowable course change between TF segments is 90 degrees.

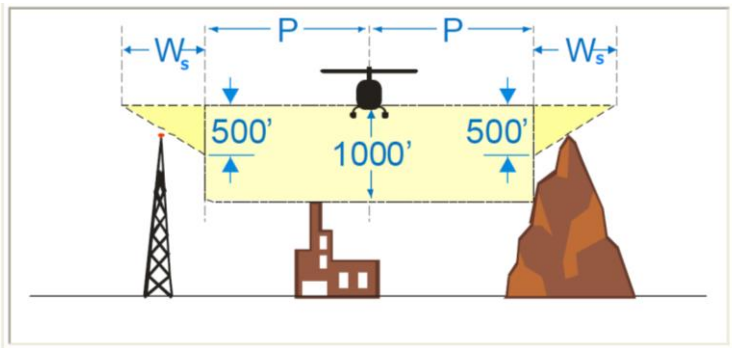
Note: For 90 KIAS speed, limit initial segment turn to a MAXIMUM of 60 degrees with a basic “Y” approach configuration for COPTER RNAV (GNSS) procedures.

c. **Area – <u>Length</u>.** The maximum segment length (total of sub segments) is 50 NM. Minimum length of sub segments is determined as described in section 2, paragraphs 8.2.13.a(2) and 8.2.13.b(1).

d. **Area – <u>Width</u>** (see table 8-2-2).

e. **Obstacle Clearance.** The initial OEA begins at the segment beginning fix early ATT and ends at the segment ending fix late ATT. Apply 1,000 ft of ROC over the highest obstacle in the primary OEA. The ROC in the secondary area is 500 ft at the primary boundary tapering uniformly to zero at the outer edge (see figure 8-2-11).

Figure 8-2-11: Enroute/Feeder/Initial Segment ROC



Note: Allowance for precipitous terrain should be made as specified in TP308/GPH209, Volume 1, paragraph 323b.

Calculate the secondary ROC values using formula 2-12a.

Formula 2-12a: Enroute/Feeder/Initial Secondary ROC (Standard), Initial ROC (Mountainous)

$$ROC_{secondary} = 500 \cdot \left(1 - \frac{d}{W_s}\right)$$

Where:

W_s = width (ft) of secondary

d = distance (ft) from edge of primary area measured perpendicular to boundary

500*(1-d/Ws)

Calculate the secondary ROC values for designated mountainous areas using formula 2-12b. Consult TP308/GPH209, Volume 1, para 1720 for possible adjustments to formula output.

Formula 2-12b: Enroute/Feeder Secondary ROC (Mountainous)

$$ROC_{secondary} = 500 \cdot \left(1 - \frac{d}{D}\right) + (500 \text{ or } 1000)^{*}$$

Where:

D = width (ft) of secondary

d = distance (ft) from edge of primary area measured perpendicular to boundary

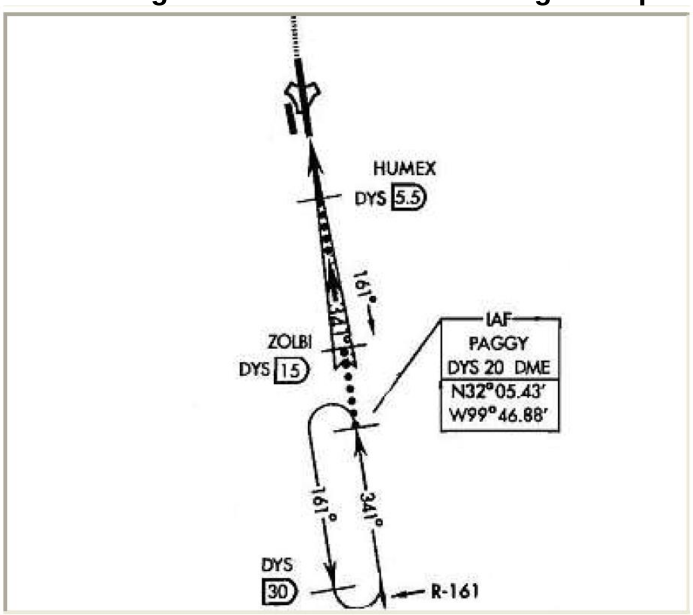
500*(1-d/D)+(500 or 1000)*

***NOTE:** For mountainous regions requiring obstacle clearance of 1500’ add 500’ and add 1000’ for the regions requiring 2000’ obstacle clearance.

f. **Holding Pattern Initial Segment.** A holding pattern may be incorporated into the initial segment procedure design where an operational benefit can be derived; e.g., arrival holding at an IAF, course reversal pattern at the IF, etc. See TP308/GPH209 Volume 1, Chapter 18, Holding Pattern Criteria, for RNAV holding pattern construction guidance.

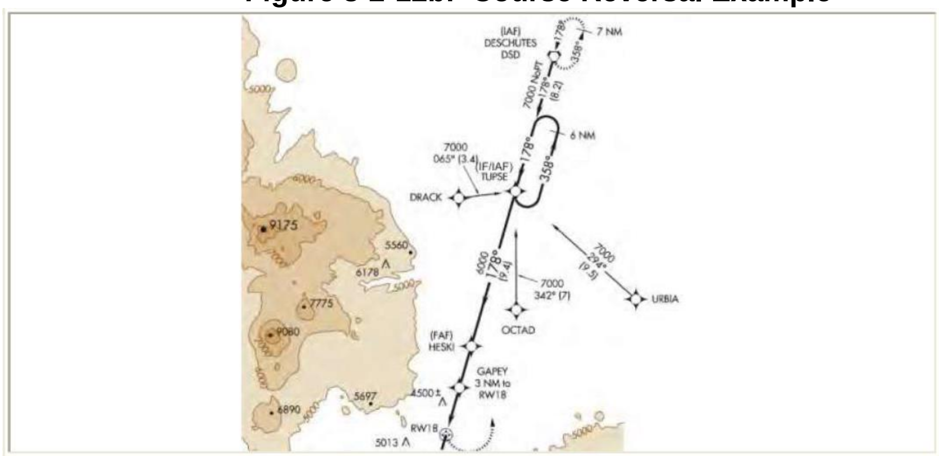
1) Arrival Holding. Ideally, the holding pattern inbound course should be aligned with the subsequent TF leg segment (tangent to course at the initial fix of the subsequent RF segment). See figure 8-2-12a. If the pattern is offset from the subsequent TF segment course, the subsequent segment length must accommodate the resulting DTA requirement. Establish the minimum holding altitude at or above the IAF/IF (as appropriate) minimum altitude. MEA minimum altitude may be lower than the minimum holding altitude.

Figure 8-2-12a: Arrival Holding Example



2) Course Reversal. Ideally, establish the minimum holding altitude as the minimum IF fix altitude (see figure 8-2-12b). In any case, the published holding altitude must result in a suitable descent gradient in the intermediate segment: optimum descent gradient in the initial and intermediate segment is 400 ft/NM (6.58%, 3.77°); maximum is 600 ft/NM (9.87%, 5.64°). If the pattern is offset from the subsequent TF segment course, the subsequent segment length must accommodate the resulting DTA requirement. Maximum offset is 90 degrees.

Figure 8-2-12b: Course Reversal Example



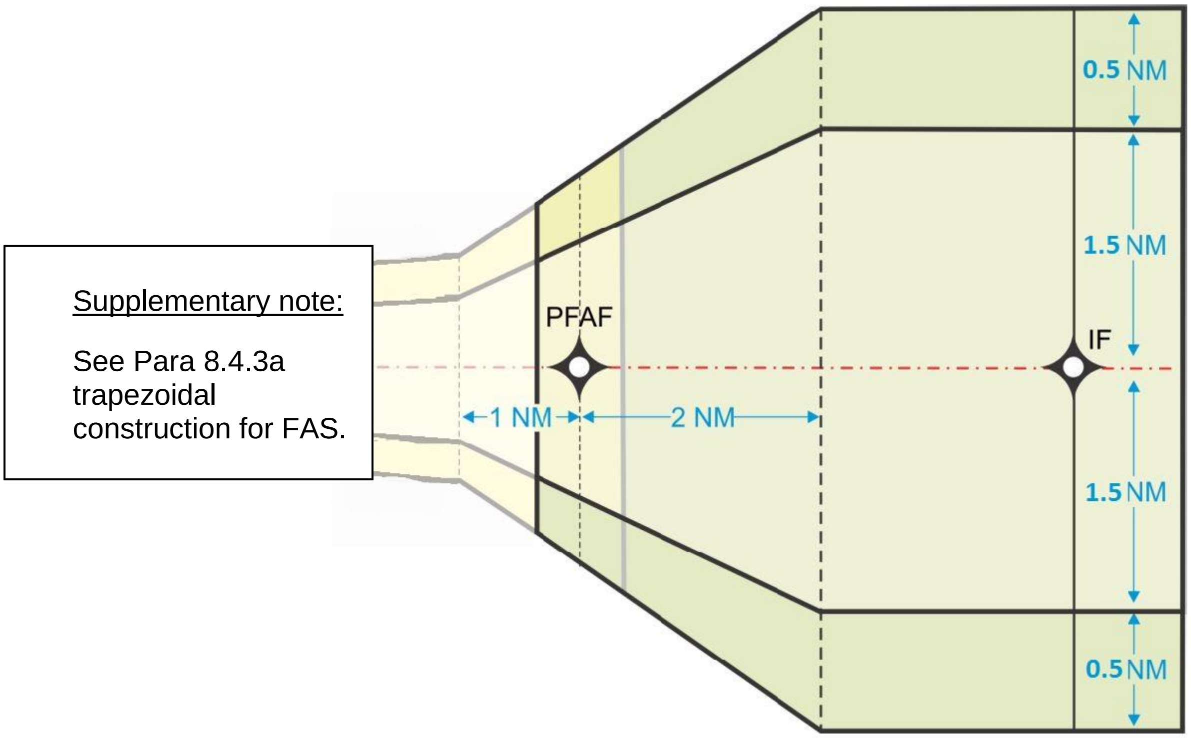
8.2.17. **Intermediate Segment.** The intermediate segment primary and secondary boundary lines connect abeam the plotted position of the PFAF at the appropriate primary and secondary final segment beginning widths.

a. **Alignment** (Maximum Course Change at the PFAF). LNAV & LP. Align the intermediate course within 30 degrees of the final approach course (30 degrees maximum course change).

b. **Length (Fix to Fix).** The minimum Helicopter category segment length is 2 NM. Where turns over 30 degrees at the IF are required, the minimum is 3 NM. Where turns to and from the intermediate segment are necessary, determine minimum segment length using formula 2-6 or formula 2-7, as appropriate.

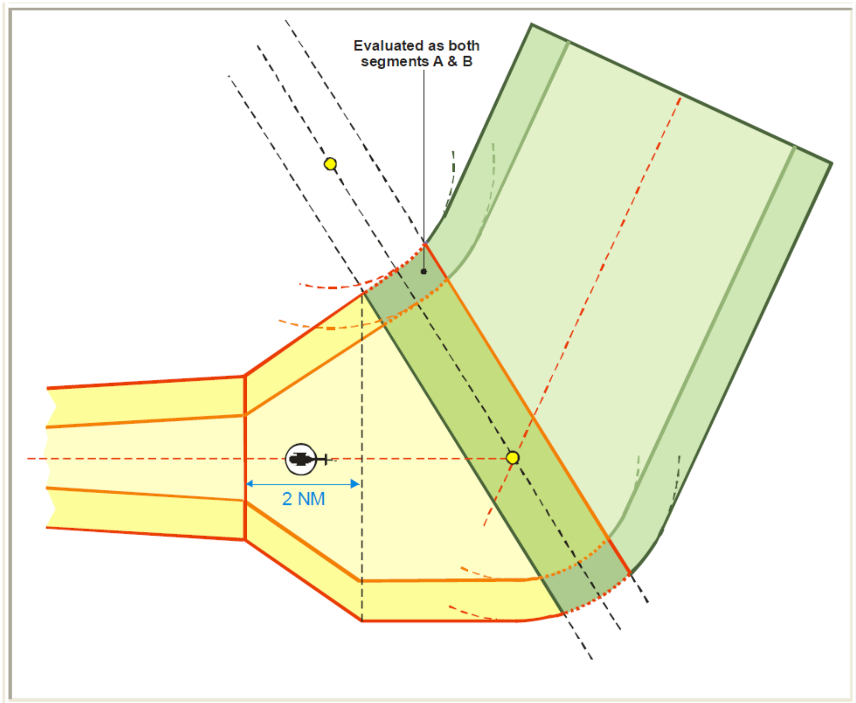
c. **Width.** The intermediate segment primary area tapers uniformly from ±1.5 NM at a point 2 NM prior to the PFAF to the outer boundary of the X OCS abeam the PFAF (1 NM past the PFAF for LNAV). The secondary boundary tapers uniformly from 1 NM on each side of the primary area at a point 2 NM prior to the PFAF to the outer boundary of the Y OCS abeam the PFAF (1 NM past the PFAF for LNAV). See figure 8-2-13a.

Figure 8-2-13a: RNAV Intermediate Segment (LNAV Final)



If a turn is designed at the IF, it is possible for the inside turn construction to generate boundaries outside the normal segment width at the taper beginning point 2 miles prior to the PFAF. Where these cases occur, the inside (turn side) boundaries are a simple straight line connections as illustrated in figure 8-2-13b.

Figure 8-2-13b: RNAV Turn at IF (LNAV Final)



Maximum turn at the PFAF is 30 degrees. When a PFAF turn is constructed, minimum FAS length is 3 NM for turns greater than 15 degrees. Where the RNAV or LP intermediate course is not an extension of the FAC, use the following construction (see figure 8-2-13c).

1) LNAV Offset Construction. Where LNAV intermediate course is not an extension of the final course, use the following construction (see figure 8-2-13c, upper graphic).

Step 1: Construct line A perpendicular to the intermediate course 2 NM prior the PFAF.

Step 2: Construct line B perpendicular to the intermediate course extended 1 NM past the PFAF.

Step 3: Construct the inside turn boundaries by connecting the points of intersection of line A with the turn side intermediate segment boundaries with the intersection of line B with the turn side final segment boundaries.

Step 4: Construct arcs centered on the PFAF of 1 NM and 1.5 NM radius on the non-turn-side of the fix.

Step 5: Connect lines from the point of intersection of line A and the outside primary and secondary intermediate segment boundaries to tangent points on the arcs constructed in step 4.

Step 6: Connect lines tangent to the arcs created in step 4 that taper inward at 30 degrees relative to the FAC to intersect the primary and secondary final segment boundaries as appropriate. The final segment evaluation extends to a point ATT prior to the angle bisector. The intermediate segment evaluation extends ATT past the angle bisector. Therefore, the area within ATT of the angle bisector is evaluated for both the final and intermediate segments.

2) LP Offset Construction. Where LP intermediate course is not an extension of the final course, use the following construction (see figure 8-2-13c, lower graphic).

Step 1: Construct line A perpendicular to the intermediate course 2 NM prior the PFAF.

Step 2: Construct line B perpendicular to the intermediate course extended 1 NM past the PFAF.

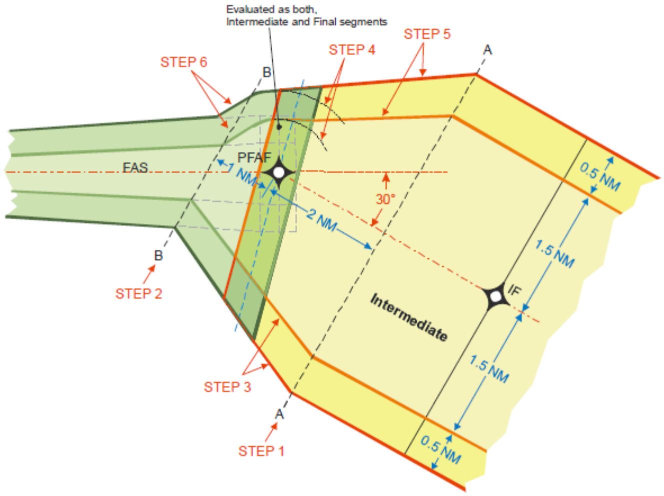
Step 3: Construct the inside turn boundaries by connecting the points of intersection of line A with the turn side intermediate segment boundaries with the intersection of line B with the turn side final segment boundaries.

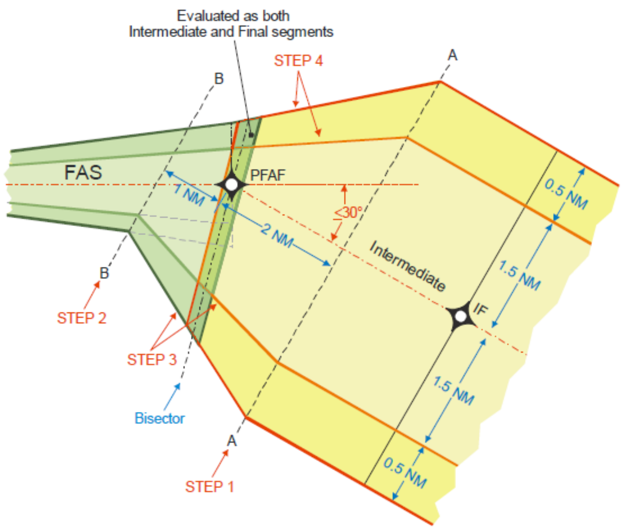
Step 4: Connect lines from the point of intersection of line A and the outside primary and secondary intermediate segment boundaries to the final segment primary and secondary final segment lines at a point perpendicular to the final course at the PFAF.

Note: MDA must not occur at a greater distance from HGC than the turn-side point of intersection of the expanded outer boundary line with the final segment secondary boundary (intersection of line “B” with secondary boundary in figure 8-2-13c lower graphic). If a higher MDA is required, then the degree of offset must be less.

The final segment evaluation extends to a point ATT prior to the angle bisector. The intermediate segment evaluation extends ATT past the angle bisector. Therefore, the area within ATT of the angle bisector is evaluated for both the final and intermediate segments.

Figure 8-2-13c: Offset LNAV/LP Turn at PFAF Construction

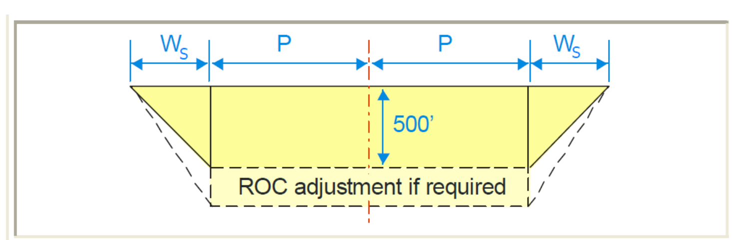




3) RF intermediate segments. Reserved.

d. **Obstacle Clearance.** The intermediate OEA begins at the segment beginning fix early ATT and ends at the segment ending fix late ATT. Apply 500 ft of ROC over the highest obstacle in the primary OEA. The ROC in the secondary area is 500 ft at the primary boundary tapering uniformly to zero at the outer edge (see figure 8-2-14).

Figure 8-2-14: Intermediate Segment ROC



Calculate intermediate secondary ROC values using formula 2-13.

Formula 2-13: Intermediate Secondary ROC ($\mathbf{ROC_{SECONDARY}}$)

$$ROC_{secondary} = (500 + adj) \cdot \left(1 - \frac{d_{primary}}{W_S}\right)$$

Where:

$d_{primary}$ = perpendicular distance (ft) from edge of primary area

W_S = Width (ft) of the secondary area

adj = TP308, Vol 1, Para 323 adjustments

(500+adj)*(1-$d_{primary}$/W_S)

e. **Minimum IF to FHP Distance** (applicable for LP procedures with no turn at PFAF). Locate the IF <u>at least</u> d_{IF} (NM) from the FHP (see formula 2-14).

Formula 2-14: Minimum IF Distance ($\mathbf{d_{IF}}$)

$$d_{IF} = 0.3 \cdot \frac{d}{a} - d \cdot \frac{0.3048}{1852}$$

Where:

d = distance (ft) from FPAP to FHP

a = width (ft) of azimuth signal at FHP

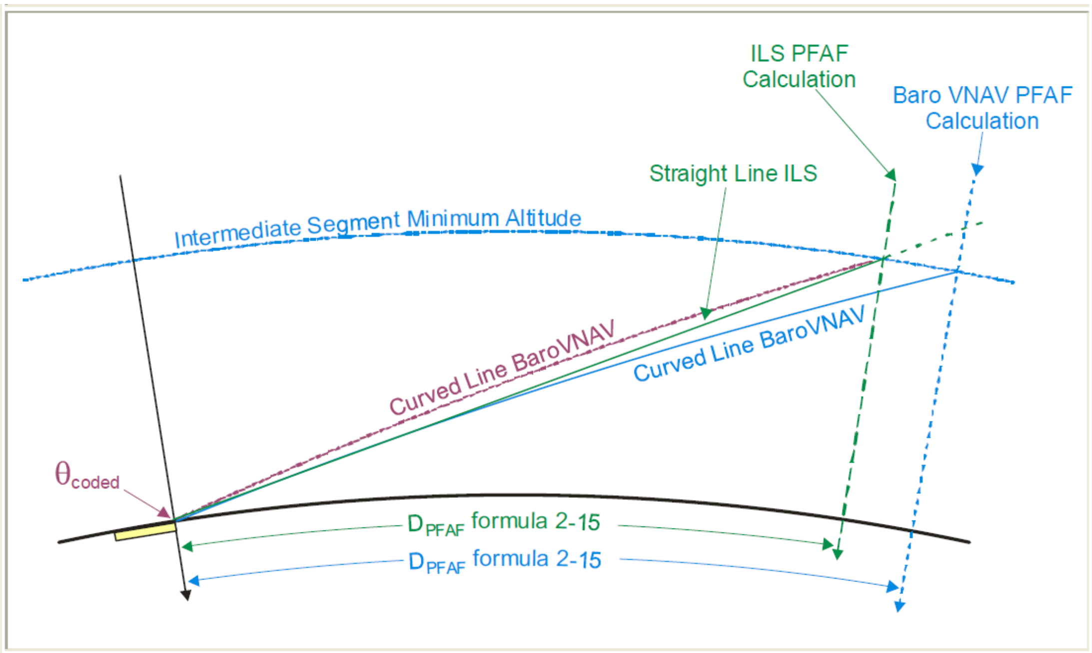
Note: See chapter 4, table 4-1, column 3

0.3*d/a-d*0.3048/1852

Basic Vertically Guided Final Segment General Criteria

8.2.18. Determining Precise Final Approach Fix/Final Approach Fix (PFAF/FAF) Coordinates (see figure 8-2-15 fixed-wing example).

Figure 8-2-15: Determining PFAF Distance to LTP (Example)



Geodetically calculate the latitude and longitude of the PFAF using the true bearing from the Heliport Geometric Centre (HGC) to the PFAF and the horizontal distance ($\mathbf{D_{PFAF}}$) from the HGC to the point the glidepath intercepts the intermediate segment altitude. The LNAV (BaroVNAV) glidepath is a curved line (logarithmic spiral) in space. Calculation the PFAF distance from the HGC using formula 2-15 (calculates the LNAV PFAF distance from HGC; i.e., the point the curved line BaroVNAV based vertical path intersects the minimum intermediate segment altitude (see TP308/GPH209 Volume 2 for additional information).

Formula 2-15: LNAV PFAF

$$D_{PFAF} = \frac{\mathrm{In}\left(\frac{r + alt}{r + HRP_{elev} + HCH}\right) \cdot r}{\tan(\theta)}$$

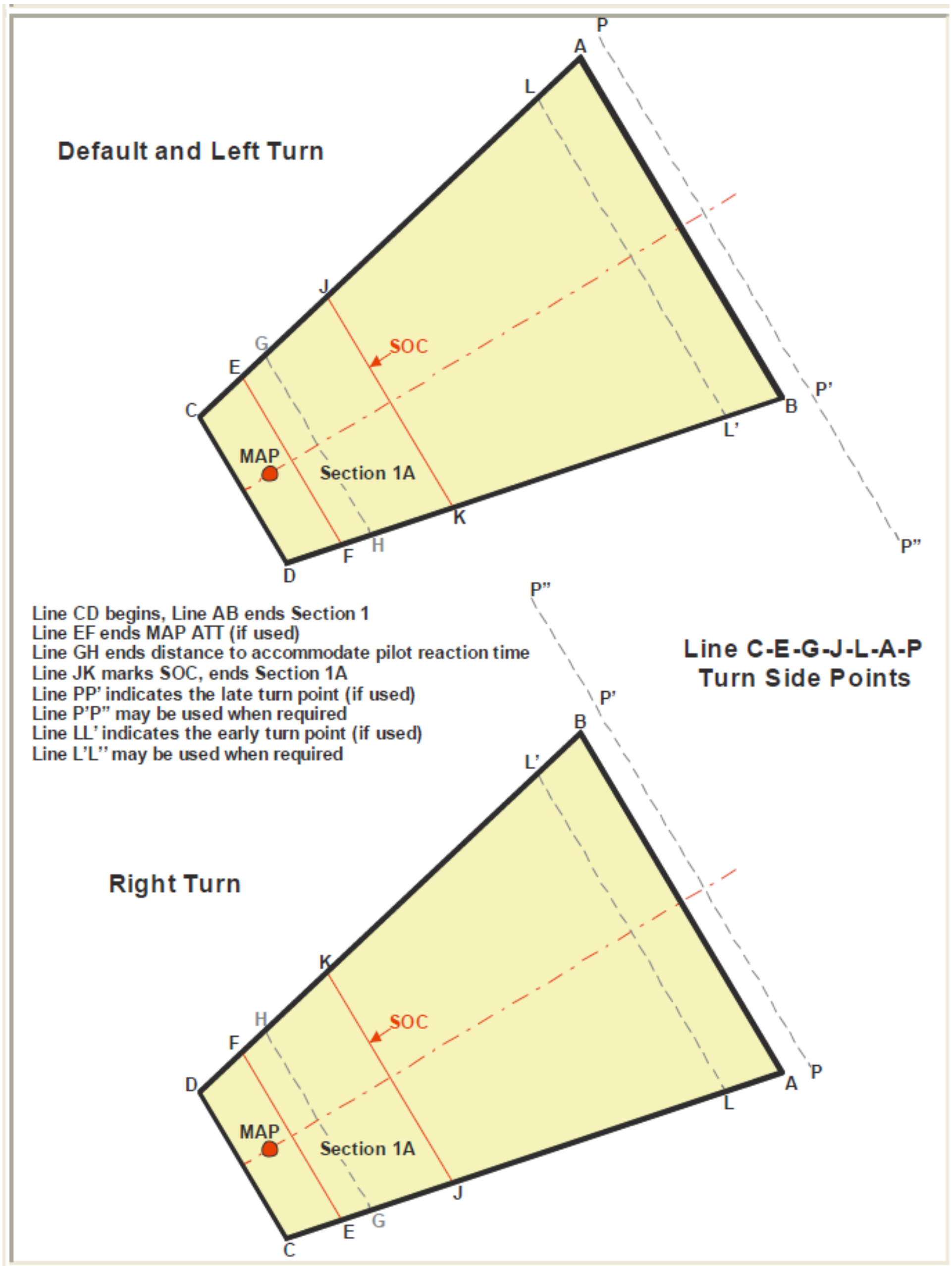
where alt = minimum intermediate segment altitude
HRP_{elev} = HRP MSL elevation
HCH = Heliport Crossing Height value
r = 20890537
θ = glidepath angle

Note: D_{PFAF} is the distance from HGC.

8.2.19. **Common Fixes.** Design all procedures published on the same chart to use the same sequence of charted fixes.

8.2.20. **Missed Approach Segment (MAS) Conventions.** Figure 8-2-16 defines the MAP point OEA construction line terminology and convention for section 1.

Figure 8-2-16: MAS Point/Line Identification



The missed approach obstacle clearance standard is based on a minimum helicopter climb gradient of 400 ft/NM, protected by a ROC surface that rises at 304 ft/NM. The MA ROC value is based on a requirement for a 96 ft/NM (400-304 = 96) increase in ROC value from the start of- climb (SOC) point located at JK. The actual slope of the MA surface is (1 NM in feet)/304≈19.987. In manual application of TERPS, the rounded value of 20:1 has traditionally been applied. However, this order is written for automated application; therefore, the full value (to 15 significant digits) is used in calculations. The nominal OCS slope ($MA_{OCSslope}$) associated with any given missed approach climb gradient is calculated using formula 2-16.

Formula 2-16: Helicopter Missed Approach OCS Slope

$$MA_{OCSslope} = r \cdot \ln\left(\frac{\frac{1852}{0.3048 \cdot (CG - 96)} + r}{r}\right)$$

Where:
CG = Climb Gradient (nominally 400 ft/NM)

r*ln((1852/(.3048*(CG-96))+r)/r)

a. **Charted Missed Approach Altitude.** Apply TP308/GPH209 Volume 1, paragraphs 277d and 277f to establish the preliminary and charted missed approach altitudes.

b. **Climb-In-Holding.** Apply TP308/GPH209 Volume 1, paragraph 277e for climb-inholding guidance.

SECTION 3: TERMINAL OPERATIONS

8.3. Terminal Operations.

8.3.1. Approach Configuration. The BASIC “Y” or “T” approach configuration should be the basis of procedure design. Segment length is affected by altitude to be lost, fix tolerances, and turn magnitude at the fixes. The **optimum** design incorporates a basic **Y** or **T** configuration. This design eliminates the need for a specific course reversal pattern. Where the **optimum** design cannot be used and a course reversal is required, establish a holding pattern at the initial or intermediate approach fix. General (70 KIAS) procedures should not deviate from these shape and dimension configurations unless there is an operational advantage. Construct IAFs within 25 NM of the airport reference point/heliport geometric centre (ARP/ HGC). See section 2, paragraph 8.2.16 for construction methods.

Note 1: Allowance for precipitous terrain should be made as specified in TP308/GPH209 Volume 1, paragraph 323 b.

Note 2: For 90 KIAS speed, limit initial segment turn to a MAXIMUM of 60 degrees with a basic “Y” approach configuration for COPTER RNAV (GNSS) procedures.

Table 8-3-1. Helicopter GPS MINIMUM Initial/Intermediate/Final Segment Lengths

Course Intercept Angle (Degrees)	Minimum Leg Length (NM)
00 – 30	2.0
> 30 - 90 *	3.0

* Final segment 30-degree MAXIMUM intercept angle for Global Positioning System (GPS) and Wide Area Augmentation System (WAAS) procedures.

a. **Initial Approach Segment.** The initial approach segment begins at the IAF and ends at the IF. The initial segment/subsegment obstacle evaluation area (OEA) begins at the early ATT of the segment beginning fix and ends at the late ATT of the segment/subsegment ending fix. Course change at the IF must not exceed 90 degrees. Construct the inbound leg of course reversal holding patterns within 30 degrees of the intermediate course (IF/IAF). Apply section 2, paragraph 8.2.16 for course reversal using holding pattern criteria. Do not establish a holding pattern in lieu of procedure turn at the PFAF. See section 2 for construction methods.

(1) Length. The initial segment begins at IAF and ends at the IF. The length should not exceed 10 NM unless operational requirements mandate a longer segment. Determine the **minimum** length using the greater distance from formulas 2-7, 2-8, and table 8-3-1.

(2) Width.

(a) Primary Area. 1.5 NM each side of the course centerline.

(b) Secondary Area. 0.5 NM on each side of the primary area.

Obstacle Clearance. Provide a **minimum** of 1,000 ft of required obstacle clearance (ROC) in the primary area. In the secondary area, provide 500 ft of ROC at the inner edge, tapering uniformly to zero at the outer edge (see section 2, figure 8-2-12). Calculate the secondary ROC using section 2, formula 2-12a or formula 2-12b. Establish initial segment altitudes in 100-ft increments that meet or exceed minimum ROC.

(3) Descent Gradient for Initial Segments (see section 2, paragraph 2.13).

b. **Intermediate Segment.** The intermediate segment begins at the IF and ends at the PFAF. The intermediate segment OEA begins at the early ATT of the segment beginning fix and ends at the late ATT of the segment ending fix. The intermediate segment is used to prepare the helicopter speed and configuration for final approach segment entry; therefore, the gradient should be as flat as possible. At a point beginning 2.0 NM from the PFAF, construct a taper to join the final approach segment (FAS).

(1) Alignment. The maximum course change at the PFAF is 30 degrees.

(2) Area.

(a) Length. The intermediate segment begins at the IF and ends at the PFAF. The length should not exceed 5.0 NM (optimum length is 3.0 NM). Determine the minimum length using the greater distance from formulas 2-7, 2-8, and table 8-3-1.

(b) Width.

<u>1 Primary Area</u>. 1.5 NM each side of the segment centerline, beginning at the earliest IF position. The segment taper begins 2.0 NM prior to the plotted position of the PFAF to reach a 0.55 NM width at the PFAF plotted position (see section 2, figures 8-2-13a, 8-2-13b, and 8-2-13c).

Note: For 90 KIAS speed, change 0.55 NM to 0.70 NM.

<u>2 Secondary Area</u>. 0.50 NM on each side of the primary area.

(3) Obstacle Clearance. Provide a MINIMUM of 500 ft of ROC in the primary area. In the secondary area, provide 500 ft of ROC at the inner edge tapering to zero feet at the outer edge. Establish altitudes for each intermediate segment in 100-ft increments, and round to the next higher 100-ft increment. Calculate the secondary ROC using section 2, formula 2-13 (see section 2, figure 8-2-14).

(4) Descent Gradient for Intermediate Segments (see section 2, paragraph 2.13).

SECTION 4: IFR FINAL AND VISUAL SEGMENTS

8.4. IFR Final and Visual Segments.

8.4.1. **General.** The approach procedure type is determined by the visual segment. The instrument flight rule (IFR) final approach segment (FAS) applies to all three types of procedures. Use the criteria in section 3 for the construction of the initial and intermediate segments up to the precise final approach fix (PFAF), and section 5 criteria for the missed approach segment construction. Apply section 4, paragraph 8.4.3 criteria to LNAV IFR final segments, and section 4, paragraph 8.4.9 to WAAS LP IFR final segments.

Note: Section 4 graphics are not drawn to scale.

a. **Final Segment Stepdown Fix (SDF).** An SDF may be applied where the MDA can be lowered 60 ft, or a visibility reduction can be achieved. TP308/GPH209, Volume 1, paragraph 289 applies, with the following exceptions:

(1) Establish step-down fix locations in 0.10 NM increments.

(2) The minimum distance between stepdown fixes is 1 NM.

(3) Establish stepdown fix altitudes using 20-ft increments, rounded to the next **higher** 20-ft increment. For example, 2104 becomes 2120.

(4) Where a Remote Altimeter Setting Source (RASS) adjustment is in use, the published stepdown fix altitude must be established no lower than the altitude required for the greatest amount of adjustment (i.e., the published minimum altitude must incorporate the greatest amount of RASS adjustment required).

(5) Descent gradient: Section 4, paragraphs 8.4.3.a(3), 8.4.3.a(4), and 8.4.3.a(5) apply.

(6) Obstacles eliminated from consideration (3.5:1 area) under this paragraph must be noted in the procedure documentation.

(7) Use formula 4-4 in section 4, paragraph 8.4.3.a(6) concerning TP308/GPH209, Volume 1, paragraph 289 to determine the OIS elevation at an obstacle and minimum fix altitude based on an obstacle height.

(8) To mitigate surface penetrations:

- Remove obstruction, or
- Reduce obstruction height, or
- Adjust the MDA, or
- Combination of options.

8.4.2. **Missed Approach.** Construct the missed approach for all procedures using section 5 criteria.

8.4.3. The three procedure types are:

- IFR to an IFR Heliport.
- Point-in-Space (PinS) Approach (Proceed VFR).
- IFR to an IFR Runway.

a. **LNAV IFR Final Approach Segment (FAS).** The IFR FAS begins at the PFAF and ends at the missed approach point (MAP) (see figure 8-4-1). This FAS construction is unique to helicopters. It applies trapezoidal rather than the linear construction used for fixed-wing applications. Locate LNAV PFAF using section 2, formula 2-15. MAP location should provide the best compromise of lowest visibility and visual segment descent angle (VSDA). For general (70 KIAS) procedures, the preferred approach paths should be aligned with the prevailing wind direction to avoid downwind and minimize crosswind operations. Other approach/departure paths should be based on the assessment of the prevailing winds or when this information is not available, the separation between such flight paths and the preferred flight path should be at least 135 degrees.

(1) Alignment. The IFR final segment connects the PFAF to the MAP. The course change at the PFAF from the intermediate course to the final approach course (FAC) must not exceed 30 degrees. The MAP is located on the FAC between the PFAF and a point no closer to the helipoint than 0.3 NM from the visual segment reference line (VSRL). For a straight-in approach, the course change at the MAP must not exceed 30 degrees to an IFR heliport helipoint **or** 30 degrees from a runway centerline (RCL) extended to an IFR runway threshold (RWT). Optimum alignment is coincident with the RCL. When the alignment exceeds 5 degrees the optimum alignment point is 1,500 ft from the RWT on RCL.

(2) Area. The obstacle evaluation area (OEA) begins at the earliest PFAF along-track tolerance (ATT) and ends at the latest MAP ATT (see figure 8-4-1).

(a) Length. The IFR final approach segment begins at the PFAF and ends at the MAP. The length should not exceed 10 NM (**optimum** length is 3 NM). Determine the **minimum** length using the greater of descent distance, formula 2-7 or 2-8, and table 8-3-1.

(b) Width.

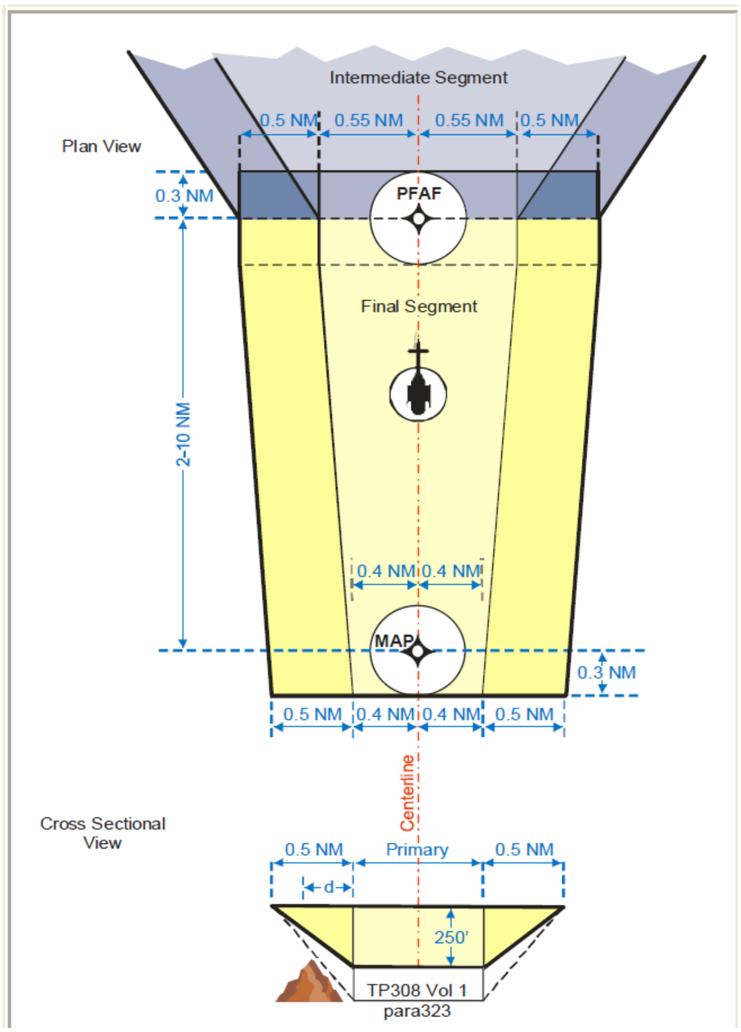
<u>**1**</u> **Primary Area.** The primary area boundary begins 0.55 NM***** each side of the final segment centerline at the earliest PFAF ATT. The width remains constant until the latest PFAF ATT. It then tapers to 0.40 NM***** at the latest MAP ATT.

***Note:** For 90 KIAS speed, change 0.55 NM to 0.70 NM and 0.40 NM to 0.50 NM (primary area).

__2__ **Secondary Area.** The secondary area boundary is constant, 0.50 NM each side of the primary area. Calculate the primary half-width at any distance from latest MAP ATT using formula 4-1a.

(c) Required Obstacle Clearance. Primary area required obstacle clearance (ROC) is 250 ft. Secondary ROC is 250 ft at the edge of the primary area, tapering uniformly to zero at the outer edge. Calculate secondary ROC using formula 4-1b.

Figure 8-4-1: LNAV Final Segment Construction



Formula 4-1a: Final Area Half-Width (W_P)

$$W_P = P_{W2} + \left(\frac{P_{W1} - P_{W2}}{D_1}\right) \cdot D_2$$

Where P_{W1} = Primary Width, PFAF, (0.55 or 0.7) NM
P_{W2} = Primary Width, latest MAP ATT, (0.4 or 0.5) NM
D_1 = PFAF to MAP distance (NM)
D_2 = Latest MAP ATT to desired point (NM)
W_T = Final Total Width (ft) (Wp+0.5NM)

P_{W2}+((P_{W1}- P_{W2})/D_1)*D_2

Formula 4-1b: Secondary Area ROC ($ROC_{secondary}$)

$$ROC_{secondary} = (250 + adj) \cdot \left(1 - \frac{d_{primary}}{W_S}\right)$$

Where adj = TP308 Vol1 para 323 adjustments (ft)
$d_{primary}$ = distance (perpendicular to C/L from edge primary area (ft))
W_S = Secondary area width (ft)

(250+adj)*(1-$d_{primary}$/W_S)

(3) Descent Gradient/Angle [PinS Approach]. The descent gradient/angle is measured from the plotted positions of the PFAF at PFAF altitude to the MAP at MDA. Calculate the final segment descent angle using formula 4-2. (Where required, calculate descent gradient using section 2, formula 2-10).

Formula 4-2: Final Approach Angle to MAP (DescentAngle)

$$DescentAngle = atan\left(\frac{r}{c} \cdot In\left(\frac{r+a}{r+b}\right)\right)$$

Where:
c = PFAF to MAP distance (ft)
a = PFAF altitude MSL
b = MDA at MAP MSL

Note 1: For 90 KIAS speed, normal descent gradient/angle is up to 478 ft/NM (4.5 degrees). Descent gradient/angle up to 800 ft/NM (7.5 degrees) may be granted by Transport Canada for inclusion in the Restricted CAP.

Note 2: The visual segment descent gradient is considered separately in approaches to VFR heliports or VFR runways.

(4) Descent Gradient/Angle to an IFR Runway or an IFR Heliport. Apply the same descent gradient/angle in section 4, paragraph 8.4.3.a(3) for an IFR approach to an IFR runway, but the distance/elevation calculations begin at the PFAF and end at Runway Threshold (RWT)/Threshold Crossing Height (TCH)

elevation (see figure 8-4-2b). For an IFR approach to an IFR Heliport, the distance/elevation calculations begin at the PFAF and end at Helipoint Crossing Height (HCH) (see figure 8-4-2c). Apply formula 4-3 for descent angle, and section 2, formula 2-10 for descent gradient:

Formula 4-3: Descent Angle to Runway or Helipoint Crossing Height (HCH)

$$\mathbf{DescentAngle = atan\left(\frac{r}{c} \cdot ln\left(\frac{r+a}{r+b}\right)\right)}$$

Where:
- c = PFAF to RWT/helipoint distance (ft)
- a = PFAF Altitude MSL
- b = TCH/HCH elevation at RWT or HCH

Figure 8-4-2a: Descent Angle, PFAF to MAP for PinS Approach Procedures

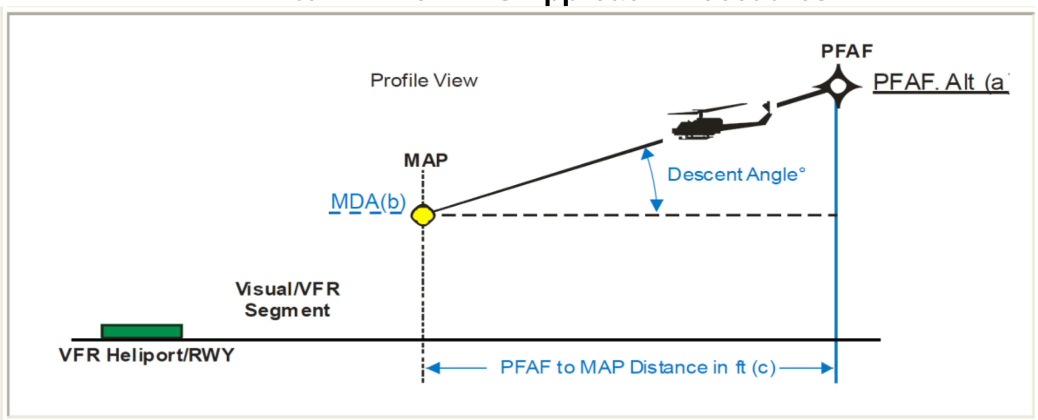


Figure 8-4-2b: Descent Angle, PFAF to TCH for IFR Approach to IFR Runway

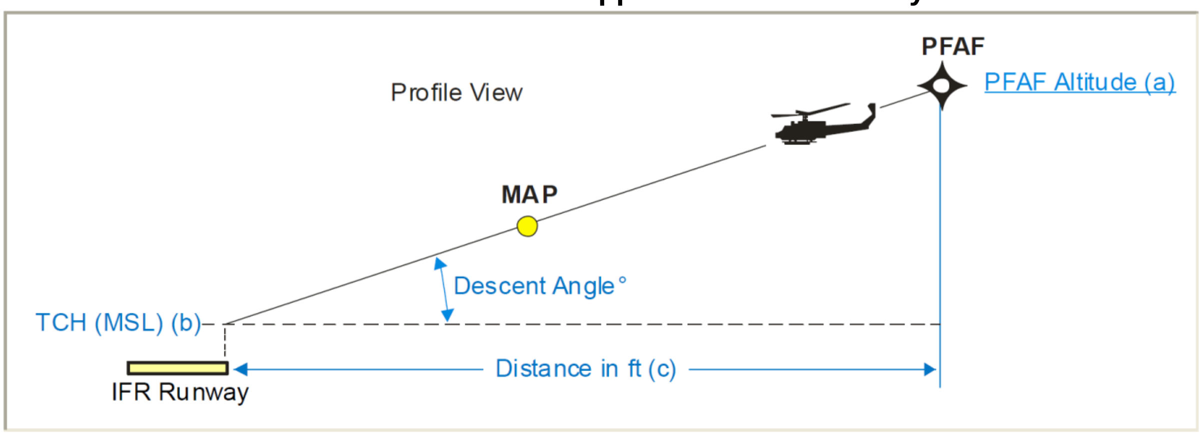
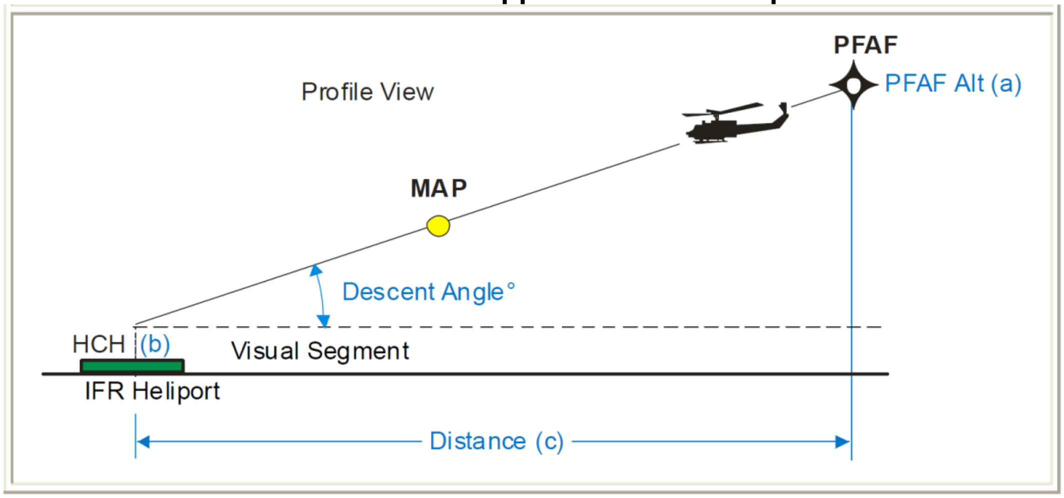


Figure 8-4-2c: Descent Angle,
PFAF to HCH for IFR Approach to IFR Heliport



(5) Stepdown Descent Gradient/Angle. When a stepdown fix is used, measure the descent gradient/angle from the PFAF at the PFAF altitude to the stepdown fix at the minimum fix altitude, then to the MAP at the MDA. For a stabilized approach, provide a constant gradient/angle from the PFAF to the MAP, (may require raising the PFAF altitude). A stepdown fix must be located no closer than 0.6 NM to the PFAF or MAP.

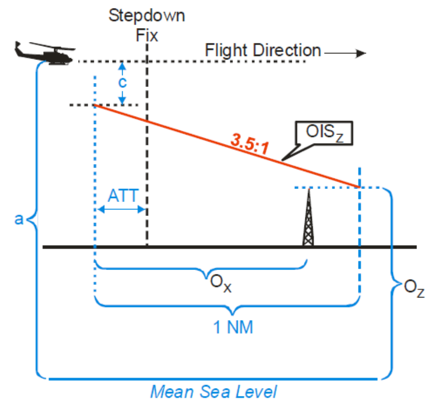
(6) Existing Obstacles Close to the PFAF or Stepdown Fix. If the segment descent gradient/angle is less than 800 ft/NM (7.5 degrees), TP308/GPH209 Volume 1, paragraph 289 may be applied substituting an OIS slope of 3.5:1 vice 7:1. Calculate the OIS Elevation and Minimum fix altitude using formula 4-4.

Formula 4-4: OIS Elevation & Minimum Fix Altitude (OIS_z & MFa)

$$OIS_z = (r + a - c) \cdot e^{\frac{-O_x}{3.5 \cdot r}} - r$$

$$MFa = (r + O_z + c) \cdot e^{\frac{O_x}{3.5 \cdot r}} - r$$

Where:
- a = MSL fix altitude (ft)
- c = ROC plus adjustments (TP308 Volume 1, para 323)
- O_X = Obstacle along-track distance (ft) from ATT prior to fix (1 NM max)
- O_Z = MSL obstacle elevation (ft)
- MFa = Minimum Fix Altitude (rounded to next higher 100-ft increments)



OISZ=(r+a-c)*e^(-O_X/(3.5*r))-r
MFa=(r+O_Z+c)*e^(O_X/(3.5*r))-r

8.4.4. **IFR Heliport Visual Segment.** The IFR Heliport visual segment connects the MAP to the helipoint. The visual segment OCS starts at the VSRL and extends to the later of a point 250 ft below the MDA or the latest MAP ATT (see figures 8-4-3 and 8-4-4).

a. **Alignment.** The IFR Heliport visual segment connects the MAP to the helipoint. The course change at the MAP from the FAC must not exceed 30 degrees.

b. **Area.** The obstacle evaluation area (OEA) begins at the Visual Segment Reference Line (VSRL) and extends toward the MAP as defined below:

(1) Length. The IFR Heliport Visual segment begins at the MAP and ends at the Heliport (see profile figures 8-4-3 and 8-4-4).

(2) Width. The visual segment splay begins at the Visual Segment Reference Line (VSRL). It splays from the VSRL endpoints relative to the FAC to the latest FAS primary area width at the latest MAP ATT (see plan view figure 8-4-6 (right)). Where the OCS surface extends to a point 250 ft below the MDA, the boundary follows the primary area to its end point (see plan view figures 8-4-4 and 8-4-6 (left)).

c. **Obstacle Clearance Surface.** The OCS begins at the VSRL and extends 1.0 degree below the VSDA (see figures 8-4-3, 8-4-4 and formula 4-6).

Formula 4-6: OCS Elevation (OCS_{elev})

$$OCS_{elev} = (r + HE) \cdot e^{\frac{atan(\beta)}{r}} - r$$

Where:

HE = Helipoint elevation MSL
D = Distance obstacle to VSRL (ft)
β = OCS Angle

Figure 8-4-3: IFR Heliport Visual Segment OCS Terminating at Latest MAP Position

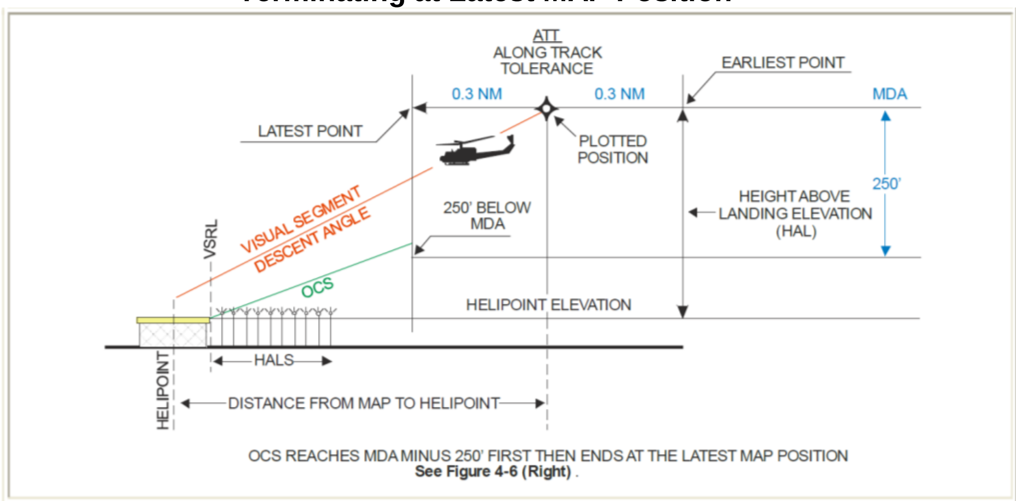
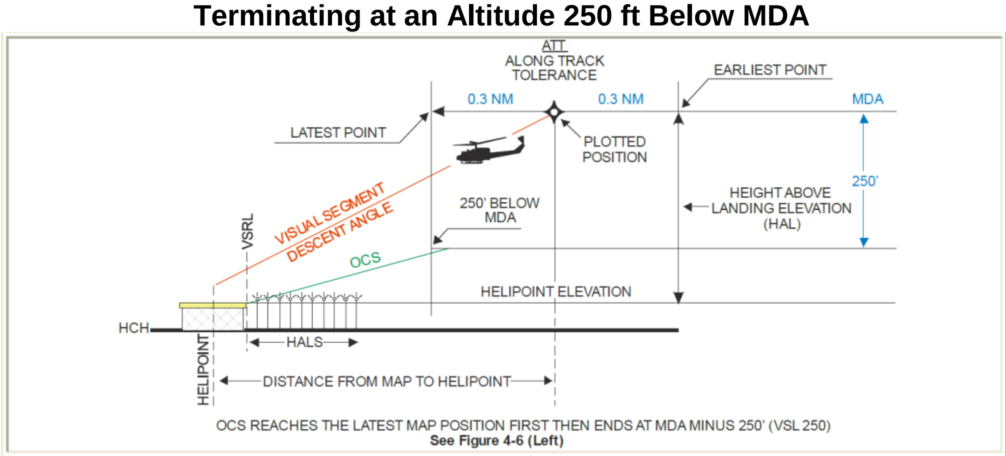


Figure 8-4-4: IFR Heliport Visual Segment OCS Terminating at an Altitude 250 ft Below MDA



Supplementary note: IFR Heliport HAL, VSDA-based Visual Segment Length (VSL_{250}), and Visual Segment Descent Angle (VSDA) Computations. Calculate HAL, VSRL to a point 250 ft below MDA (VSL_{250}), and VSDA using the following steps (see figure 8-4-7):

(a) Calculate HAL using formula 4-7:

Formula 4-7: Height Above Landing Area Elevation (HAL)

HAL= MDA-Helipoint Elevation (HE)
MDA-HE

(b) Calculate VSDA using formula 4-8:

Formula 4-8: Visual Segment Descent Angle (VSDA)

$$\mathbf{VSDA = atan\left(\frac{r}{c} \cdot In\left(\frac{r + HAL + HCH}{r + HCH}\right)\right)}$$

Where:

c = MAP to Helipoint Distance (ft)
HAL = Formula 4-7 output
HCH = Heliport Crossing Height

(c) Calculate visual segment length from the VSRL to a point 250 ft below MDA (VSL_{250}) using formula 4-9.

Formula 4-9: Visual Segment Length (VSL_{250})

$$\mathbf{VSL_{250} = \frac{\left(r \cdot In\left(\frac{r + a}{r + HE}\right)\right)}{tan(VSDA - 1)}}$$

Where:

HAL = Formula 4-7 output
a = HAL-250 (MSL)
HE = Heliport elevation
VSDA = Formula 4-8 output

Figure 8-4-5: IFR Heliport Visual Segment Area

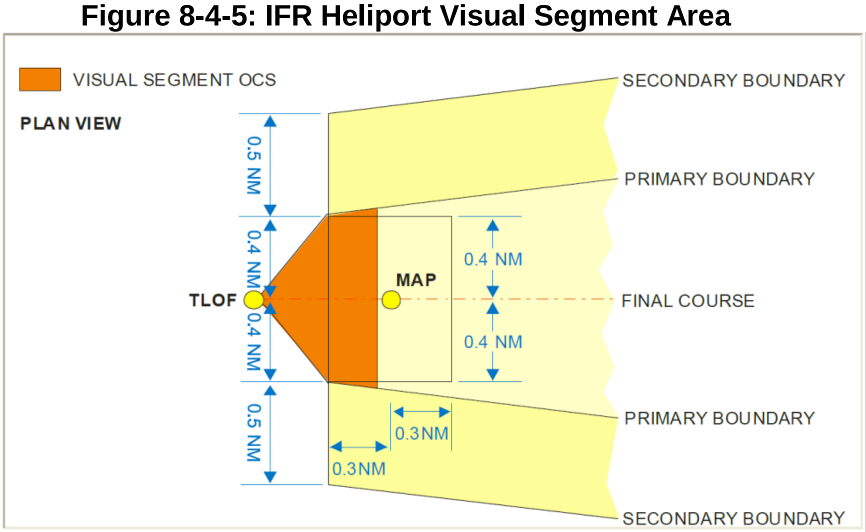
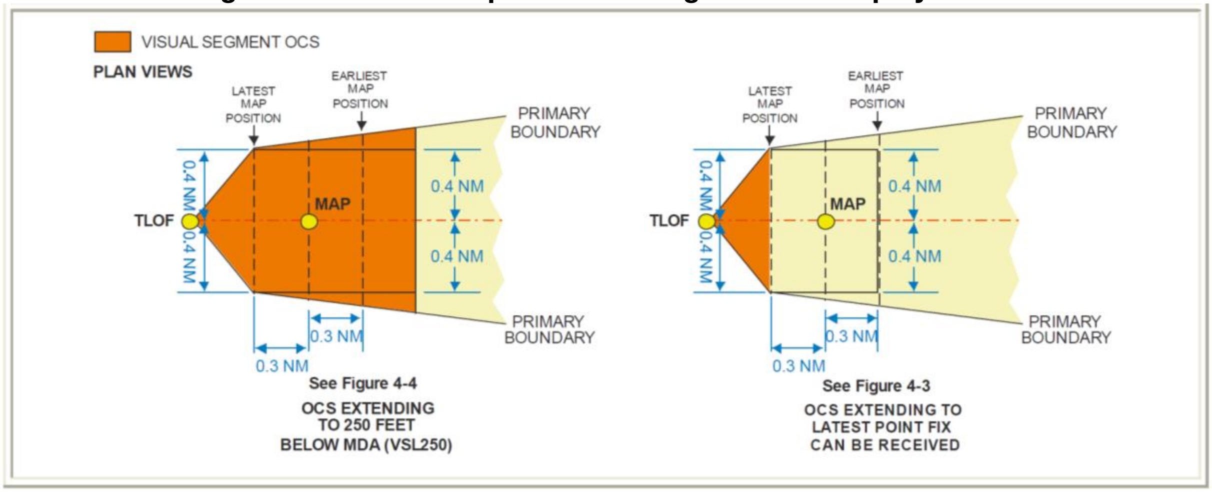


Figure 8-4-6: IFR Heliport Visual Segment Area Splays



d. RESERVED

e. RESERVED

8.4.5. **RESERVED**

8.4.6. **RESERVED**

8.4.7. **PinS Approach (Proceed VFR).** The VFR segment on a PinS Approach (Proceed VFR) approach procedure provides a measure of obstacle protection/identification to allow a safe transition from IFR to VFR flight. The area is not intended to support IFR descent.

Apply TP308/GPH209 Volume 5, Chapter 1 pertaining to PinS Approach criteria, except no requirement exists for a MAP to be located beyond 2,600 ft of the helipoint. A PinS Approach (Proceed VFR) procedure may be developed to a heliport, multiple heliports, or a geographical area associated with a specific heliport. Compute the distance for the Remote Altimeter Setting Source (RASS) adjustment for the MDA and stepdown altitudes for the PinS Approach procedures from the source to the MAP.

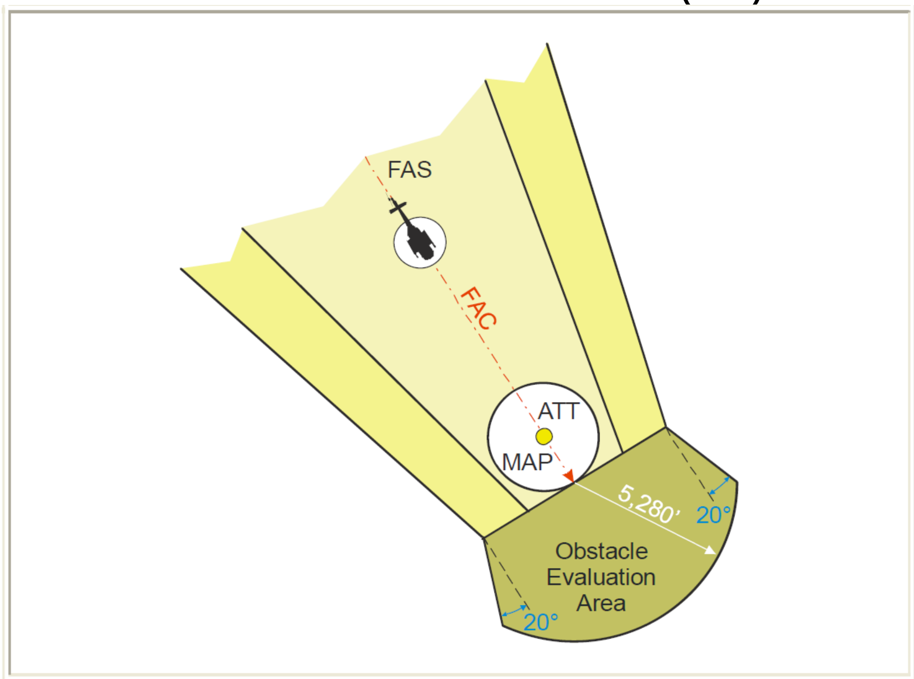
a. **Alignment.** The PinS Approach visual segment is a 5,280 ft-radius arc segment centered at the FAC and the latest MAP ATT intersection.

b. **Area.** The PinS Approach OEA is a 5,280 ft-radius arc segment centered at the FAC and the latest MAP ATT intersection. The arc segment is laterally bounded by 20 degree splay lines (relative the FAC-extended), originating at the FAS secondary boundaries and the latest MAP ATT (see figure 8-4-13).

c. **Lengt**h. A 5,280 ft radius as described above.

d. **PinS Approach visual segment OIS** (see section 4, paragraph 8.4.7.e). This surface **must not** be penetrated.

**Figure 8-4-13: PinS Approach (Proceed VFR)
VFR Transition Area Obstacle Evaluation (OEA)**



e. **Obstacle Clearance in the PinS Approach VFR Segment.** Add 250 ft of ROC (without adjustments) to the highest obstacle/terrain within the VFR area and round to the next higher 20-ft increment. The final MDA is the higher of the MDAs calculated for the final and VFR segments.

f. **Visibility.** The **minimum** final segment visibility is 1 SM.

8.4.8. **IFR to an IFR Runway.**

a. **Configuration and Alignment.** The MAP location should provide the best compromise of lowest visibility and VSDA. Except where the alignment is to the RWT, the mandatory MAP location is at the FAC and RCL intersection. Where the alignment is to the RCL, the optimum MAP location is at the RWT, with optional MAP location along the FAC between the PFAF and the RWT.

b. **Area.** The final OEA begins at the earliest PFAF ATT and ends at the latest MAP ATT, RWT, or a point abeam the RWT, whichever is farthest. Apply section 4, paragraph 8.4.3.a criteria for the IFR segment OEA and ROC (see figure 8-4-1).

c. **Descent Gradient/Angle.** Calculate the FAS descent angle from the PFAF altitude at the plotted position of the PFAF to the TCH at RWT. Apply section 4, paragraph 8.4.3.a(4).

d. **Visual Segment.** Establish a 40 ± 5 ft TCH for runways where no VGSI is installed. Where a VGSI is installed, a final descent gradient and VSDA may be established to coincide with the gradients/angles for angles of 3.0 degrees or more. If the descent gradient/angle cannot be published coincident (within ± 0.20 degrees) and TCH values within 3 ft of the published VGSI glide slope angle, publish a note on the chart.

e. **Minimum.** See TP308/GPH209 Change 6.1, Volume 2, Chap 1, Para 127.

8.4.9. **WAAS LP Criteria.** The WAAS LP criteria apply to the final approach only. For all other segments apply GPS criteria except where noted for a turn at the PFAF, and missed approach constructions that are different. This implementation of WAAS does not include a glidepath function for these procedures. Criteria in this section provide a narrower OEA in the IFR FAS and OIS in the visual segment. The segment lengths and descent rate/gradients are the same as section 4, paragraph 8.4.3. The intermediate segment begins with the same width at the GPS intermediate fix (IF), reference section 3, paragraph 8.3.1.b, tailored to the beginning WAAS FAS width, reference section 4, paragraph 8.4.9.d at the PFAF. Apply section 4, paragraph 8.4.7 to design approaches in the visual/visual flight rule (VFR) segments, and apply section 4, paragraphs 8.4.8 and 8.4.9 for the IFR FAS OEA and ROC. Apply an OIS, reference section 4, paragraph 8.4.8.d. Apply section 4, paragraph 8.4.7 for the analysis of the VFR area of a Point-in-Space (PinS) Approach (Proceed VFR) approach.

Figure 8-4-17 depicts the basic configuration for determining the Flight Path Alignment Point (FPAP) and fictitious helipoint (FHP) coordinates. Locate the FHP 2,600 ft from the

MAP. The FPAP is a point defined by the World Geodetic System 1984 (WGS-84) latitude, longitude, and is located 9,023 ft from the FHP.

a. **Minimums.** See TP308 Change 6.1, Volume5, Chap 1, Para 127.

b. Use The Following Steps for WAAS LP Procedure Construction:

Step 1: Determine the FAS course alignment, MAP, FHP, and FPAP coordinates.

Step 2: Calculate the distance (ft) from the FHP to the PFAF (D_{PFAF}) using formula 4-11. Calculate the primary and secondary area widths at any distance from FHP to the earliest point the PFAF can be received using formulas 4-11 and 4-13 (see figure 8-4-14).

Formula 4-11. LP PFAF (D_{PFAF})

$$D_{PFAF} = \frac{\ln\left(\frac{r + alt}{r + FPH_{elev} + HCH}\right) \cdot r}{\tan(\theta)}$$

Where:

alt = minimum intermediate segment altitude

FHP_{elev} = FHP MSL elevation

HCH = HCH value

θ = glidepath angle

Step 3: After constructing the IFR final trapezoid area, analyze the FAS by determining the controlling obstacle within the IFR final segment by applying the ROC in section 4, paragraph 8.4.9.d and determining the minimum descent altitude (MDA).

Step 4: When constructing a PinS Approach (Proceed VFR) approach, apply section 4 criteria for the VFR segment and adjust the MDA of the IFR segment after an analysis of the VFR segment if required.

Step 5: Construct the missed approach using section 5.

c. **Determine FAS Course Alignment, FPAP and FHP Coordinates.** The FAS course determines the positional relationship between the FPAP and the FHP. Calculate the FPAP latitude and longitude coordinates using the MAP as a starting point after determining the procedure final approach course (FAC). Use the direct program and extend the FAS course as an azimuth at a distance of 2,600 ft from the MAP to determine the FHP coordinates. Extend this course 9,023 ft beyond the FHP to calculate the FPAP coordinates (see figure 8-4-14 and table 8-4-1).

Figure 8-4-14: FPAP and FHP Coordinates

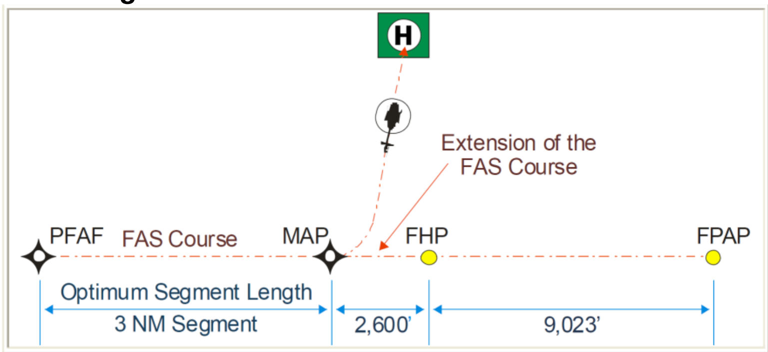


Table 8-4-1: FPAP Information

FPAP Distance from FHP	± Splay	± Width	Length Offset
9,023 ft	2.0°	350 ft (106.75 m)*	0

*Round result to the nearest 0.25 m.

d. **Area.** The FAS OEA begins at the earliest PFAF position and ends at the MAP latest ATT (see figure 8-4-16). The PFAF and MAP ATT is ±40 m. Apply 250 ft of ROC in the primary area (plus adjustments). The secondary area ROC is 250 ft at the primary boundary tapering uniformly to zero at the outer edge. The beginning primary area width nearest the FHP is 867.79 ft, and the secondary areas are 468.60 ft (see figures 8-4-15b and 8-4-16). Calculate the primary and secondary widths at any point between FHP and PFAF using formulas 4-12 (primary) and 4-13 (secondary).

(1) Length. The **standard** IFR final segment length PFAF to MAP is 3 NM but is also determined by descent gradient. The **minimum** length is 2 NM and the **maximum** length is 50,000 ft. (see figure 8-4-15a).

Figure 8-4-15a: WAAS LP Final Segment

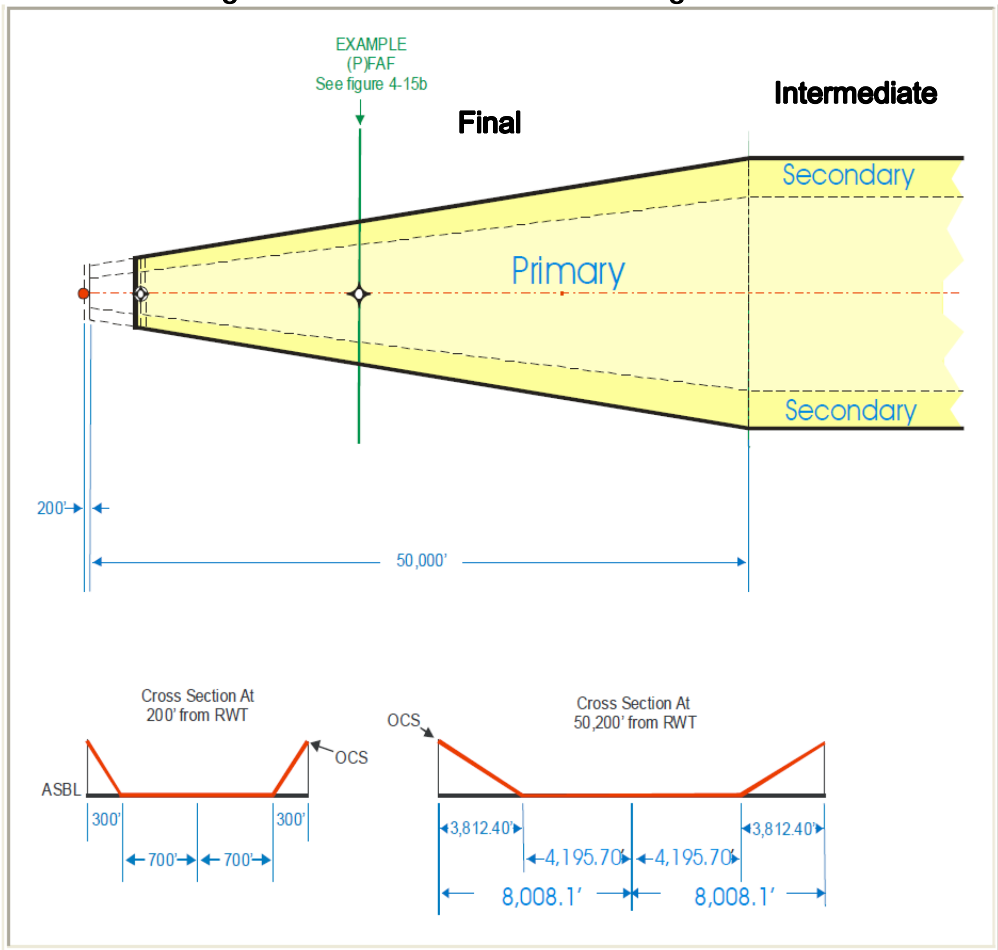


Figure 8-4-15b: WAAS LP Final Segment Construction

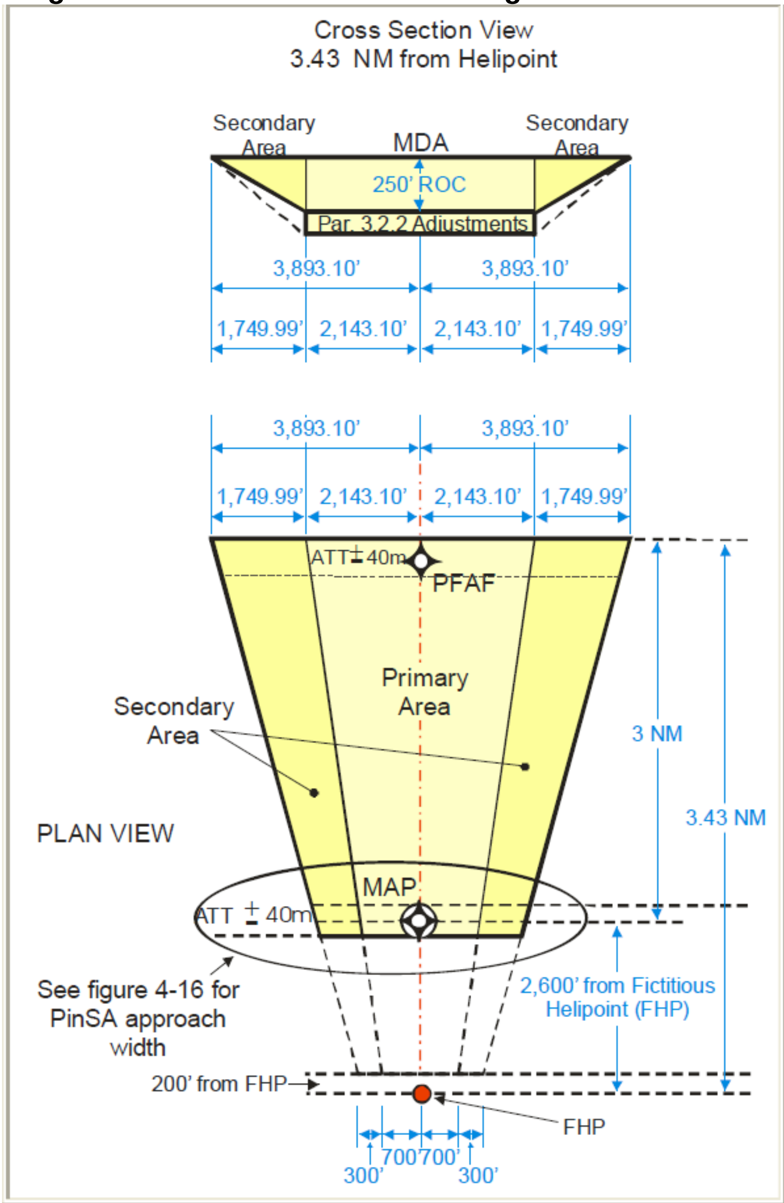
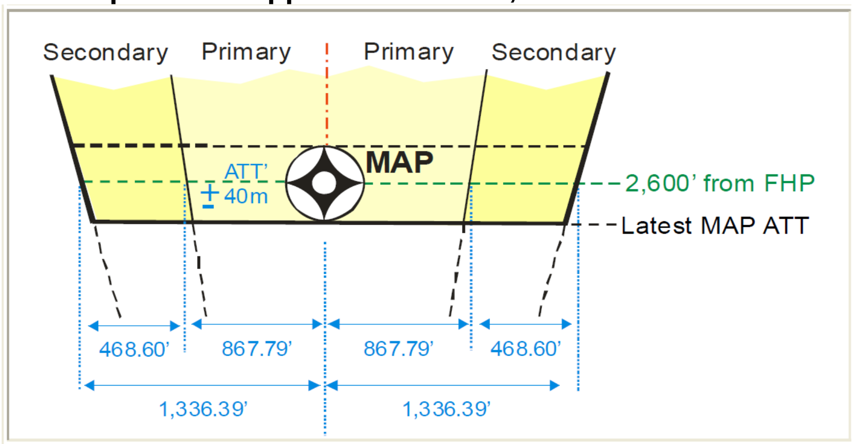


Figure 8-4-16: OCS Beginning Width, IFR to VFR Heliport and Copter PinS Approach FAS at 2,600 ft from FHP



(2) The primary area half-width (D_P) each side of FAC at its origin (2,600 ft from FHP) is 867.79 ft. The primary area expands uniformly to 3,495.70 ft from FAC at a point 50,200 ft from FHP. From 50,200 ft outward, the OEA is linear (boundaries parallel the centerline). The OEA begins at the earliest PFAF ATT and ends 2,600 ft from the FHP (MAP latest ATT). Calculate primary area half-width at any point in final using formula 4-12 (see figures 8-4-15a, 8-4-15b, and 8-4-16).

Calculate the perpendicular distance (ft) D_p from FAC to the primary area boundary at any distance (d_{FHP}) using formula 4-12:

Formula 4-12: Half-Width of Primary Area (D_p)

$$D_p = 1/2 \text{ Primary Area Width (ft)} = 0.0699139\,(d_{FHP} - 200) + 700$$

d_{FHP} = Distance (ft) from FHP, along course

$$0.0699139 * (d_{FHP} - 200) + 700$$

(3) The perpendicular distance from FAC to outer secondary boundary (D_S) is 1,336.39 ft at the origin, and expands uniformly to 7,008.1 ft at 50,200 ft from the FHP (see figures 8-4-15a, 8-4-15b, and 8-4-16). Calculate D_S (ft) using formula 4-13.

Formula 4-13: Distance Secondary (D_s)

$$D_S = \text{Secondary Boundary Dist. (ft)} = 0.140162\,(d_{FHP} - 200) + 1000$$

Where:

D_S = Course to Outer Secondary Distance (ft)

d_{FHP} = Distance from FHP (ft), along course

$$0.140162 * (d_{FHP} - 200) + 1000$$

e. **Required Obstacle Clearance (ROC).** Primary ROC is 250 ft. The MDA can be no lower than the controlling obstacle height adjusted for obstacle accuracy tolerance (see TP308/ GPH209 Annex E – Terrain and Obstacle Data) plus the ROC value plus adjustments rounded to the next higher 20 ft-increment. Calculate secondary area ROC using formula 4-14.

Formula 4-14: Secondary Area ROC ($ROC_{secondary}$)

$$ROC_{secondary} = (250+adj) \cdot \left(1 - \frac{d_{primary}}{W_s}\right)$$

Where: adj = *TP308*, Volume *1* para *323*

$d_{primary}$ = perpendicular distance (ft) from primary area edge

W_s = Secondary Area Width (ft)

(250+adj)*(1-$d_{primary}$/W_s)

f. **FAS Descent Angle/Gradient.** Apply section 4, paragraphs 8.4.3.a(4) and 8.4.3.a(5).

g. **PinS Approach.** Apply section 4, paragraph 8.4.9 to determine a preliminary MDA based on the FAS OEA. Apply section 4, paragraphs 8.4.7 and 8.4.7.e for the VFR segment analysis.

SECTION 5: MISSED APPROACH

8.5. Missed Approach.

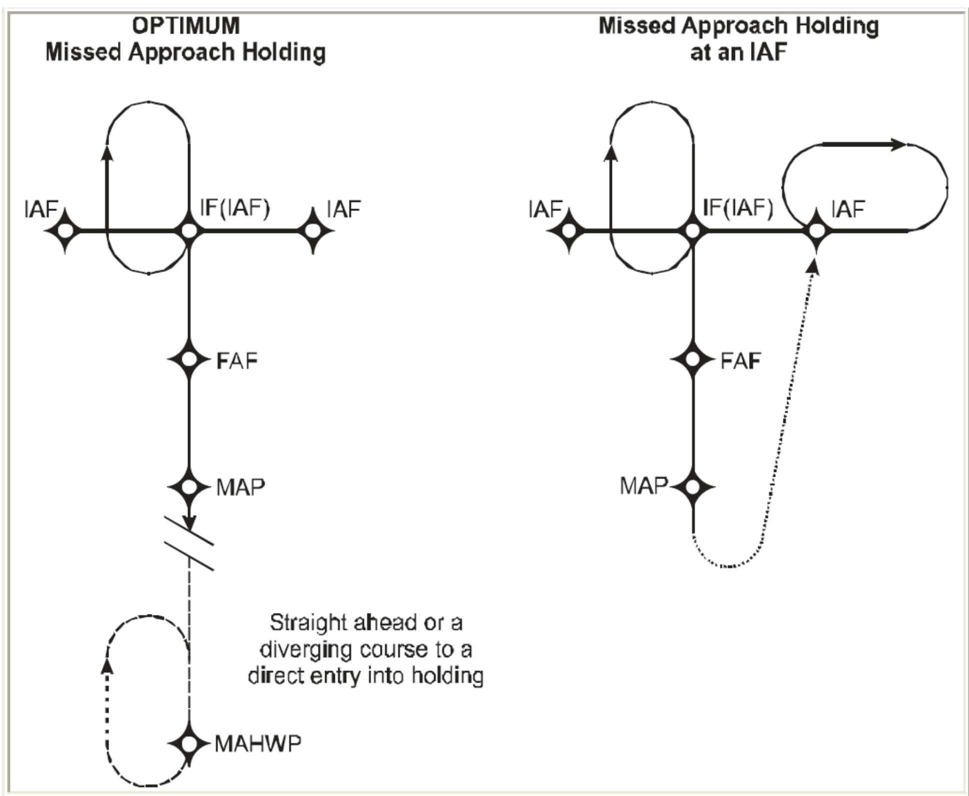
8.5.1. General.

a. Missed Approach (MA) Construction.

(1) Speed. Apply 70 KIAS or 90 KIAS procedures (see section 1, paragraph 8.1) as applicable. Apply wind values (see section 2, formula 2-3b) and bank angles (see section 2, table 8-2-4).

(2) Optimum Flight Path. The missed approach segment ends at a holding point designated by a missed approach holding fix (MAHF). Optimum routing is straight ahead to a direct entry into holding at the MAHF. If the MA routing terminates at a “T” IAF, optimum MA holding pattern alignment is with the initial inbound course, with either a teardrop or direct entry into holding (see figure 8-5-1a).

Figure 8-5-1a: Missed Approach Optimum Flight Paths



Note: Figures are NOT drawn to scale.

b. **Obstacle Clearance Standard.** Calculate the nominal OCS slope ($MA_{OCSSLOPE}$) associated with a given missed approach climb gradient using section 2, formula 2-16. See section 2, paragraph 8.2.19 for Missed Approach Conventions.

c. **Missed Approach Section 1** (MAS-1). Section 1 begins at earliest MAP along-track tolerance (ATT) and extends to the start-of-climb (SOC), or the point where the aircraft is projected to cross 400 ft above airport/heliport elevation, whichever is the greatest distance from MAP. See figure 8-5-1b for MA segment point and line designations. Figure 8-5-2 depicts the Section 1/Section 2 (partial), OCS plan and profile view beginning at an altitude of MDA minus 100 ft plus adjustments (see section 4 for greater final segment detail).

Figure 8-5-1b: MAS Point/Line Identification

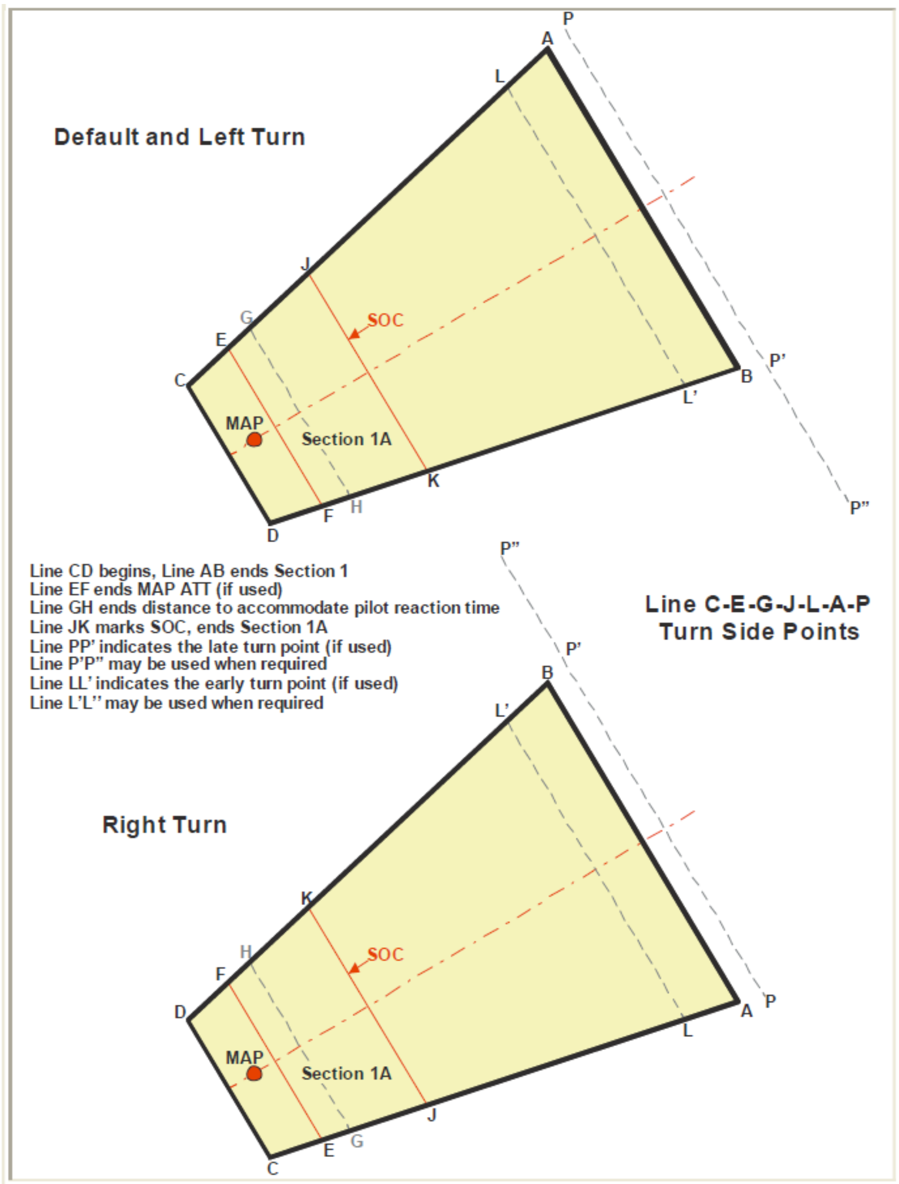
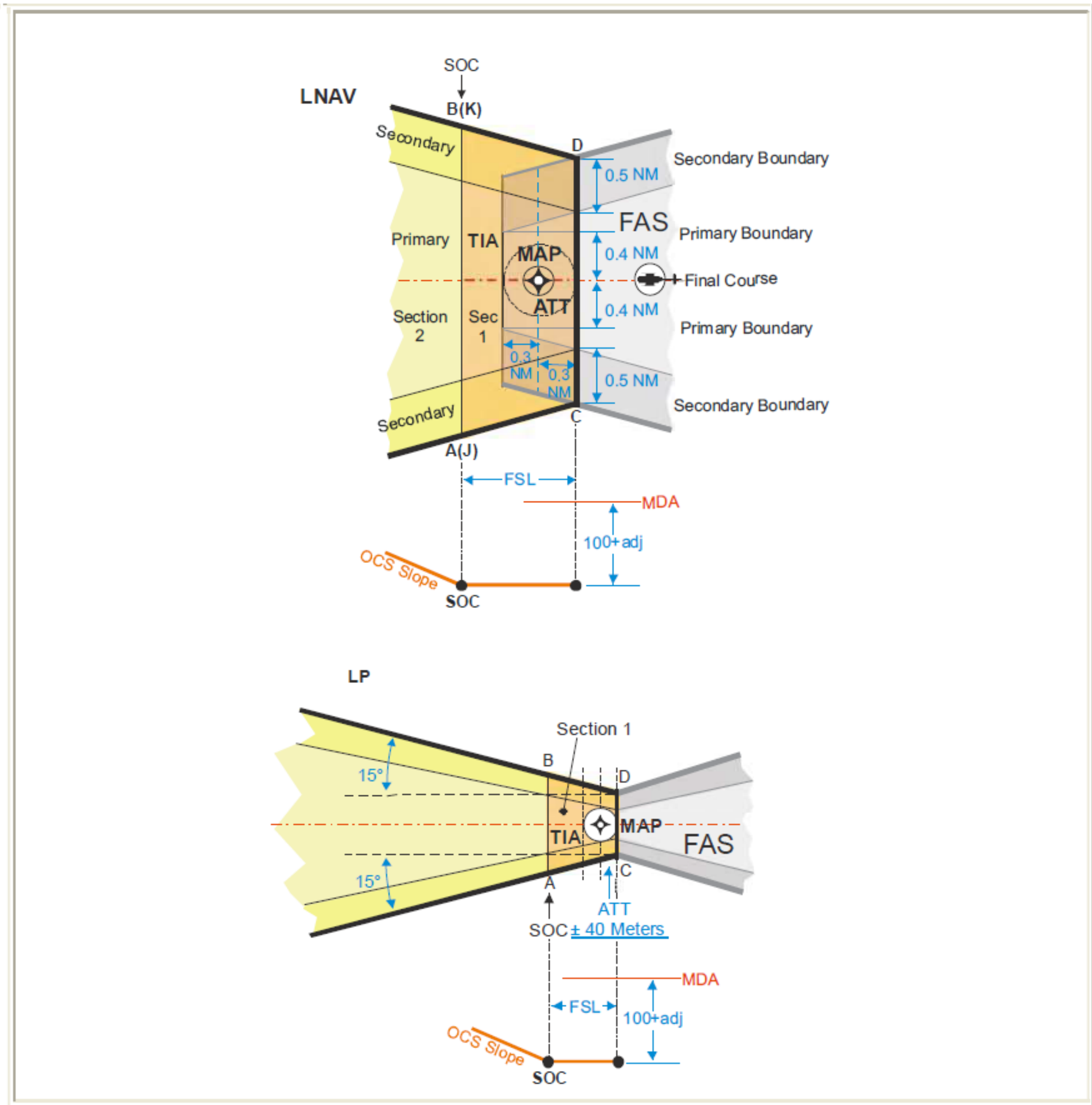


Figure 8-5-2: Missed Approach Section 1



(1) Length.

(a) Flat Surface Length (FSL).

1 LNAV. Section 1 flat surface begins at CD (0.3 NM prior to the MAP) and extends (distance FSL feet) to JK.

2 LP. Section 1 flat surface begins at CD [40 meters prior to the MAP] and extends (distance FSL feet) to JK.

Step 1: Calculate the FSL value using formula 5-1. Use section 4, final segment formulas 4-1a, (LNAV primary and total), and 4-12 (LP primary), and 4-13 (LP Secondary distance) to determine MAS starting widths.

Formula 5-1: Flat Surface Length (FSL)

$$FSL = 8 \cdot \frac{\frac{1852}{0.3048}}{3600} \cdot \left(\left(V_{KIAS} \cdot \frac{171233 \cdot \sqrt{(288+15) - 0.00198 \cdot MDA}}{(288 - 0.00198 \cdot MDA)^{2.628}} \right) + 10 \right) + 2 \cdot ATT$$

8*(1852/0.3048/3600)*((V_{KIAS}*(171233*((288+15)-0.00198*MDA)^0.5)/(288-0.00198*MDA)^2.628)+10)+2*ATT

Note: FSL time is 3 seconds reaction, and 5 seconds delay. “ATT” units will be in NM.

(2) Section 1 end location (AB).

(a) MDA ≥ 400 ft above airport/heliport elevation. Locate AB coincident with JK.

(b) MDA < 400 ft above airport/heliport elevation. Locate AB at $\frac{1852}{0.3048\ CG}$ feet beyond JK for each foot of altitude needed to reach 400 ft above airport/heliport/surface elevation. The surface between JK and AB is a rising slope commensurate with the standard rate of climb (400 ft/NM). Find the appropriate CG-related slope using section 2, formula 2-16.

(c) Required/assigned turning altitude > 400 ft above airport/heliport elevation. Locate AB and apply the surface described in section 5, paragraph 8.5.1.c(2)(b) until reaching the assigned turning altitude.

(3) Width. LNAV and LP.

(a) LNAV. Splay each secondary area outer boundary line outward 15 degrees relative to the missed approach course (MAC) from the secondary area outer edge at CD (0.3 NM prior to MAP) until it reaches a point 2 NM from MAC. Splay the primary area boundary uniformly outward from the primary area edge at CD to reach 1.5 NM from MAC at the same distance the secondary reaches full width. Calculate the distance from MAC to the MAS-1 OEA primary and outer secondary boundary at any distance from CD using formula 5-1a.

Calculate final primary and secondary widths at CD using section 4, final formula 4-1a.

(b) LP. Splay each secondary area outer boundary line outward 15 degrees relative to the MAC from the secondary area outer edge at CD (40 meters prior to MAP) until it reaches a point 2 NM from MAC. Splay the primary area boundary uniformly outward from the primary area edge at CD to reach 1.5 NM from MAC at the same distance the secondary reaches full width. Calculate the distance (ft) from MAC to the MAS-1 OEA primary and outer secondary boundary at any distance from CD using formula 5-1a. Calculate final primary and secondary widths at CD using section 4, final segment formulas 4-12 and 4-13.

Formula 5-1a: LNAV/LP Section 1 Primary & Secondary Width

$$\mathbf{MAS_{Yprimary}} = \mathbf{d} \cdot \frac{\tan(15°)\cdot\left(1.5\cdot\frac{1852}{0.348} - W_p\right)}{2\cdot\frac{1852}{0.348} - W_s} + W_p$$

$$\mathbf{MAS_{Ysecondary}} = \mathbf{d} \cdot \tan(15°) + W_s$$

Where:

d = along-track distance (ft) from the CD line ≤ 45352.743

W_p = Primary Start Half Width (ft) (final formula)

W_s = Secondary Start Width (ft) (final formula)

(4) Obstacle Clearance Section 1.

(a) The nominal MAS-1 OCS is a flat surface. The MSL surface height (HMAS) is equal to the MDA minus 100 ft plus adjustments (see formula 5-1b). No obstacle may penetrate this surface.

(b) Where Section 1 extends beyond SOC (JK), no obstacle may penetrate the CG-associated OCS slope between SOC and AB. Find helicopter altitude at AB using formula 5-1c.

Formula 5-1b: HMAS

$$\text{HMAS} = \text{MDA} - (100 + \text{adj})$$

Where:

adj = precipitous terrain, remote altimeter (only if full time), and excessive length of final adjustments

MDA-(100+adj)

Formula 5-1c: Section 1 End Helicopter Altitude ($Copter_{AB}$)

$$Copter_{AB} = (r + MDA\ or\ DA) \cdot e^{\frac{AB_{NM} \cdot CG}{r}} - r$$

Where:

AB_{NM} = SOC to AB distance (NM)
CG = applied climb gradient (ft/NM)

(r+(MDA or DA))*e^((AB$_{NM}$*CG)/r)-r

d. These criteria cover two basic MA constructions:

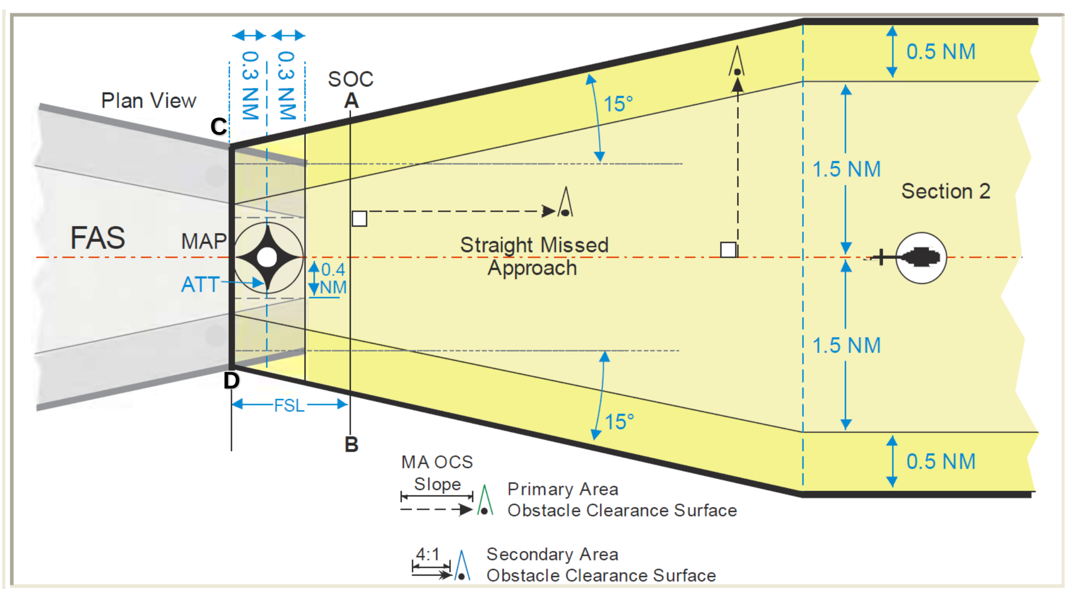
- Straight missed approach; and
- Turning missed approach.

Note: These construction methods accommodate traditional combination straight and turning missed approaches.

(1) The section 2 obstacle evaluation area (OEA) splays 15 degrees relative to the nominal track to reach full width (see figure 8-5-3). The OEA ends at the MA Holding Fix (MAHF) latest ATT. Apply the Section 2 standard MA OCS slope beginning from AB. Calculate MA OCS slope values using section 2, formula 2-15.

Note: All references to ‘standard MA OCS slope’ and/or use of ‘20:1’ refer to section 2, formula 2-16 output, with an input climb gradient (CG) of 400 ft/NM.

Figure 8-5-3: Straight Missed Approach



(2) Where a higher than standard CG (400 ft/NM) is required, apply the CG and the CG-related OCS from the SOC. Apply secondary areas as specified in this section. Measure the 4:1 secondary OCS perpendicular to the nominal track,

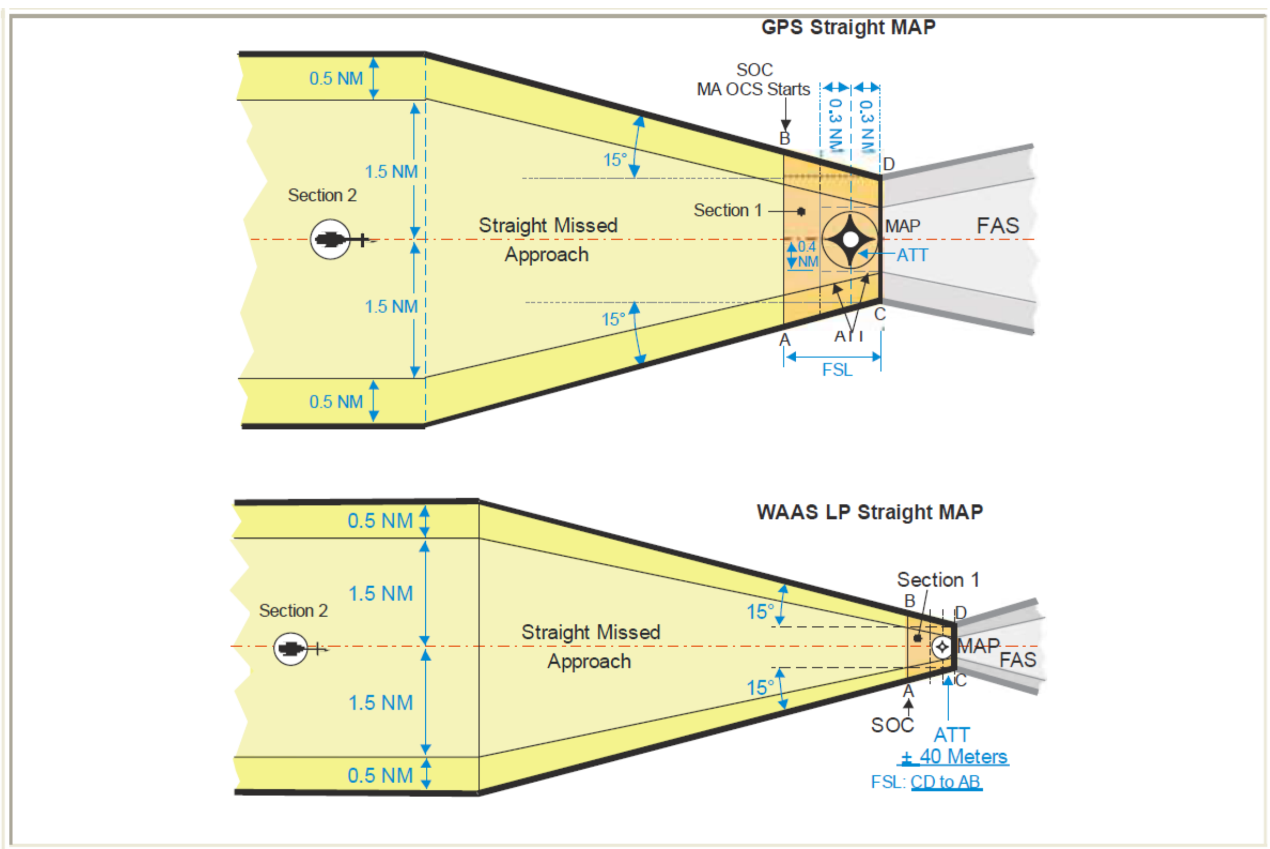
measured from the primary boundary, or perpendicular to the primary boundary when considering arcs, diagonal corner-cutters, etc.

(3) Locate the MAHF within 25 NM of the ARP/ HGC. Determine minimum leg length for course changes following the first fix after the MAP using the greater distance from section 2, formulas 2-6, 2-7, and 2-9a, climb distance required, and section 3, table 8-3-1.

(4) Design MA holding for 90 KIAS, or the appropriate restricted speed.

8.5.2. **Straight Missed Approach.** The straight missed approach course (MAC) is a continuation of the final approach course (FAC). The straight MA section 2 OEA begins at section 1 end (AB) and splays at 15 degrees relative to the nominal track until reaching full primary and secondary width (0.5-1.5-1.5-0.5). Apply the section 2 standard OCS, or the OCS associated with a higher CG, beginning at AB from the section 1 end OCS elevation. (When the increased CG is no longer required, revert to the section 2 standard OCS). Determine primary OCS elevation at an obstacle by measuring the along-track distance from AB to a point at/abeam the obstacle. Where the obstacle is located in the secondary area, apply the primary OCS slope to a point abeam the obstacle, then apply the 4:1 secondary slope (perpendicular to the track) from the primary boundary to the obstacle (see section 5, figures 8-5-3, 8-5-4).

Figure 8-5-4: Straight Missed Approach (GPS/LNAV / LP)



8.5.3. **Turning Missed Approach.** Apply turning criteria when requiring a turn at or beyond SOC. Where secondary areas exist in section 1, they continue to full width in section 2. Terminate turn-at-fix turn-side secondary areas not later than the early turn point. Do not apply turn-side secondary areas for turn-at-altitude construction. The terms 'inside turn' and 'outside turn' are used to reduce verbiage in describing turn associated construction and relationships. Where required, alternate construction steps (indicated by Step #ALT) are provided to supplement or replace the primary step.

There are two types of turn construction for the first MA turn:

- Turn at an altitude (see section 5, paragraph 8.5.3.a):
  - Always followed by a DF leg ending with a DF/TF connection

- Turn at a fix (see section 5, paragraph 8.5.3.b):
  - Always followed by a TF leg ending with a TF/TF connection.
  - May be followed by an RF leg (which requires advanced avionics) when the initial straight leg has reached full width, ending with an RF/TF or RF/RF connection. RF turn initial fix must be located where the aircraft is at least 500 ft above airport elevation.

Following a turn, the minimum segment length must be the greater of:

- The minimum length calculated using section 2, formulas 2-6, 2-7 and 2-9a.

- The distance from previous fix to the intersection of the 30-degree converging outer boundary line extension and the nominal track, (plus segment end fix DTA).

Minimum DF leg length must accommodate 6 seconds (minimum) of flight time based on either 70 KIAS or 90 KIAS, as appropriate, applied between the wind spiral (WS)/direct-to-fix-line tangent point, and the earliest manoeuvring point of the DF/TF fix. Convert to TAS using section 2, formula 2-3a and the MAHF altitude.

a. **Turn at an Altitude.** Apply turn-at-an-altitude construction unless the first MA turn is at a fix. Since pilots may commence the MA at altitudes higher than the MDA and helicopter climb rates differ, turn-at-an-altitude construction protects the large area where turn initiation is expected. This construction also provides protection for 'turn as soon as practicable' and combination straight and turning operations. When a required turning altitude exceeds the minimum turning altitude (400 ft above the airport, heliport, or height above surface), specify the turning altitude in a 100-ft increment. Where operationally required, 20-ft increments may be applied.

Note: 'Turn as soon as practicable' includes, but is not limited to operational suitability, flight characteristics/capability, appropriate altitude, positioned at or beyond the MA early ATT, as well as the feasibility, workability, and viability of the intended maneuver.

Track guidance is assumed throughout the operation; therefore, dead reckoning (DR) segments are not considered. Apply turning MA criteria whenever the MAC differs from the FAC. The following applies:

- Section 1/Section 2 connection is depicted in section 5, figure 8-5-5 for a minimum altitude turn-at-altitude MA. The CD is the earliest the MAP can be received. AB is the SOC (section 5, figure 8-5-6 depicts higher than minimum altitude turns).

Figure 8-5-5: Turn at Altitude Missed Approach, ≤ 75° (Minimum Turning Altitude)

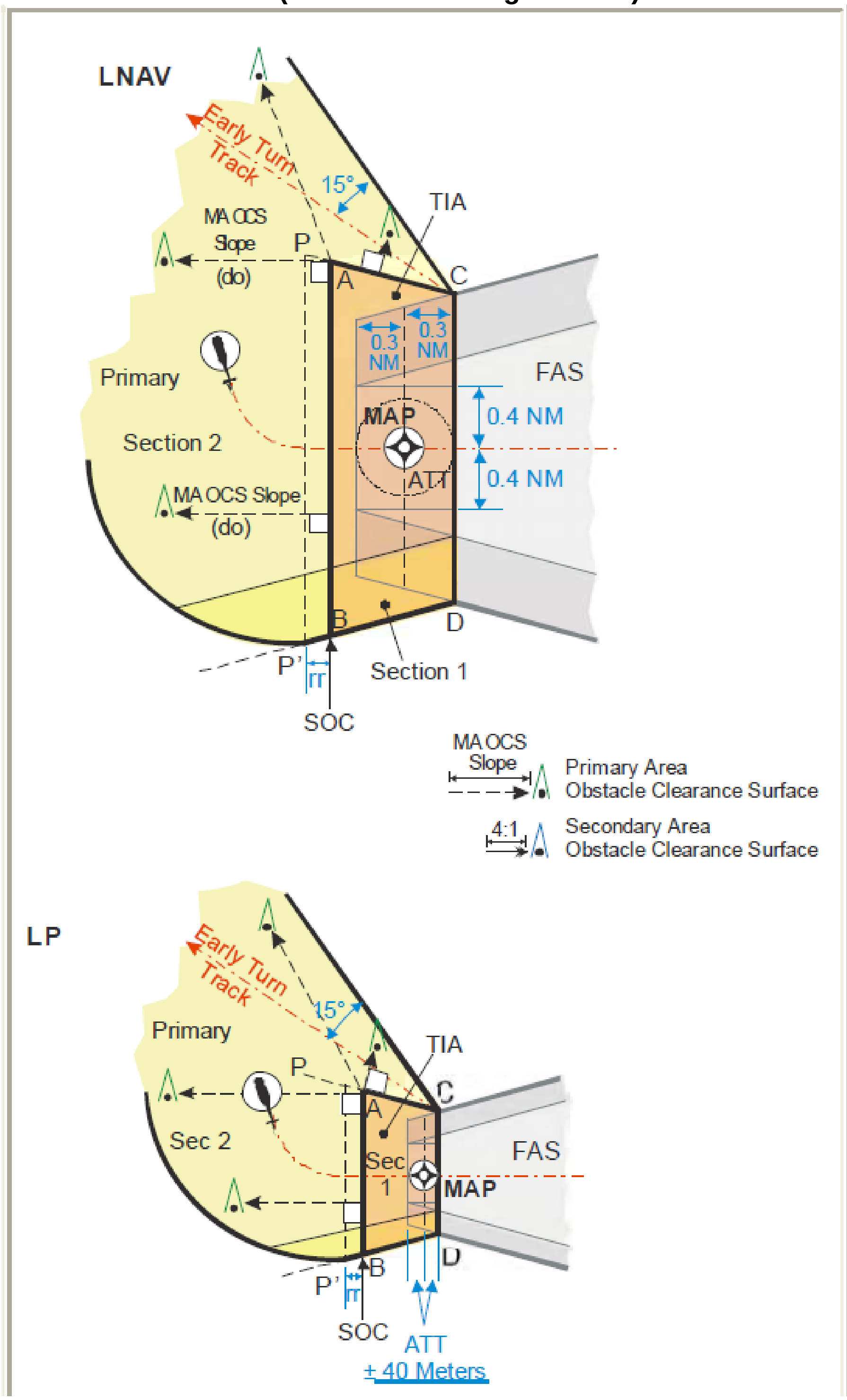
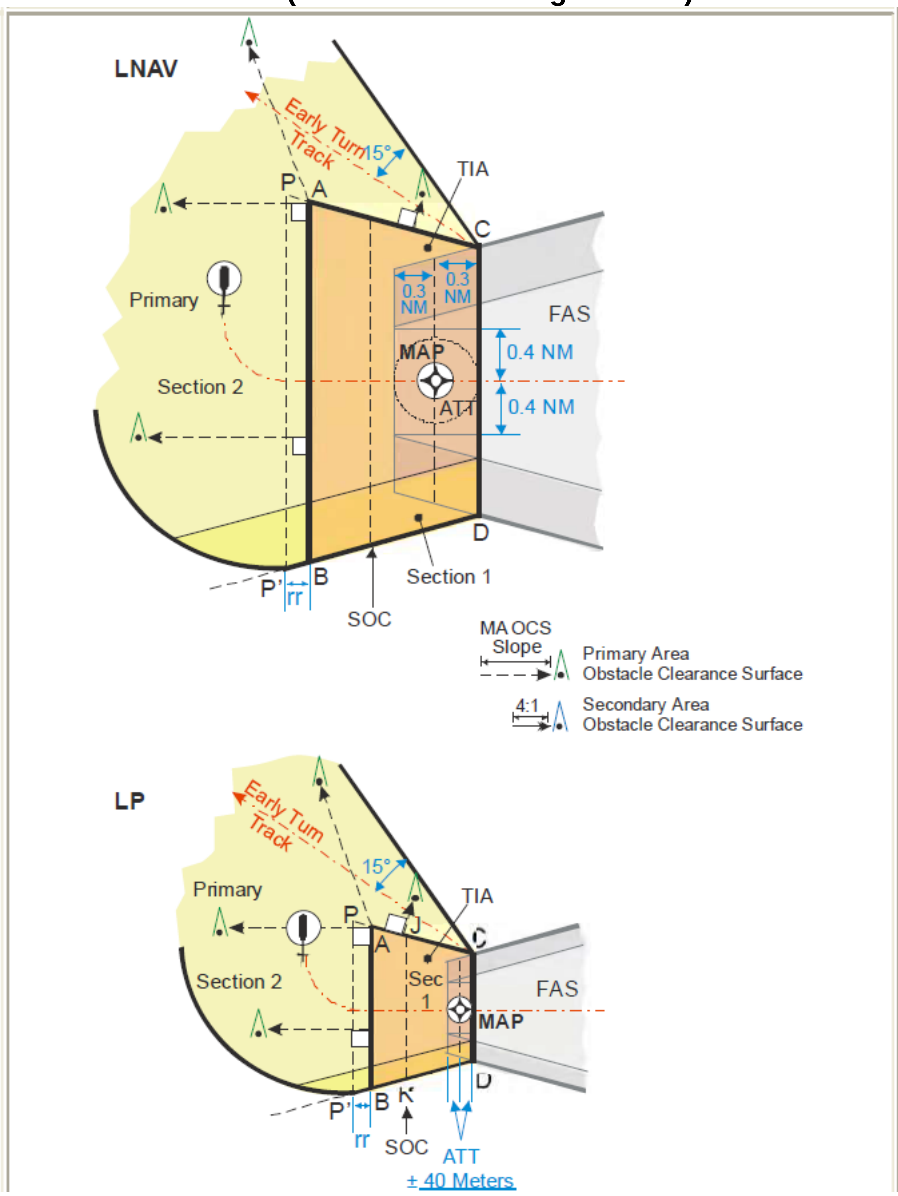


Figure 8-5-6: Turn at Altitude Missed Approach, ≤ 75° (> Minimum Turning Altitude)



- Section 2 and section 1 connect at AB.
- Construct section 2 outside-turn boundaries using WS vice specified radii. Construct outside boundaries in relation to these WS and late turn track (see section 5, figures 8-5-9, 8-5-13, 8-5-15).
- Construct inside-turn boundaries in relation to the early turn track (see section 5, figures 8-5-5, 8-5-6).

- Apply the standard OCS slope (or the assigned CG-associated slope) beginning at AB at AB OCS height. The secondary 4:1 surface rises from the primary OCS.

(1) Turn Initiation Area (TIA). Construct the TIA, a portion of a straight MA, beginning from the earliest MA turn point (CD), and ending where the specified minimum turning altitude is reached, (AB or LL’). Base the TIA length on the climb distance required to reach the turning altitude. The TIA minimum length must place the aircraft at an altitude from which obstacle clearance is provided in section 2 outside the TIA. The TIA boundary varies with length, the shortest B-A-C-D, where AB overlies JK. Where the TIA is contained within section 1, B-A-J-C-D-K defines the boundary. Where the required turn altitude exceeds that supported by section 1, the TIA extends into section 2, (see figure 8-5-8 and FAA 8260.58 publication for construction examples) and points L’-L-A-J-C-D-K-B define its boundary. In this case, L-L’ is the early turn point based on the helicopter climbing at the prescribed CG. Calculate TIA length using section 5, formula 5-2a. A 4:1 secondary is depicted on the non-turning side of the primary (see section 5, figures 8-5-6, 8-5-8, and 8-5-9).

Figure 8-5-7: Turn at Altitude Missed Approach, > 75˚ (Minimum Turn Altitude)

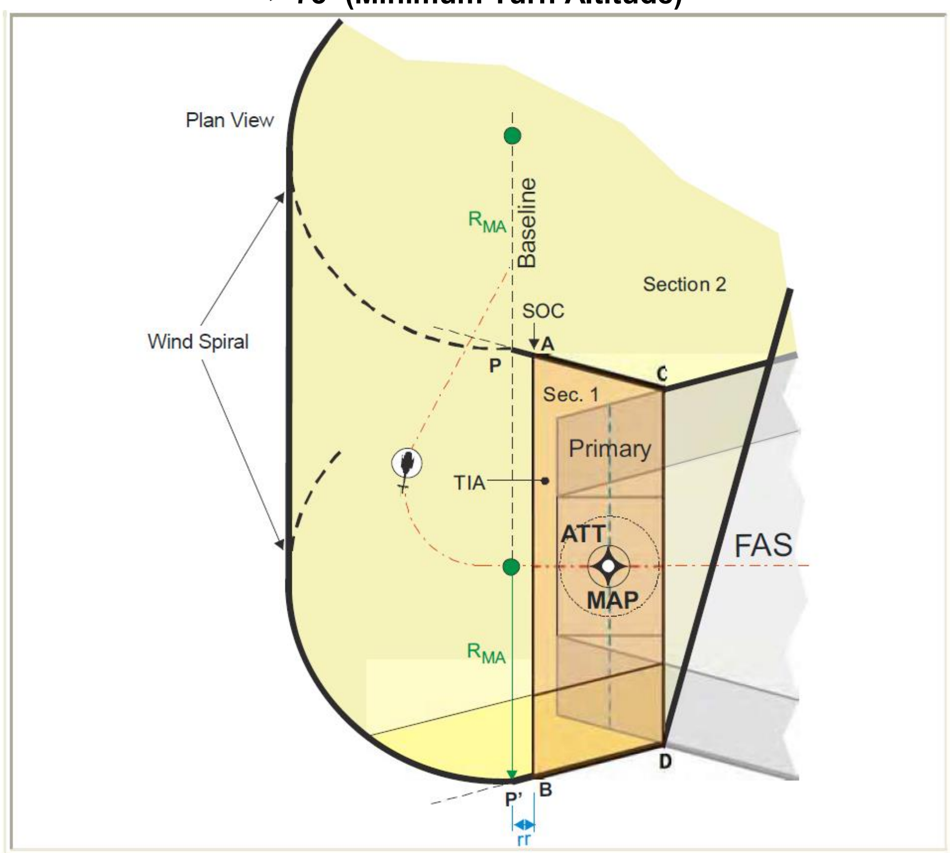
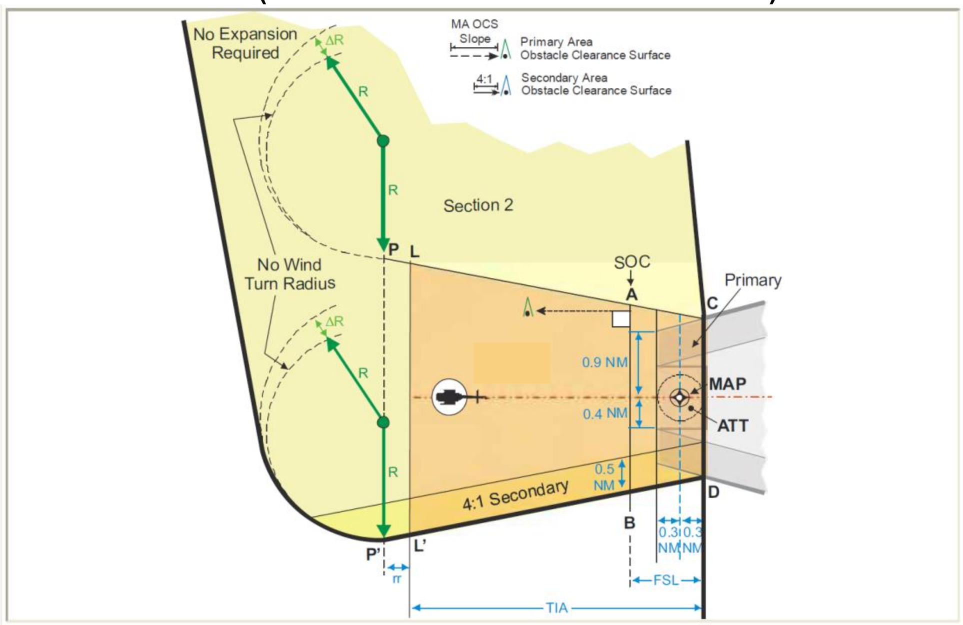


**Figure 8-5-8: Turn at Altitude Missed Approach,
≤ 75˚ (Greater than Minimum Turn Altitude)**



Step 1: Turn altitude. The turn altitude is either operationally specified (must be at or above altitude required by obstacles) or determined by obstacle evaluation. Evaluate the nominal OCS. If the OCS is penetrated, mitigate the penetration with one or a combination of the following:

- Raise MDA.
- Establish a climb gradient that clears the obstacle.
- Move MAP.
- If the penetration is outside the TIA, consider raising the climb-to altitude.

(a) Determine the helicopter required minimum turning altitude:

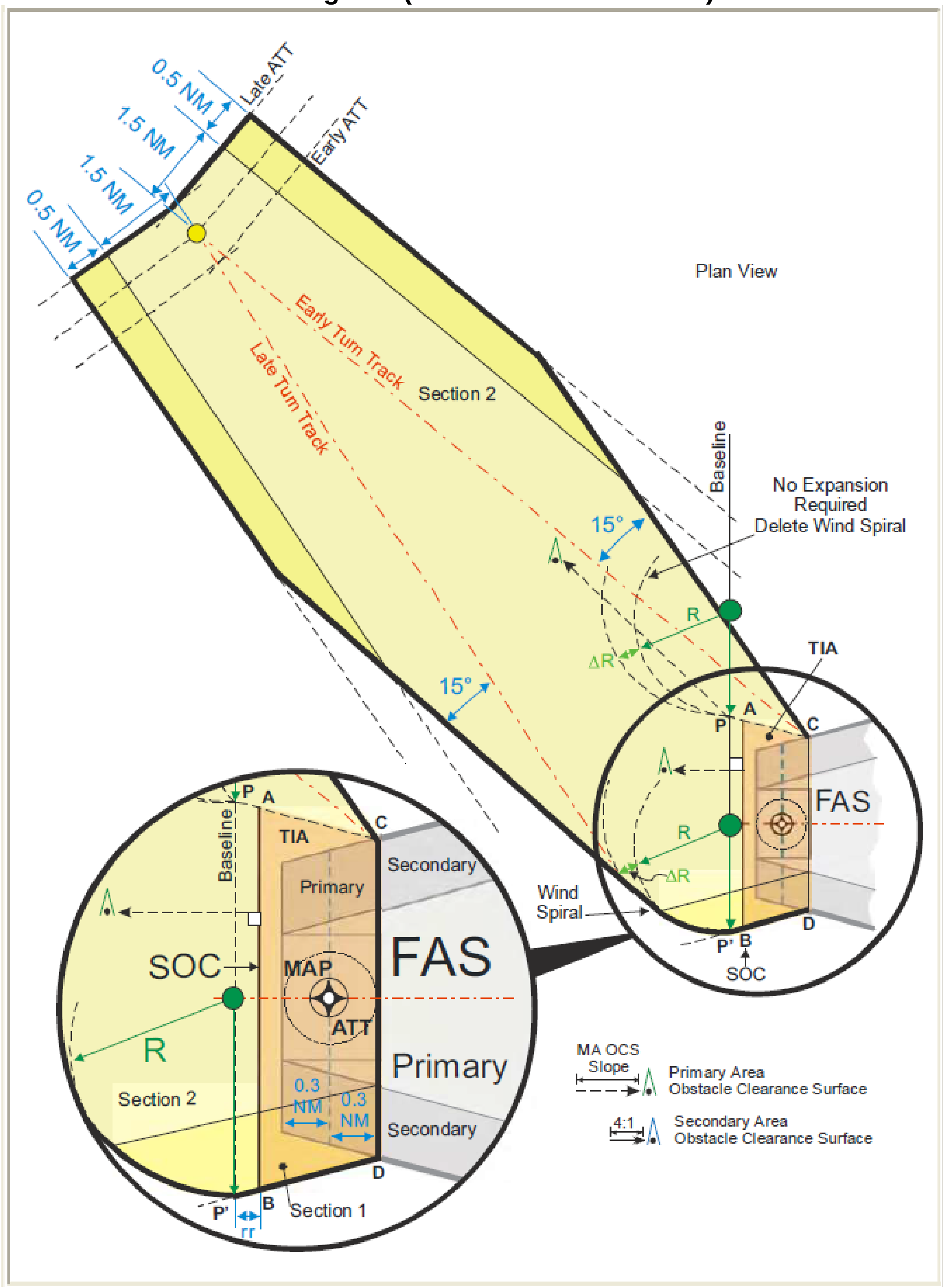
- Identify the controlling obstacle in section 2 (straight MA).
  - For straight OCS/CG/length options.
- Identify the controlling obstacle in section 2, (typically turn-side).
- Find the shortest distance from the TIA lateral boundary to the obstacle.
- Apply this distance and the MA OCS slope to find the TIA-to-obstacle OCS rise.
- The minimum TIA boundary, (and OCS end elevation) equals the obstacle elevation minus OCS rise.
- The minimum turn altitude is the sum of (TIA OCS boundary elevation) and (final ROC), rounded to the next higher 100 ft-increment (where operationally required, 20-ft increments may be applied).

Note 1: TIA lateral boundary is the straight segment (portion) lateral boundary until the required minimum turn altitude and TIA length are established.

Note 2: Repeat Step 1 until acceptable results are obtained.

The specified altitude must equal or exceed the section 1 end altitude. Find section 1 end altitude using section 5, formula 5-1c or formula 5-2a for $\mathrm{TIA}_{\mathrm{lenght}}$.

Figure 8-5-9: Turn at Altitude Missed Approach, ≤ 75 Degrees (Minimum Turn Altitude)



Step 2: Calculate TIA length (ft) using section 5, formula 5-2a (see section 5, figures 8-5-6 and 8-5-8).

Formula 5-2a: $\mathrm{TIA}_{\mathrm{length}}$

$$TIA_{length} = FSL \cdot \frac{r}{(r + MDA)} + \frac{r}{CG} \cdot \frac{1852}{0.3048} \cdot \ln\left(\frac{r + turn_{alt}}{r + MDA}\right)$$

Where MDA = Final MDA
CG = Climb Gradient (Standard 400 ft/NM)
$turn_{alt}$ = required turn altitude

FSL*r/(r+MDA)+r/CG*1852/0.3048*ln((r+$turn_{alt}$)/(r+MDA))

Step 3: Locate the TIA end at a distance $\mathrm{TIA}_{\mathrm{length}}$ beyond CD (from Step 2) (LL') where the applied OCS reaches the required TIA end surface elevation (from Step 1).

Step 4: Locate the latest turn point, (PP') at distance rr (from section 2, formula 2-4a) beyond the TIA end (AB/LL'). See example section 5, figures 8-5-6 and 8-5-8.

(2) OEA Construction after TIA. The OEA includes areas to protect the earliest and latest direct tracks from the TIA to the fix. Construct the obstacle areas about each of the tracks as described below. See section 5, figures 8-5-9 through 8-5-15 for various turn geometry construction illustrations.

(a) Early Turn Track and OEA Construction. Where the early turn track from the FAC/CD intersection defines a turn less than or equal to 75 degrees relative to the FAC, the tie-back point is C (see section 5, figure 8-5-5); if the early track defines a turn greater than 75 degrees relative to the FAC, tie-back to point D (see section 5, figure 8-5-7). Where the early track represents a turn greater than 165 degrees (see section 5, figures 8-5-12 and 8-5-15), begin the early turn track and the 15-degree splay from the non-turn side TIA end + rr (section 2, formula 2-4a) (PP').

Step 1: Construct a line (defines the earliest-turn flight track), from the tieback point to the fix. See section 5, figures 8-5-9, 8-5-10, 8-5-14, and 8-5-15.

Step 2: Construct the outer primary and secondary OEA boundary lines parallel to this line (0.5-1.5-1.5-0.5 segment width). See section 5, figures 8-5-9 and 8-5-10.

Step 3: From the tie-back point, construct a line splaying at 15 degrees to intersect the parallel boundary lines or segment end, whichever occurs earlier (see section 5, figures 8-5-9 and 8-5-10).

Note: Apply secondary areas only after the 15-degree splay line intersects the primary boundary line (see section 5, figures 8-5-9, 8-5-10, 8-5-13, etc).

Step 3Alt: Where Step 3 construction provides less than full-width protection at the DF fix, construct the OEA inner boundary with a line splaying from the tieback point at 15 degrees relative the direct-to-fix line, (or greater where required to provide full-width protection at the DF fix), until it intersects the parallel boundary lines (not later than tangent/tangent-extension to the full-width-arc about the fix), and provides full-width protection at or before the DF fix. DF secondary areas begin/exist only where full width primary exists. See section 5, figures 8-5-10, 8-5-14, and 8-5-15.

Note: Where excessive splay results (dependent upon various conditions but generally in the 20-25 degree range), consider modifying the segment to avoid protection and/or construction difficulties.

Figure 8-5-10: Turn at Altitude Missed Approach, > 75 degrees (Minimum Turn Altitude)

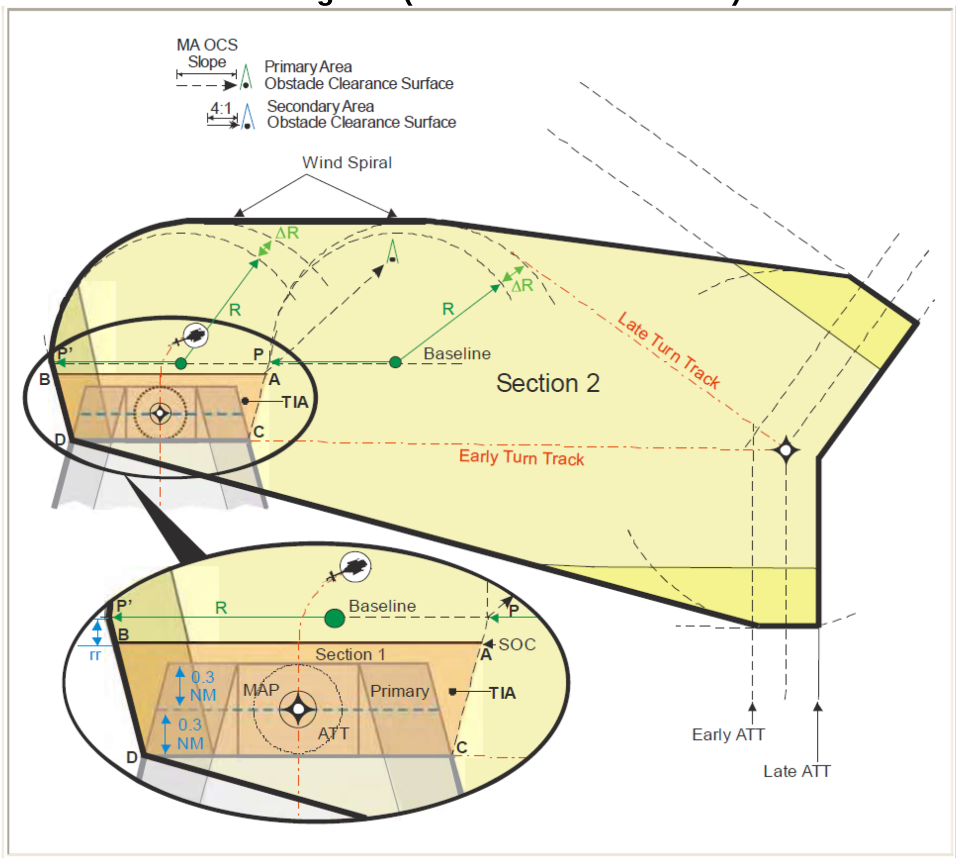


Figure 8-5-11: 70 KIAS Missed Approach Segment, > 75 degrees, ≤ 165 degrees (Minimum Turn Altitude) 2 WS

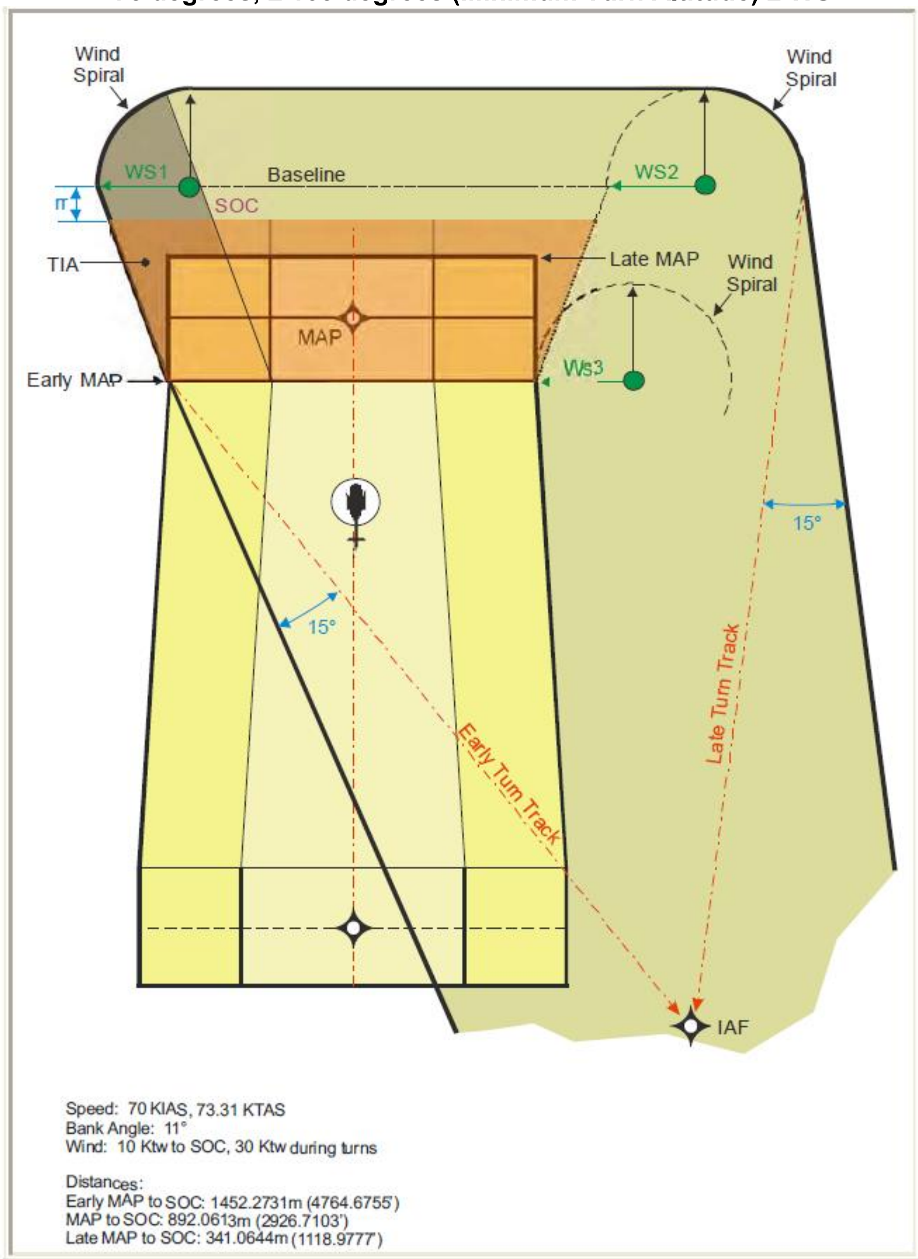


Figure 8-5-12: 90 KIAS Missed Approach Segment, > 165 degrees (Minimum Turn Altitude) 3 WS

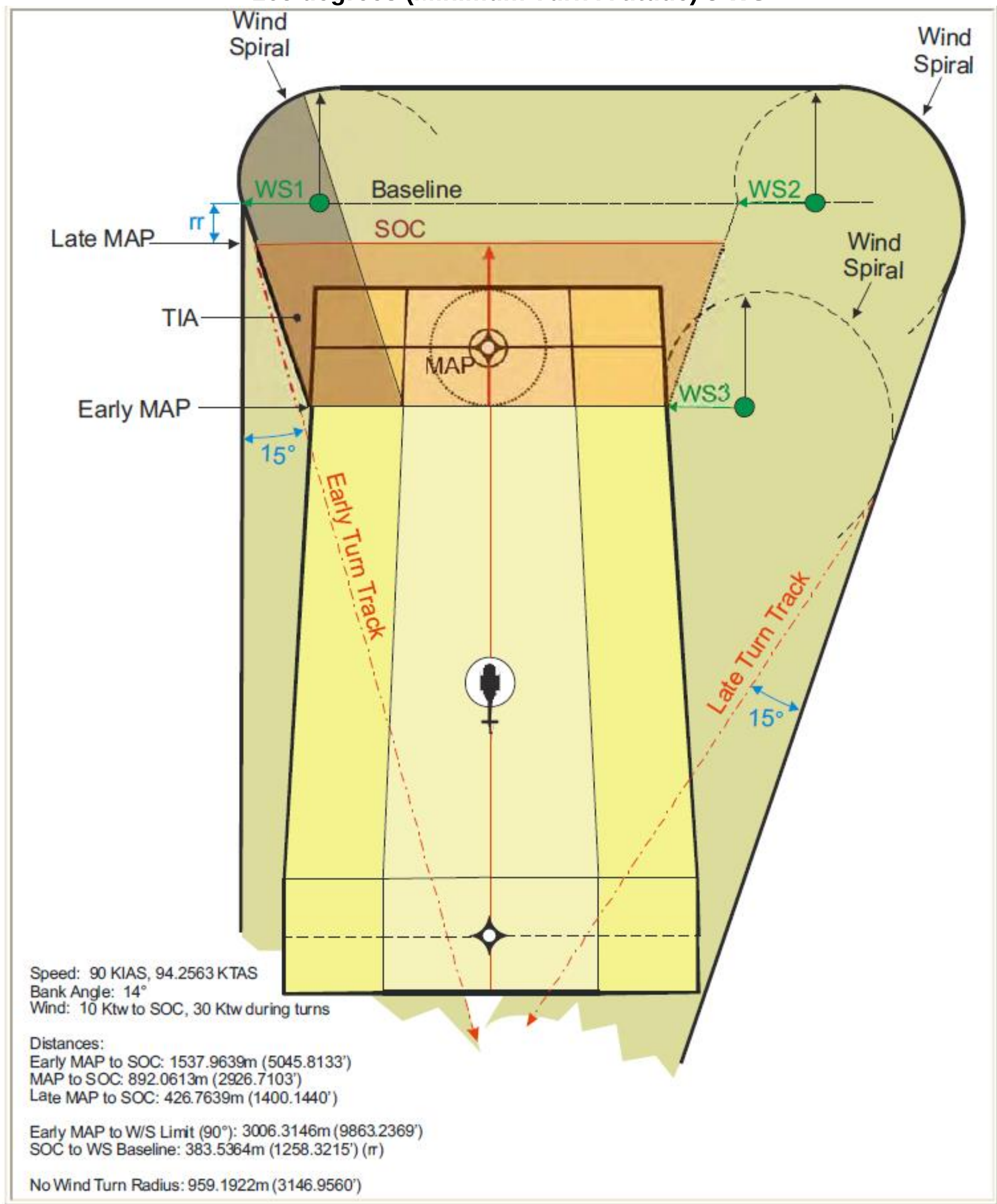


Figure 8-5-13: Direct to Fix Segment Following a TIA completion ≤ 75 Degrees (One WS)

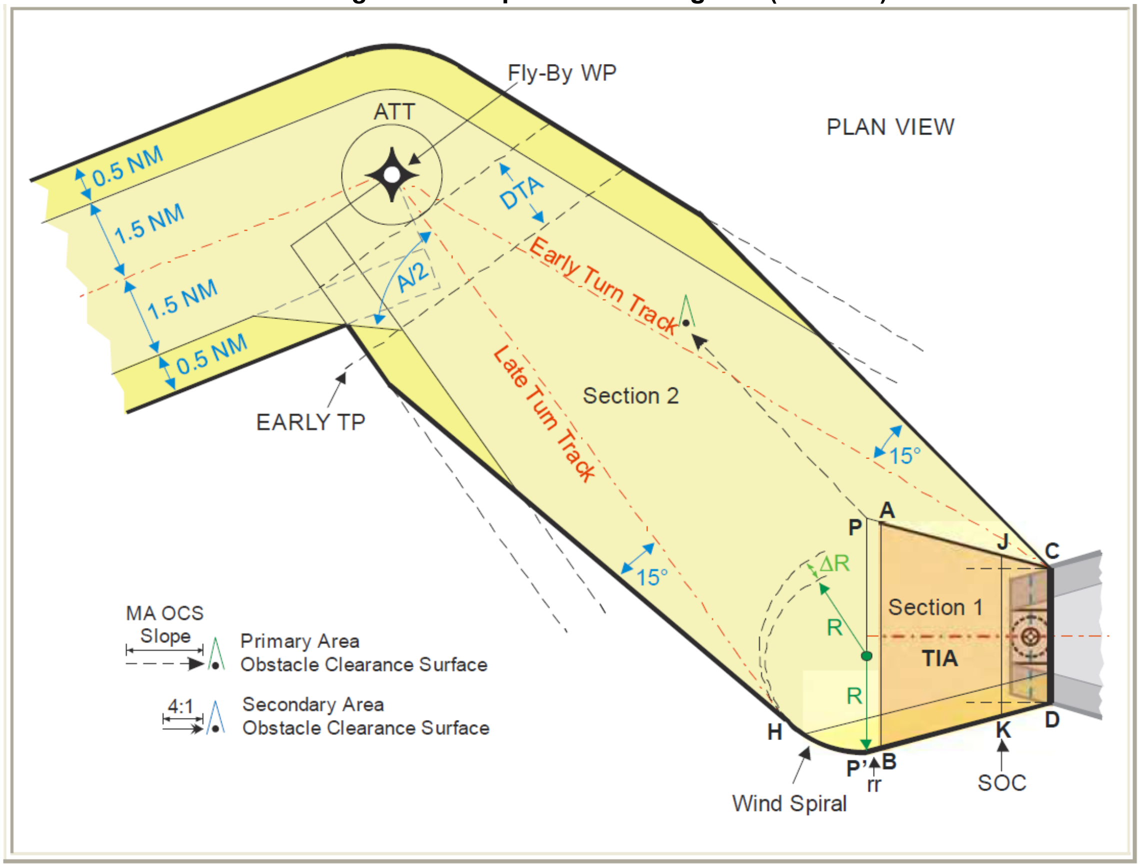


Figure 8-5-14: Direct to Fix Segment
Following a TIA completion >75 degrees (Two WS)

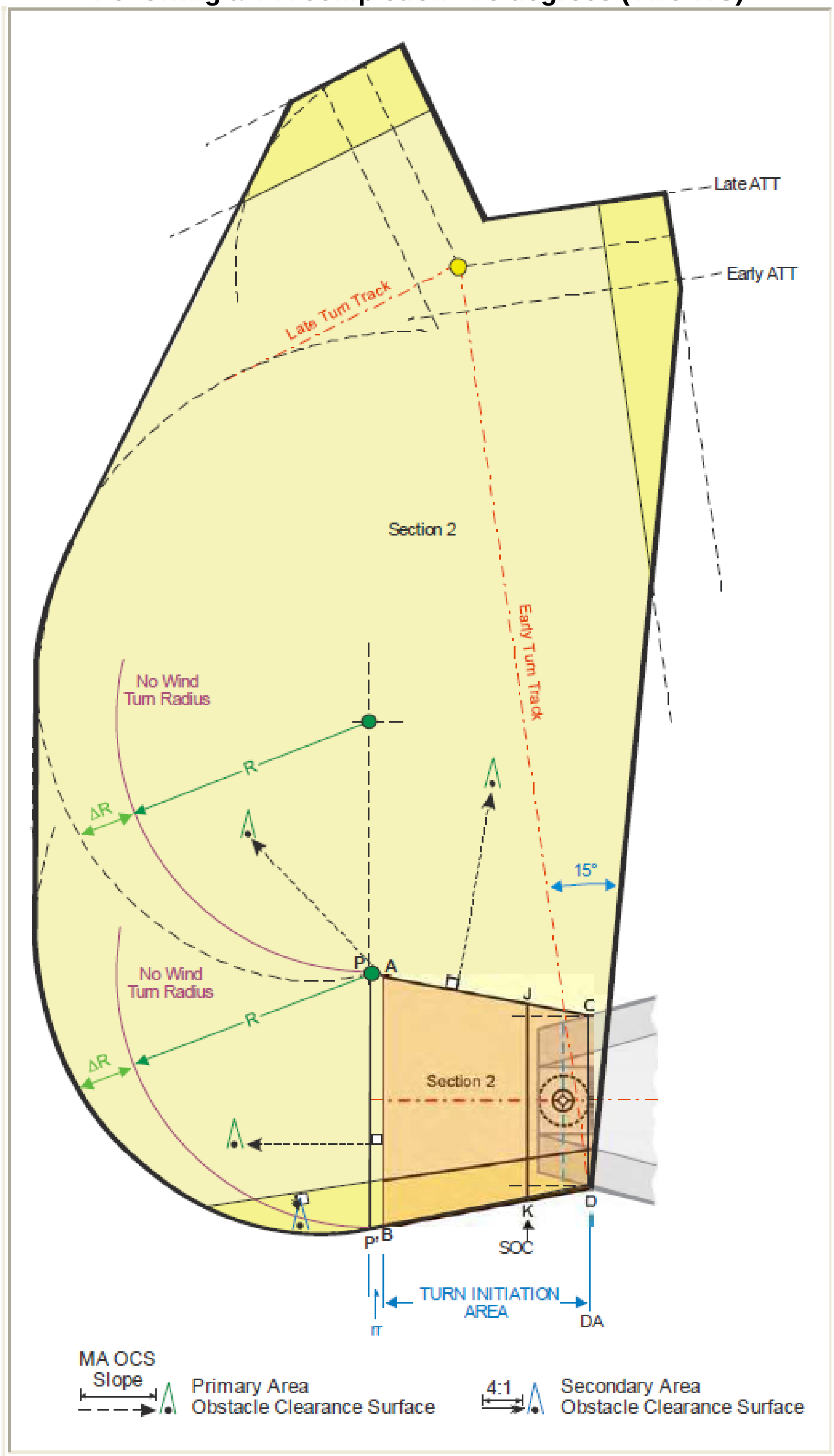
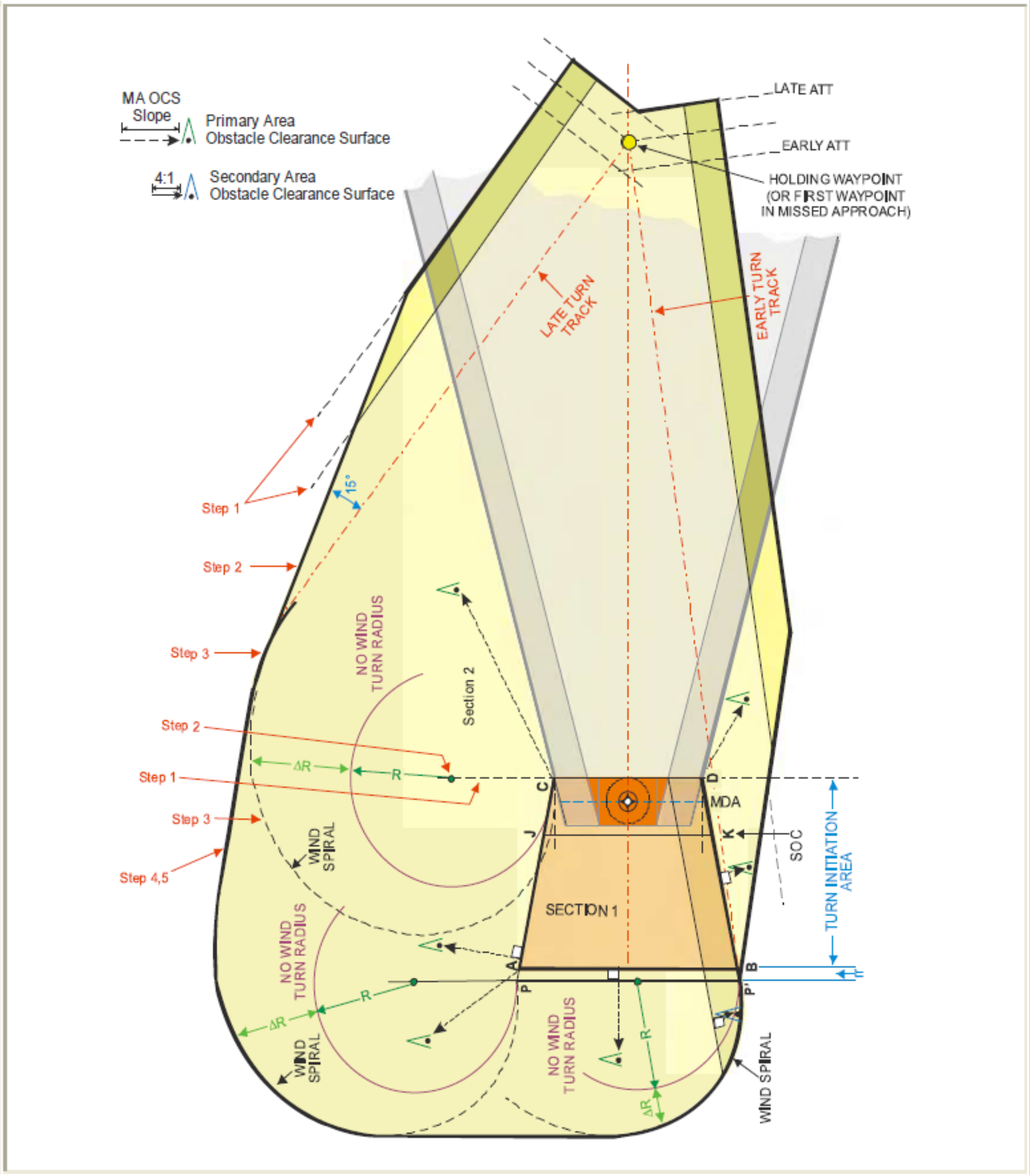


Figure 8-5-15: Direct to Fix Segment
Following a TIA completion > 165 degrees 3 WS



(b) Late Turn Track and OEA Construction. Apply WSs for late-turn outer boundary construction using the following calculations, construction techniques, and bank angles of 11 degrees or 14 degrees, as appropriate.

Step 1: Find the no-wind turn radius (R) using section 5, formula 5-2b.

Formula 5-2b: No-Wind Turn Radius (R)

$$R = \frac{(V_{KTAS} + 0)^2}{\tan(Bank_{angle}) \cdot 68625.4}$$

Where:

V_{KTAS} = True Airspeed, formula 2-3a

$Bank_{ANGLE}$ = Table 2-4 value

Note: Apply the appropriate indicated airspeed and minimum assigned turn altitude when converting to true airspeed for this application.

Step 2: Calculate the Turn Rate (TR) using section 5, formula 5-2c. Maximum TR is 3 degrees per second.

Formula 5-2c: Turn Rate (TR)

$$TR = \frac{3431 \cdot \tan(Bank_{angle})}{\pi \cdot V_{KTAS}}$$

Where:

$Bank_{ANGLE}$ = Table 2-4

V_{KTAS} = Formula 2-3a

Step 2a: Calculate the Turn Magnitude ($Turn_{Magnitude}$) using the appropriate nowind turn radius and the arc distance (degrees) from turn start (at PP') to the point of tangency with a line direct to the fix.

Step 2b: Calculate the highest altitude in the turn using section 5, formula 5-2d (MAHF altitude may be used). Determine subsequent fix altitudes using fix-to-fix direct measurement and 400 ft/NM, (or higher assigned) climb rate.

Formula 5-2d: Highest Altitude Gained ($Total_{ALT}$)

$$HighestTurn = MDA_{ALT} + (2R \cdot \pi \cdot \frac{Turn_{Magnitude}}{360} \cdot CG)$$

Where:

MDA_{ALT} = Procedure MDA

R = No-wind turn radius (NM), Formula 5-2b

$Turn_{Magnitude}$ = Turn start to rollout (deg)

CG = Standard 400 ft/NM

$MDA_{ALT}+(2*R*\pi*Turn_{Magnitude}/360*CG)$

Step 3: Find the omni-directional wind component (V_{KTW}) for the highest altitude in the turn applying section 2, paragraph 8.2.11.

Step 4: Apply this common wind value (**Step 3**) to all first-turn wind spirals.

Note: Apply 30 knots for turn altitudes ≤ 2,000 ft above heliport/airport elevation.

Step 5: Calculate the wind spiral radius increase (∆R) (relative R), for a given turn magnitude (ϕ) using section 5, formulas 5-2c and 5-2e.

Formula 5-2e: Wind Spiral (WS) Radius Increase (∆R)

$$\Delta R = \frac{V_{KTW} \cdot \phi}{3600 \cdot TR}$$

Where:

V_{KTW} = Windspeed, formula 2-3b

ϕ = Degrees of turn

TR = Turn Rate, formula 5-2c

$(V_{KTW} * \phi)/(3600 * TR)$

b. **Turn-At-A-Fix.** The first MA turn-at-a-fix may be a fly-by or fly-over fix. Use fly-by unless a fly-over is required for obstacle avoidance or where mandated by specific operational requirements. The turn fix early-turn-point must be at or beyond section 1 end.

(1) Early/Late Turn Points.

(a) The fly-by fix early-turn-point is located at (FIX-ATT-DTA) prior to the fix.

(b) The fly-by fix late-turn-point is located at a distance (FIX + ATT – DTA + rr) from the fix.

Fly-by fixes (see section 5, figure 8-5-16).

$Early_{TP}$ = Fix - ATT - DTA

$Late_{TP}$ = Fix + ATT - DTA + rr

(c) The fly-over early-turn-point is located at a distance (FIX - ATT) prior to the fix.

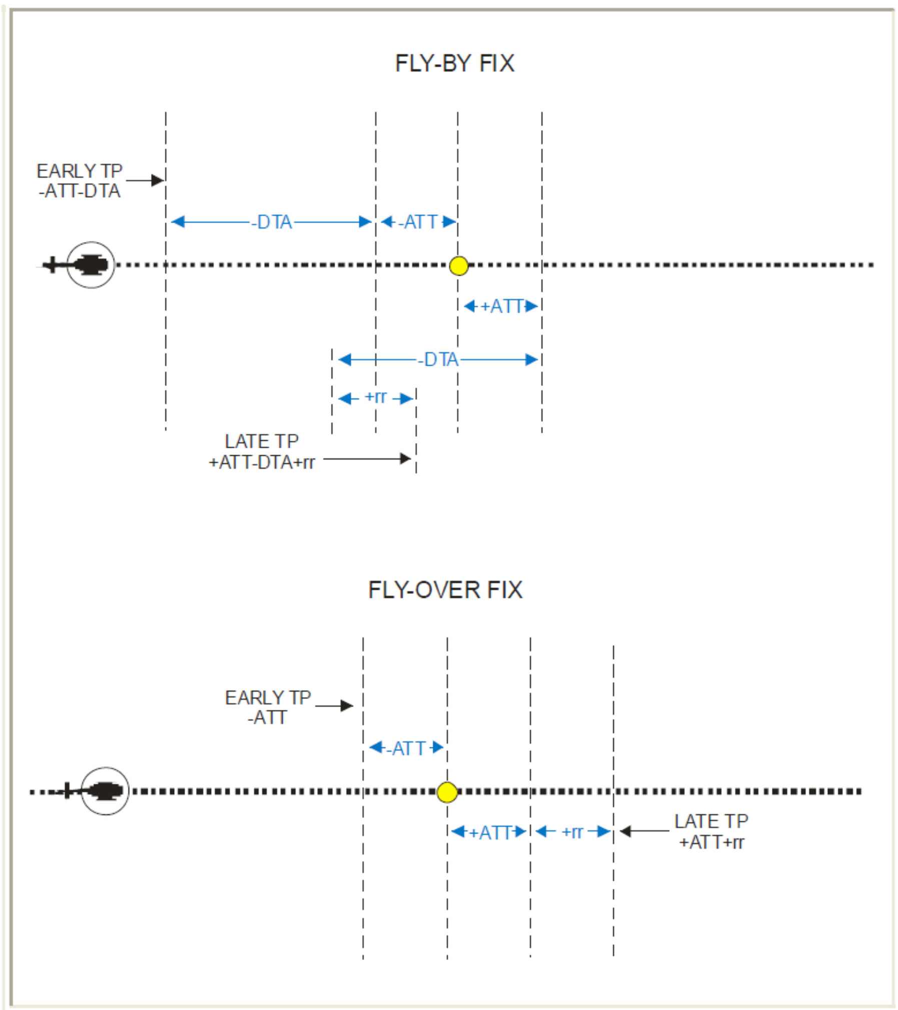
(d) The fly-over late-turn-point is located at a distance (FIX + ATT + rr) beyond the fix.

Fly-over fixes (see section 5, figure 8-5-16).

$Early_{TP}$ = Fix - ATT

$Late_{TP}$ = Fix + ATT + rr

Figure 8-5-16: Fly-Over/Fly-By Diagrams



(2) Turn-at-a-fix. (First MA turn) Construction. The recommended maximum turn is 70 degrees; the absolute maximum is 90 degrees. The first turn fix must be located on the final approach track extended.

Step 1: Calculate aircraft altitude at AB using section 5, formula 5-1c.

Step 2: Calculate fix distance based on minimum fix altitude. Where the first fix must be located at the point the helicopter reaches or exceeds a specific altitude, apply section 5, formula 5-2f (using the assigned/applied CG), to calculate fix distance (D_{fix}) (NM) from SOC (AB/JK) (see section 5, figures 8-5-17 through 8-5-20).

Formula 5-2f. Fix Distance (D_{fix})

$$D_{fix} = \ln\left(\frac{Minalt_{fix} + r}{Copter_{SOC} + r}\right) \cdot \frac{r}{CG}$$

Where:

$Minalt_{fix}$ = Minimum altitude required at fix
$Copter_{SOC}$ = Copter AB (SOC) altitude
CG = Climb Gradient (Standard 400 ft/NM)

ln((Minaltfix+r)/(Copter$_{soc}$+r))*r/CG

Figure 8-5-17: Turn at a Waypoint (fly-by)

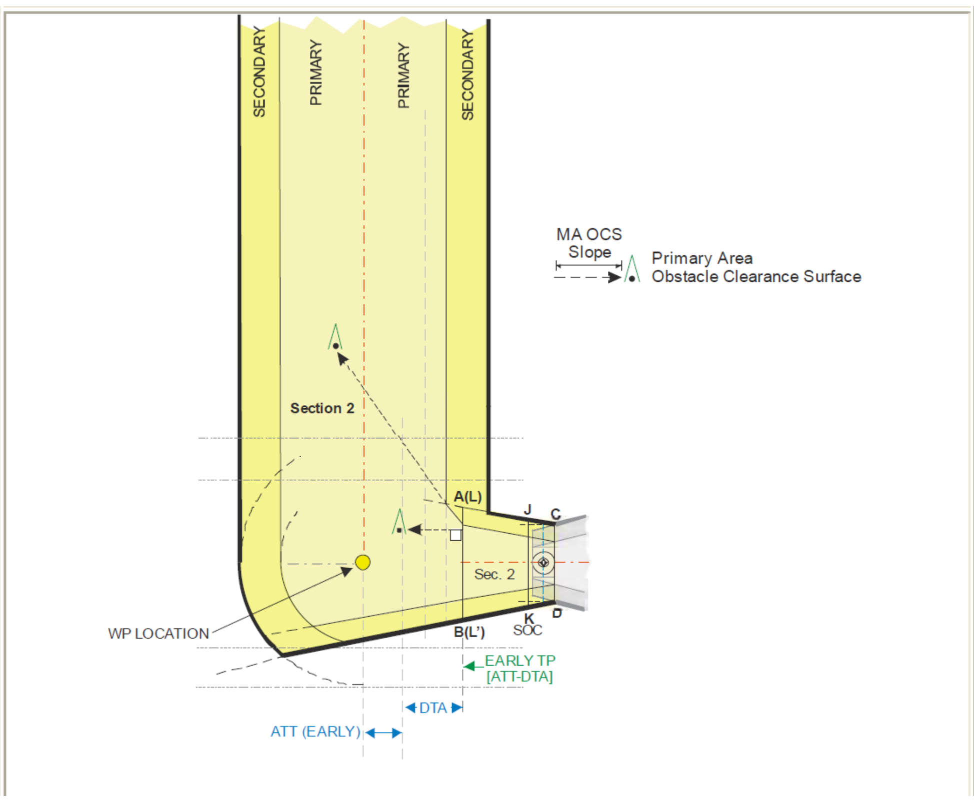


Figure 8-5-18a: Turn at a Waypoint (fly-by)

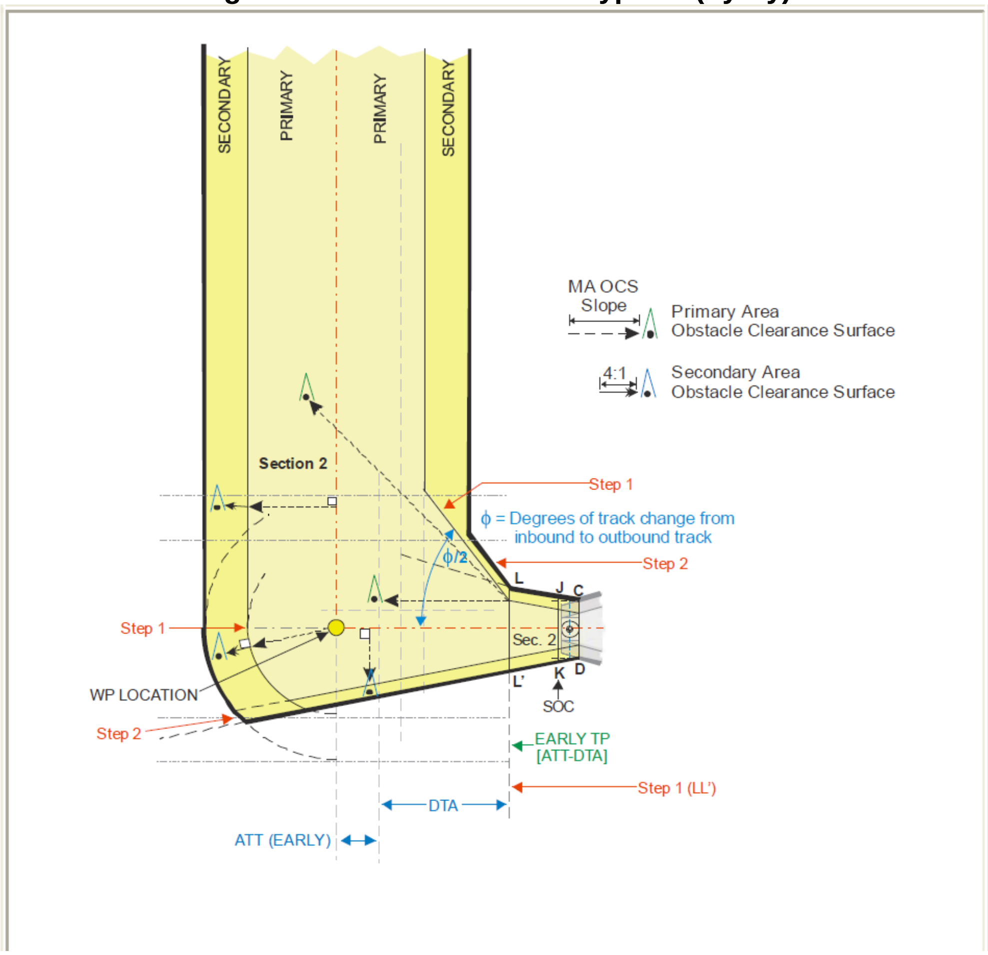


Figure 8-5-18b: Turn at a Waypoint (fly-by)

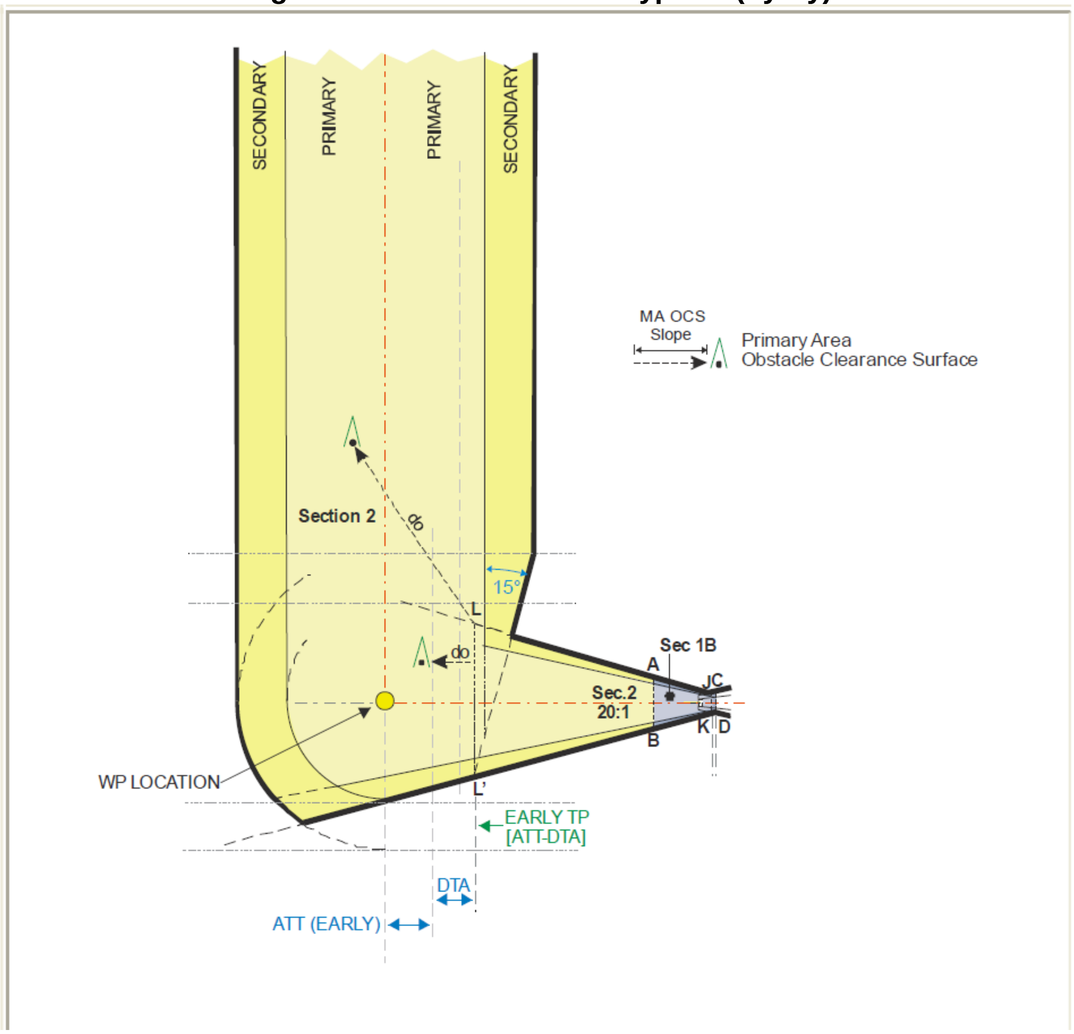


Figure 8-5-19: Turn at a Waypoint (fly-over) ≤ 75 Degrees

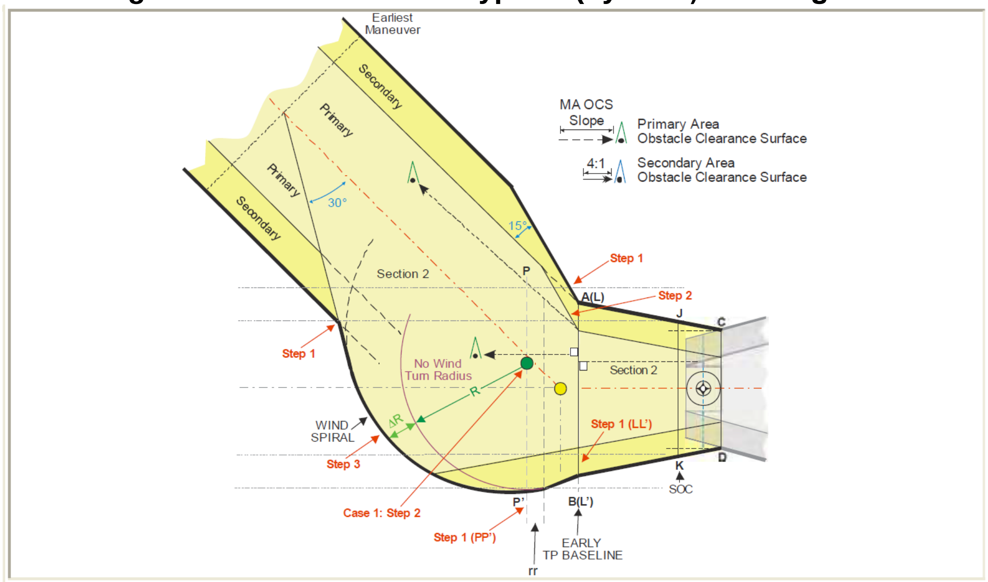
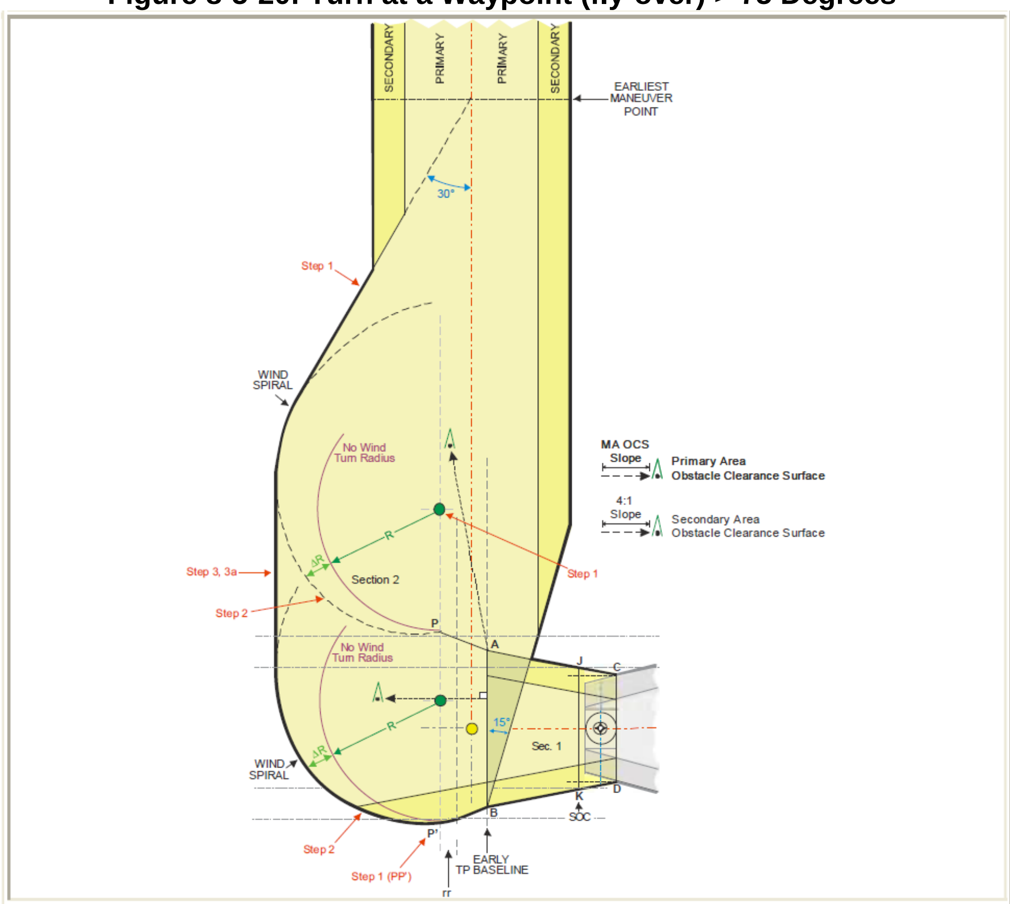


Figure 8-5-20: Turn at a Waypoint (fly-over) > 75 Degrees



Step 3: Calculate the altitude a helicopter climbing at the assigned CG would achieve over an established fix using section 5, formula 5-2g.

Formula 5-2g: Altitude Achieved at Fix ($\mathbf{Alt_{fix}}$)

$$Alt_{fix} = (r + Copter_{SOC}) \cdot e^{\left(\frac{CG \cdot D_{fix}}{r}\right)} - r$$

Where:

$Copter_{SOC}$ = Copter AB (SOC) altitude

CG = Climb Gradient (Standard 400 ft/NM)

D_{fix} = Distance (NM) from AB to fix

(r+Copter$_{SOC}$)*e^(CG*D$_{fix}$/r)-r

(3) Fly-By Turn Calculations and Construction. Consider direction-of-flight-distance positive, opposite-flight-direction distance negative.

(a) Fly-By Turn Calculations.

Step 1: Apply section 5, formula 5-2h for distance turn anticipation (DTA).

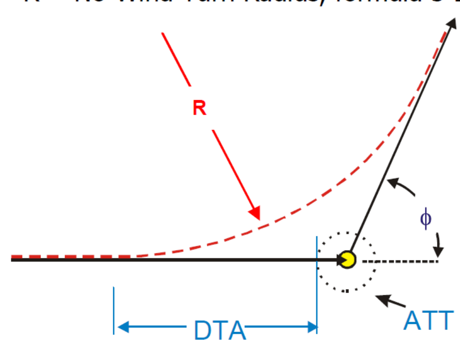
Formula 5-2h: Distance Turn Anticipation

$$DTA = R \cdot \tan\left(\frac{\phi}{2}\right)$$

Where:

ϕ = Turn/Heading Change (Degrees)

R = No-Wind Turn Radius, formula 5-2b



Calculate the fix to early-turn distance ($D_{early\ TP}$) using section 5, formula 5-2i.

Formula 5-2i: Early Turn Distance ($\mathbf{Dearly_{TP}}$)

$$D_{earlyTP} = ATT + DTA$$

Where:

ATT = along-track tolerance (NM)

DTA = Turn anticipation distance (NM), formula 5-2h

ATT+DTA

(b) Early Turn Point (ETP) and Area construction.

Table 8-5-1: Inside Turn Expansion Guide

Outbound Segment Boundary Relative ETP Connections	Expansion Line Required
Secondary & Primary **PRIOR** ETP	15-Degree Line
Secondary **Prior** ETP	15-Degree Line
Primary **Beyond** ETP	$\phi/2$
Secondary & Primary **Beyond** ETP	$\phi/2$

Note: ETP = LL' early turn point connection, 15-degree line relative the outbound segment, $\phi/2$ = half turn-angle

(c) Inside turn (Fly-By) Construction is predicated on the location of LL' and primary/secondary boundary intersections (early turn connections), relative the outbound segment, see section 5, table 8-5-1. (See section 5, figures 8-5-17 and 8-5-18).

Where no inside turn secondary area exists in section 1, apply secondary areas only after the turn expansion line/s intersect the outbound segment boundaries.

Apply the same technique to primary and secondary area connections when both inbound segment connection points fall either outside the outbound segment, or inside the outbound segment primary area. When both inbound connection points are within the outbound segment secondary area or its extension, table 8-5-1 provides a connection method for each point.

Note: Where half-turn-angle construction is indicated, apply a line splaying at the larger of, half-turn-angle, or 15 degrees, relative the outbound track. Where a small angle turn exists and standard construction is suitable for one, but not both splays; connect the uncommon splay, normally primary, to the outbound primary boundary at the same along-track distance as the secondary connection. Maintain or increase primary area as required.

Step 1: Construct a baseline (LL') perpendicular to the inbound track at distance $D_{earlyTP}$ (section 5, formula 5-2i) prior to the fix (see section 5, figures 8-5-17 and 8-5-18).

CASE 1: The outbound segment boundary, or its extension, is beyond the baseline (early-turn connection points are prior to the outbound segment boundary).

Step 1: Construct the inside turn expansion area with a line, drawn at one-half the turn angle from the inbound segment primary early turn connection point, to intercept the outbound segment primary boundary (see section 5, figure 8-5-18).

Step 2 (if required): Construct the inside turn expansion area with a line, drawn at one-half the turn angle, from the inbound segment secondary early turn connection point, to intercept the outbound segment secondary boundary (see section 5, figure 8-5-18).

CASE 2: The outbound segment secondary boundary or its extension is prior to the LL' baseline and outbound segment primary boundary or its extension is beyond the LL' baseline, (early-turn connection points are both **within** the outbound segment secondary area or its extension).

Step 1: Construct the inside-turn expansion area with a line splaying at 15-degree, (relative the outbound track) from the inbound segment secondary early turn connection point to intersect the outbound segment boundary.

Step 1Alt: Where the turn angle exceeds 75 degrees, begin the splay from L'.

Step 2: Construct the primary boundary with a line, drawn at one-half the turn angle, from the inbound segment primary early turn connection point to intercept the outbound segment primary boundary (see section 5, figure 8-5-17).

CASE 3: The outbound segment secondary and primary boundaries, or their extensions, are **prior** to the LL' baseline (primary early-turn connection point, or **both** connection points are **inside** the outbound segment primary area).

Step 1: Construct the inside turn expansion area with a line, splaying at 15-degree (relative the outbound track) from the more conservative point, (L') or (the intersection of LL' and the inbound segment inner primary boundary), to intersect the outbound segment boundaries.

Step 1Alt: Where the turn angle exceeds 75 degrees, begin the splay from L'. In this case, terminate the inside turn secondary area at the outbound segment primary boundary, since it falls before the early turn points, LL' (see section 5, figure 8-5-18a).

(d) Outside Turn (Fly-By) Construction.

Step 1: Construct the outer primary boundary using a radius of 1/2 primary width (1.5 NM), centered on the plotted fix position, drawn from the inbound segment extended primary boundary until tangent to the outbound segment primary boundary. See section 5, figure 8-5-17.

Step 2: Construct the secondary boundary using a radius of one-half segment width (2 NM), centered on the plotted fix position, drawn from the inbound segment extended outer boundary until tangent to the outbound segment outer boundary (see section 5, figures 8-5-17, 8-5-18, and 8-5-18a). Where no inbound secondary exists, use an arc of radius one-half segment width from tangent to the outbound segment secondary boundary to terminate at the inbound segment boundary.

(4) Fly-Over Turn Construction.

(a) Inside Turn (Fly-Over) Construction.

Step 1: Construct the early-turn baseline (LL') at distance ATT prior to the fix, perpendicular to the inbound nominal track.

Step 2: Refer to section 5, paragraph 8.5.3.b(3)(c), (skip **Step 1**).

(b) Outside Turn (Fly-Over) Construction.

Step 1: Construct the late-turn baseline (PP') at distance (ATT + rr) beyond the fix, perpendicular to the inbound nominal track. Calculate late turn distance using section 5, formula 5-2j (see section 5, figure 8-5-19).

Formula 5-2j: Late Turn Point Distance (D_{lateTP})

$$D_{lateTP} = ATT + (rr \bullet \frac{0.3048}{1852})$$

Where:

ATT = along-track tolerance (NM)
rr = delay/roll-in formula 2-4a

ATT+(rr*0.3048/1852)

Step 2: Apply wind spiral outer boundary construction for the first MA fly-over turn. See section 5, paragraph 8.5.3.a(2)(b) for necessary data, using the higher of section 5, formula 5-2g output, or the assigned fix crossing altitude for TAS and turn radius calculations and section 5, paragraph 8.5.5 for wind spiral construction. A non-turn side secondary area may extend into the WS1 area.

(c) Obstacle Evaluations. See section 5, paragraph 8.5.3.b(4)

(5) Section 2 Obstacle Evaluations.

(a) Turn at an Altitude Section 2. Apply the standard MA OCS slope, (or the assigned CG slope) to section 2 obstacles based on the shortest primary area distance (do) from the TIA boundary to the obstacle. Shortest primary area distance is the length of the shortest line kept within primary segments that passes through the early turn baseline of all preceding segments.

Step 1: Measure and apply the OCS along the shortest primary area distance (do) from the TIA boundary to the obstacle (single and multiple segments). See various obstacle measurement examples in section 5, figures 8-5-19 through 8-5-22.

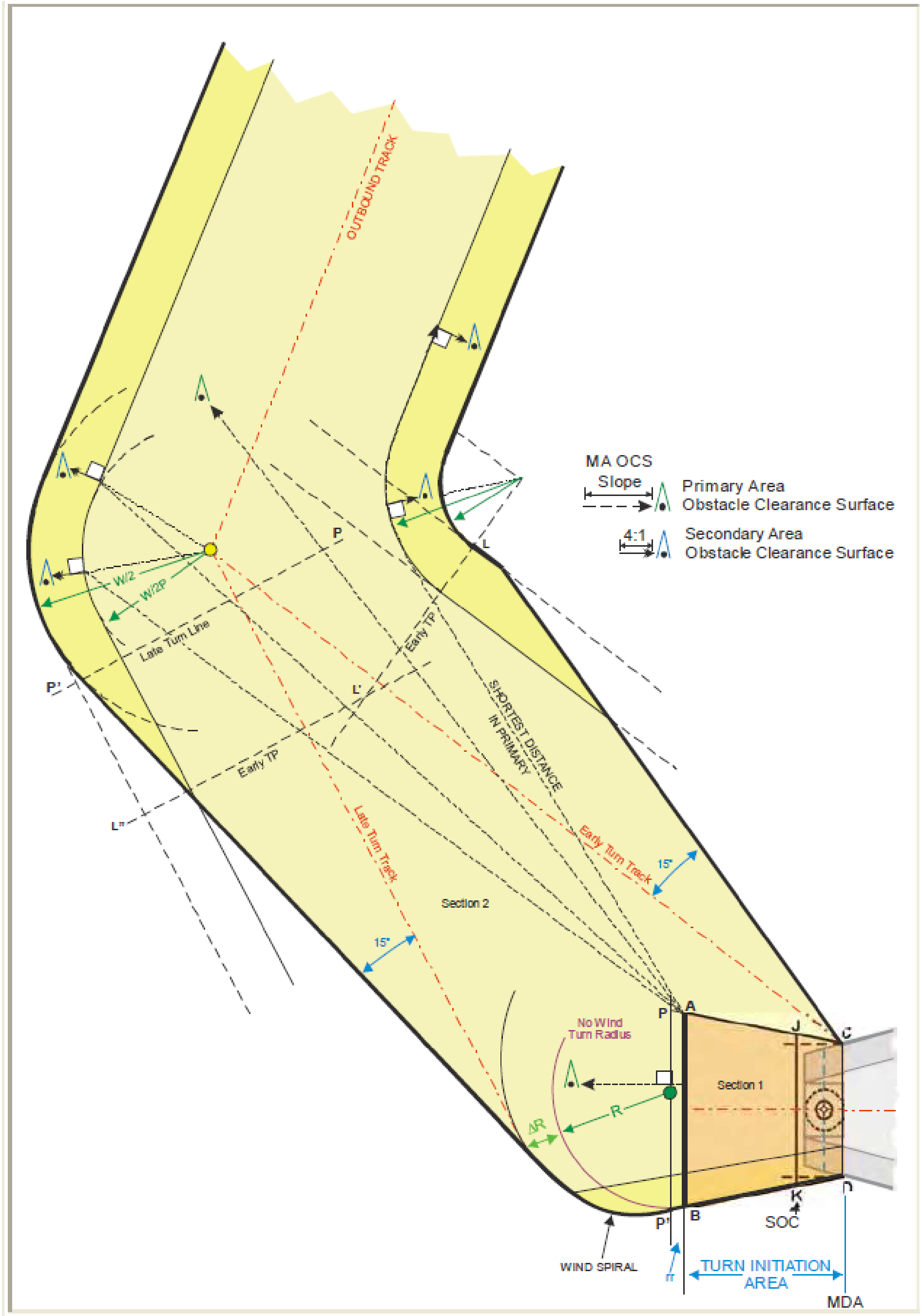
Step 2: For obstacles located in secondary areas, measure and apply the OCS along the shortest primary area distance (do) from the TIA boundary to the primary boundary abeam the obstacle, then the 4:1 slope along the shortest distance to the obstacle, (taken perpendicular to the nominal track or in expansion areas, to the primary arc, the primary corner-cutter, corner apex, or other appropriate primary boundary). Where an obstacle requires multiple measurements (an obstacle is equidistant from multiple primary boundary points, or lies along perpendiculars from multiple primary boundary points, etc.), apply the more adverse result from each of the combined primary/secondary measurements. See section 5, figures 5-19 through 5-22.

(b) Turn at Fix Section 2. Apply an inclined OCS (MA OCS) slope, beginning at SOC at the inbound-segment end OCS height.

Step 1: Measure and apply the OCS along the shortest distance (do) from AB (parallel to track) to LL', the shortest primary distance to the obstacle (single and multiple segments). See section 5, figures 8-5-19 and 8-5-20, for various obstacle measurement examples.

Step 2: For obstacles located in secondary areas, measure and apply the OCS along the shortest primary area distance (do) from the TIA boundary to the primary boundary abeam the obstacle, then the 4:1 slope along the shortest distance to the obstacle, (taken perpendicular to the nominal track or in expansion areas, to the primary arc, the primary corner-cutter, corner apex, or other appropriate primary boundary). Where an obstacle requires multiple measurements (where an obstacle is equidistant from multiple primary boundary points, or lies along perpendiculars from multiple primary boundary points, etc.), apply the more adverse result from each of the combined primary/secondary measurements (see section 5, figure 8-5-21).

Figure 8-5-21: Second Turn Fly-By Construction



8.5.4. Turning Missed Approach (Second Turn)

a. **DF/TF Turn (Second Turn, following turn-at-altitude).** Turns at the DF path terminator fix will be fly-by or fly-over to a TF leg. In either case, the outer boundary provides fly-over protection, and the inner boundary provides fly-by protection. Maximum turn angle is 90 degrees (applicable to both tracks within the DF segment).

This application provides that construction under section 2, or this section will apply, including cases where the inside and outside turn construction differs.

(1) DF/TF (Fly-By) Turn.

(a) Inside DF/TF (Fly-By) construction.

CASE 1: Full width inside secondary exists at the early turn point (LL').

Step 1: Construct a baseline (LL') perpendicular to the inbound track nearer the turn side boundary at distance $D_{earlyTP}$ (section 5, formula 5-2i) prior to the fix.

Step 2: Apply section 2 criteria.

CASE 2: Less than full width inside secondary exists at (LL').

Step 1: Apply section 5, paragraph 8.5.3.b(3)(c) criteria.

(b) Outside DF/TF (Fly-By) construction.

CASE 1: Full width outside secondary exists at the early turn point (L'L'').

Step 1: Construct a baseline (L'L'') perpendicular to the inbound track nearer the non-turn side boundary at distance $D_{earlyTP}$ (section 5, formula 5-2h) prior to the fix.

Step 2: Apply section 2 criteria. See section 5, figures 8-5-21 through 8-5-22.

CASE 2: Less than full width outside secondary exists at (L'L'').

Step 1: Apply section 5, paragraph 8.5.3.b(3)(d) criteria.

(2) DF/TF (Fly-Over) Turn.

(a) Inside DF/TF (Fly-Over) Turn Construction.

Step 1: Construct a baseline (LL') perpendicular to the inbound track nearer the turn side boundary at distance ATT prior to the fix (see section 5, figure 8-5-22).

Note: Where half-turn-angle construction is specified, apply a line splaying at the larger of half-turn-angle or 15 degrees relative the outbound track.

CASE 1: No inside secondary area exists at LL'.

Step 1: Create the OEA early-turn protection by constructing a line, splaying at the larger of one-half (1/2) the turn angle, or 15 degrees relative the outbound track, from the intersection of LL' and the inbound segment inner primary boundary to connect with the outbound TF segment boundaries. The TF secondary area begins at the intersection of this diagonal line and the outbound segment boundary.

CASE 2: Partial width inside secondary area exists at LL'.

Step 1: Create the OEA early-turn primary area protection by constructing a line, splaying at the larger of one-half (1/2) the turn angle, or 15 degrees relative the outbound track, from the intersection of LL' and the inbound segment inner primary boundary to connect with the TF segment primary boundary.

Step 2: Create the OEA early-turn secondary protection by constructing a line, splaying at the larger of one-half (1/2) the turn angle, or 15 degrees relative the outbound track, from the intersection of LL' and the inbound segment inner boundary to connect with the TF segment boundary.

CASE 3: Full width inside secondary area exists at LL'.

Step 1: Apply section 2 criteria. See section 5, figure 8-5-21.

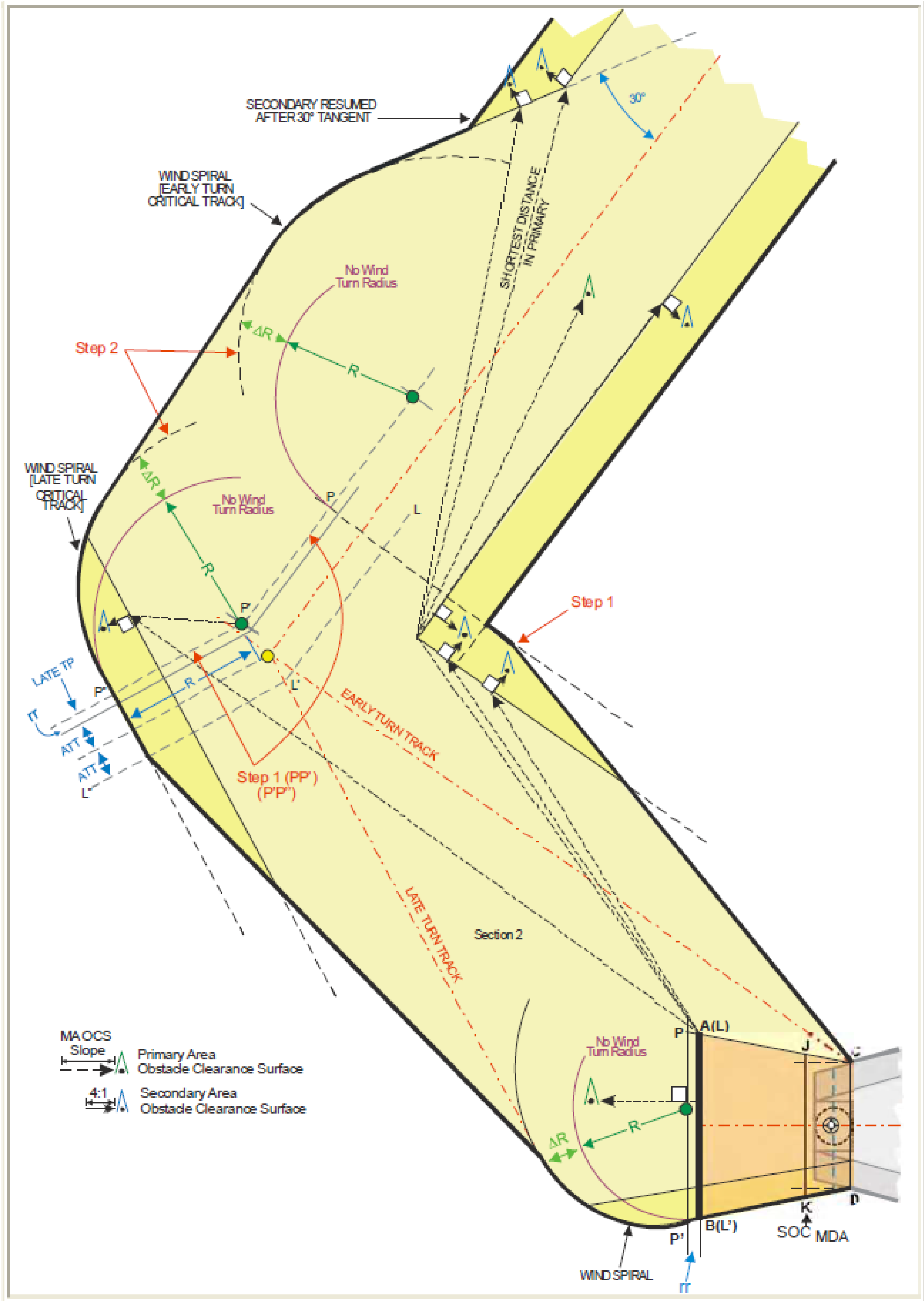
(b) Outside DF/TF (Fly-Over) Turn Construction.

Step 1: Construct the late-turn baseline for each inbound track, (PP') for the track nearer the inside turn boundary, and (P'P'') for the outer track at distance (ATT + rr) beyond the fix, perpendicular to the appropriate inbound track. See section 5, figure 8-5-22.

Note: A DF/TF Fly-Over turn is limited to 90 degrees (both inbound tracks) and should require no more than one WS per baseline. Construct the outside track WS (WS1) on base line **P'P''**, then construct WS2 on baseline **PP'**.

Step 2: Apply wind spiral construction, see section 5, paragraph 8.5.3.a(2)(b) for necessary data, and section 5, paragraph 8.5.5 for wind spiral construction See section 5, figure 8-5-22.

Figure 8-5-22: Second Turn Fly-Over Construction



b. TF/TF Turn (Second Turn, following turn-at-fix). Turns at the TF path terminator fix will be fly-by or fly-over to a TF leg. In either case, the outer boundary provides fly-over protection, and the inner boundary provides fly-by protection. Maximum turn angle is 90 degrees. This application provides that construction under section 2, or this section will apply, including cases where the inside and outside turn construction differs.

(1) TF/TF (Fly-By) Turn.

(a) Inside TF/TF (Fly-By) construction.

Step 1: Apply section 2 criteria.

(b) Outside TF/TF (Fly-By) construction.

Step 1: Apply section 2 criteria.

(2) TF/TF (Fly-Over) Turn.

(a) Inside TF/TF (Fly-Over) Turn Construction.

Step 1: Apply section 2 criteria.

(b) Outside TF/TF (Fly-Over) Turn Construction.

Step 1: Apply section 2 criteria.

8.5.5. **Wind Spiral Cases.** Wind Spiral (WS) construction applies to turn-at-an-altitude, turn-at-a fix (Fly-Over) for the first MA turn, and DF/TF (Fly-Over) for the second turn. The late-turn line P' designator is typically placed where the baselines cross. Where baseline extension is required, mark each baseline inner end with P'.

Each WS has several connection options along its boundary. The chosen connection(s) must provide the more conservative reasonable track and protection areas (see section 5, figures 8-5-23 through 8-5-25 for examples).

- A 15-degree, (or greater*) splay line to join outbound segment outer boundaries, from:
  - WS/direct-to-fix tangent point.
  - WS to WS tangent line origin.
  - WS to WS tangent line end.
  - WS/outbound segment parallel point (DF segment NA).

- A tangent line to join the next WS (see section 5, figure 8-5-25).
- A tangent line direct to the next fix (DF segment) (see section 5, figure 8-5-24).
- A tangent line, converging at 30 degrees to the segment track (TF segment) (see section 5, figure 8-5-20).

***Note:** See section 5, paragraphs 8.5.5.b(1) and 8.5.5.b(2) for alternate connection details.

Note: Where multiple WSs exist, a line from the earlier WS splaying at 15 degrees relative the tangent line between WSs may produce the more conservative construction.

Outbound segment type and turn magnitude are primary factors in WS application. Refer to section 5, table 8-5-2 for basic application differences. Calculate rr using section 2, formula 2-4a.

Table 8-5-2: MA First Turn Wind Spiral Application Comparison

	Turn At Fix (FO)	Turn At Altitude
WS1 Baseline (PP')	Fix + ATT + rr	TIA + rr
WS2 Baseline (PP')	Fix + ATT + rr	TIA + rr
WS3 Baseline (CD Ext)	NA	TIA + rr
WS Number	1 or 2	1, 2, or 3 *
Final WS Connection (Tangent line)	30° to outbound track	Direct to Fix

***Note:** Where a required turn exceeds that served by three wind spirals, consider adding fixes to avoid prohibitively large protection areas resulting from further wind spiral application.

a. **Turn-at-Fix (FO) and Turn-at-Altitude WS Comparison.** Three cases for outer-boundary wind spirals commonly exist:

- (Case 1), Small angle turns use one wind spiral (WS1);
- (Case 2), Turns near/exceeding 90° ~ use a second wind spiral (WS2); and
- (Case 3), turns near/exceeding 180° ~ use a third wind spiral (WS3).

(1) Turn-at-Altitude WS application concludes with a line tangent to the final WS direct to the next fix.

(2) Turn-at-Fix (FO) WS application concludes with a line tangent to the final WS converging at a 30-degree angle to the outbound segment nominal track. The intersection of this line with the nominal track establishes the earliest maneuvering point for the next fix. The minimum segment length is the greater of:

- The minimum length calculated using the section 2 formulas or,
- The distance from previous fix to the intersection of the 30-degree converging outer boundary line extension and the nominal track, (plus DTA). See section 5, paragraph 8.5.4.a.

(3) Second MA Turn DF/TF Turn-at-Fix (FO) WS application concludes with a line tangent to the final WS converging at a 30-degree angle to the outbound segment nominal track. This construction requires two WS baselines, one for each inbound track. Each late turn baseline is located (ATT + rr) beyond the fix, oriented perpendicular to the specific track. The baseline for the inbound track nearer the inside turn boundary is designated PP', the baseline associated with the outside turn track is designated P'P''. For convenience P' is often placed at the intersection of the two baselines, but a copy properly goes with each baseline inner end if baseline extensions are required (see section 5, figure 8-5-22).

Figure 8-5-23: WS Connection

(Inside Outbound Segment Primary Boundary)

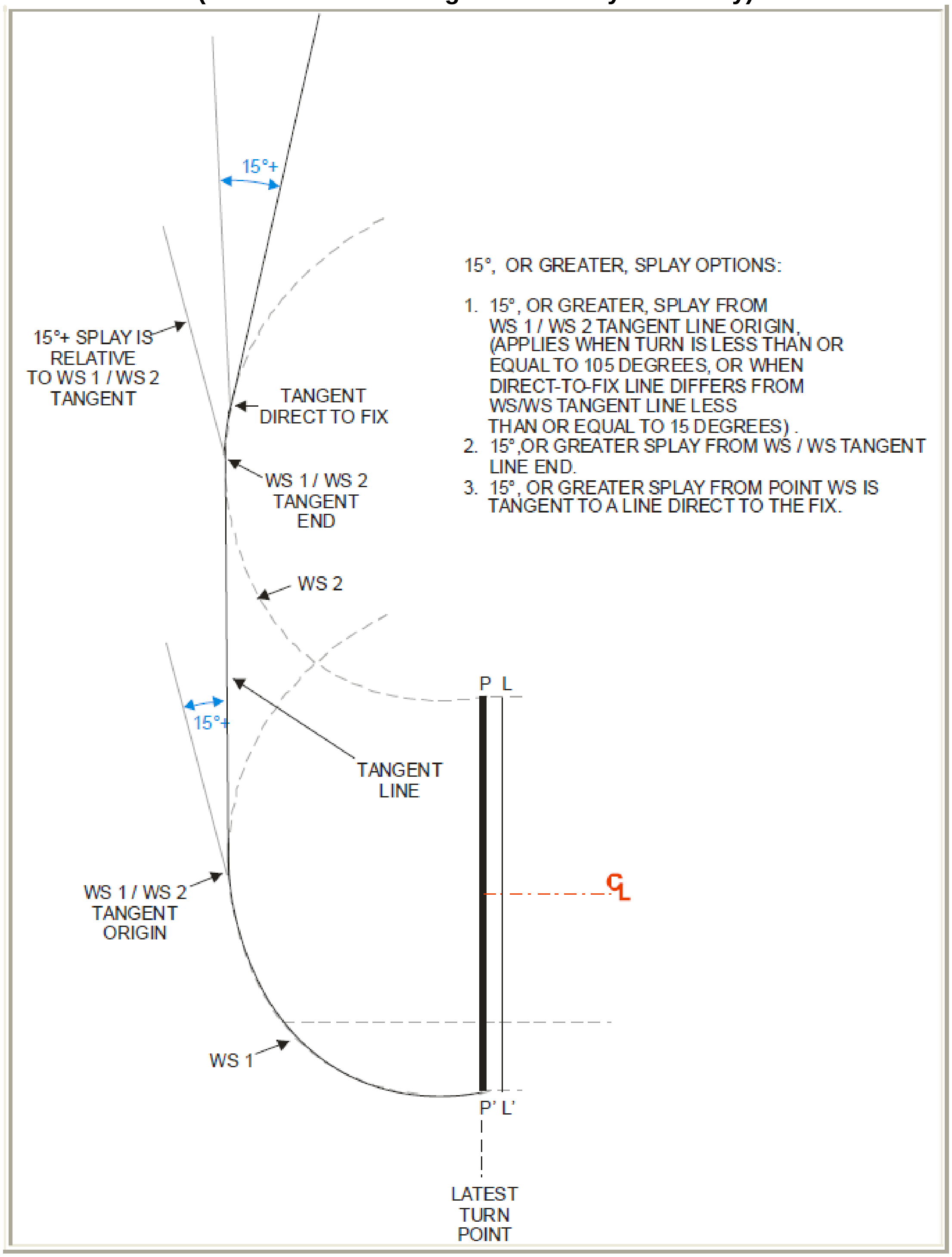


Figure 8-5-24: WS Connection (Inside Outbound Segment Primary Boundary)

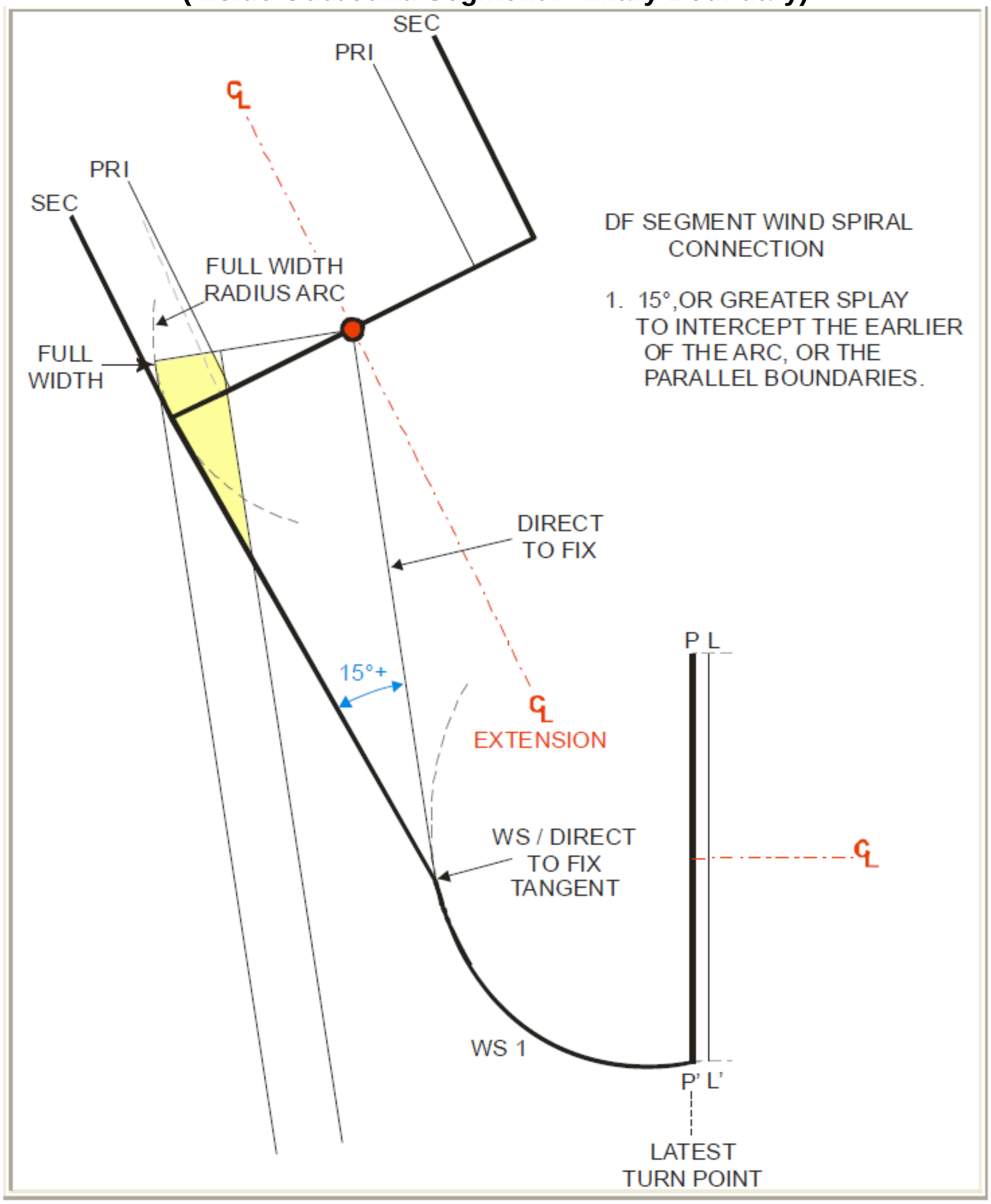
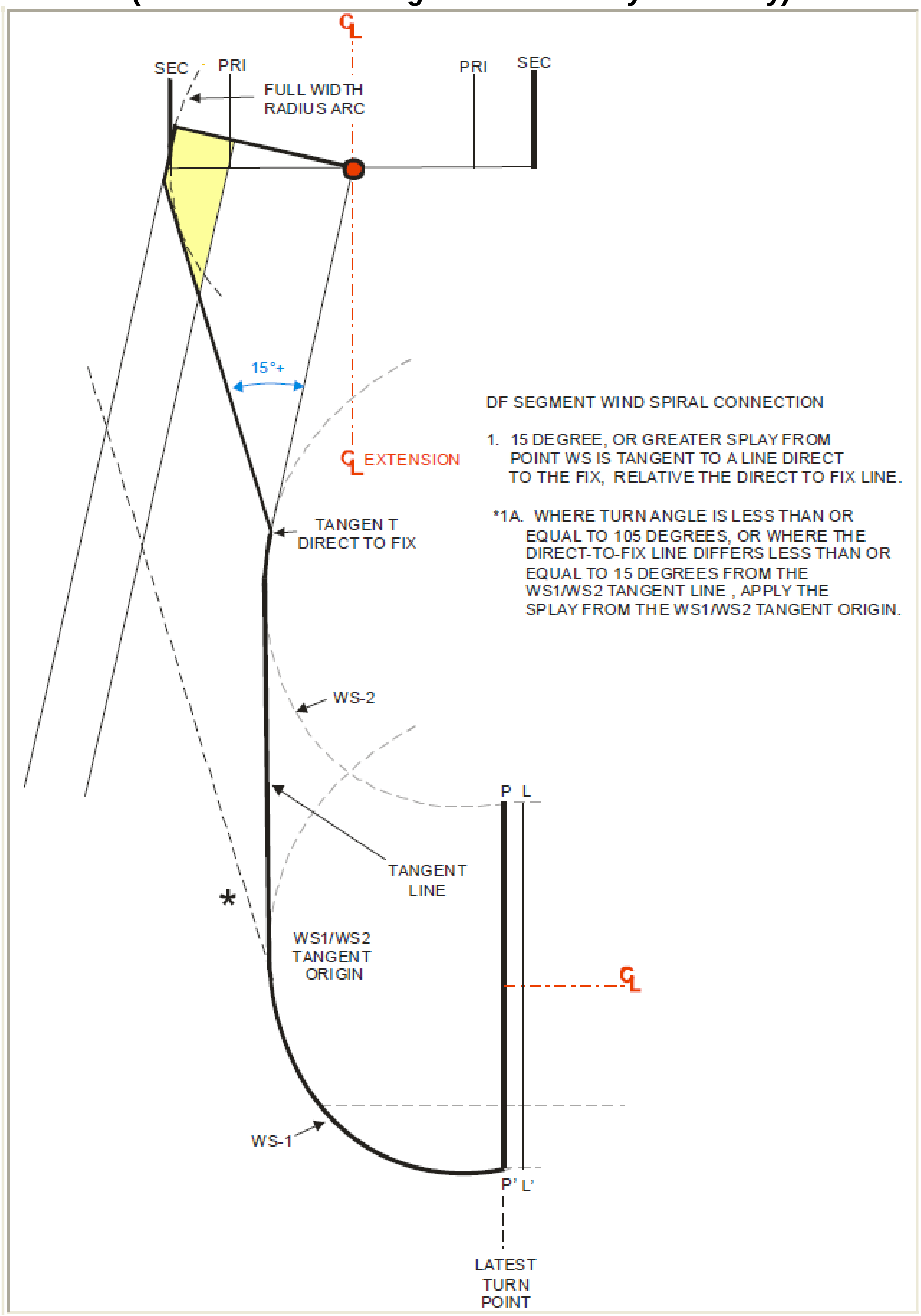


Figure 8-5-25: WS Connection
(Inside Outbound Segment Secondary Boundary)



b. **First MA Turn WS Construction.** Find late turn point distance ($D_{late\ TP}$) using section 5, formula 5-2j.

(1) CASE 1: Small angle turn using 1 WS.

Step 1: Construct the WS1 baseline, (PP’) perpendicular to the straight MA track at the late-turn-point (see section 5, table 8-5-2 for line PP’ location). See section 5, figures 8-5-5 and 8-5-8.

Step 2: Locate the wind spiral center on PP’ at distance R (no-wind turn radius, using section 5, formula 5-2b; see section 5, figure 8-5-8) from the intersection of PP’ and the inbound-segment outer-boundary extension (see section 5, figures 8-5-8 and 8-5-9).

Step 3: Construct WS1 from this outer boundary point in the direction of turn until tangent to the WS/Segment connecting line from section 5, table 8-5-2 (see section 5, figure 8-5-9).

CASE 1-1: Turn-at-Altitude (WS1 ends when tangent to a line direct to fix).

Step 1: Construct the OEA outer primary and secondary boundary lines parallel to this track (0.5-1.5-1.5-.0.5 segment width). See section 5, figure 8-5-9.

Step 2: Construct a line from the WS1 tangent point, splaying at 15 degrees from the WS1-to-fix track until it intersects the parallel boundary lines or reaches the segment end (see section 5, figure 8-5-9).

Note: Consider ‘full-width protection at the fix’ to exist where the splay line is tangent to a full-width- radius- circle about the fix.

Step 2Alt: Where **Step 2** construction provides less than full-width protection at the DF fix, construct the OEA outer boundary with a line splaying from the WS1/direct-to-fix tangent point at 15 degrees relative the direct-to-fix line, (or greater where required to provide full-width protection at the DF fix), until it intersects the parallel boundary lines (not later than tangent/tangent-extension to the full width-arc about the fix), and provides full-width protection at or before the DF fix. DF secondary areas begin/exist only where full width primary exists (see section 5, figure 8-5-9).

Note: Where excessive splay (dependent upon various conditions generally in the 35-40 degree range), consider lengthening the segment, restricting the speed, category, etc. to avoid protection and/or construction difficulties.

CASE 1-2: Turn-at-Fix (FO) (WS1 ends when tangent to a 30-degree line converging to nominal track).

Step 1: Construct the OEA outer boundary line using WS1 and the tangent 30-degree converging line until it crosses the outbound segment boundaries (see section 5, figure 8-5-19).

Step 1a: Where WS1 lies within the outbound segment primary boundary, construct the OEA boundary using WS1 and a line (from the point WS1 is parallel to the outbound segment nominal track), splaying at 15 degrees relative the outbound segment nominal track until it intersects the outbound segment boundary lines.

Step 1b: Where WS1 lies within the outbound segment secondary boundary, construct the OEA boundary using WS1 and a line (from the point WS1 is parallel to the outbound segment nominal track), splaying at 15 degrees relative the outbound segment nominal track until it intersects the outbound segment boundary line. Continue WS1 and the tangent 30-degree converging line to establish the inner primary/secondary boundary (see section 5, similar figure 8-5-24).

(2) CASE 2: Larger turn using more than 1 WS. For turns nearing or greater than 90 degrees, WS2 may be necessary. See section 5, figure 8-5-20.

Step 1: To determine WS2 necessity, locate its center on baseline PP', at distance R from the inbound-segment inner-boundary extension.

Step 2: Construct WS2 from this inner boundary point in the direction of turn until tangent to the WS/WS, or WS/Segment connecting line from section 5, table 8-5-2. See section 5, figure 8-5-20.

Step 3: Where WS2 intersects, or is outside WS1 construction, (including the connecting and expansion lines where appropriate), include WS2 in the OEA construction. Otherwise revert to the single WS construction.

Step 3a: Connect WS1 and WS2 with a line tangent to both (see section 5, figure 8-5-20).

Note: The WS1/ WS2 tangent line should parallel a line between the WS center points.

CASE 2-1: Turn-at-Altitude (WS2 ends when tangent to a line direct to fix).

Step 1: Construct the OEA outer primary and secondary boundary lines parallel to this track (0.5-1.5-1.5.0.5 segment width).

Step 2: Construct a line from the WS2 tangent point, splaying at 15 degrees from the WS2-to-fix track until it intersects the parallel boundary lines or reaches the segment end (see section 5, figure 8-5-9).

Note: Consider 'full-width protection at the fix' exists where the splay line is tangent to a full-width- radius- circle about the fix.

Step 2Alt: Where **Step 2** construction provides less than full-width protection at the DF fix, construct the OEA outer boundary with a line splaying from the WS2/direct-to-fix tangent point at 15 degrees relative the direct-to-fix line, (or greater where required to provide full-width protection at the DF fix), until it intersects the parallel boundary lines (not later than tangent/tangent-extension to the full-width-arc about the fix), and provides full-width protection at or before the DF fix. Where the turn angle is ≤ 105 degrees, or the divergence angle between the WS/WS tangent line and the direct-to-fix line is ≤ 15 degrees, apply the splay line form the WS1/WS2 tangent line origin. DF secondary areas begin/exist only where full width primary exists (see section 5, figure 8-5-9).

Note: Where excessive splay exists (dependent upon various conditions but generally greater than 30 degrees), consider using an earlier splay origin point, lengthening the segment, restricting the speed, category, etc. to avoid protection or construction difficulties (see section 5, paragraph 8.5 for origin points).

CASE 2-2: Turn-at-Fix (FO): (WS2 ends when tangent to a 30-degree line converging to nominal track).

Step 1: Construct the OEA outer boundary line using WS2 and the 30-degree converging line until it crosses the outbound segment boundaries (see section 5, figure 8-5-20).

Step 1a: Where WS2 lies within the outbound segment primary boundary, construct the OEA boundary using WS1, WS2, and a line (from the point WS1 or WS2 is parallel to the outbound segment nominal track, the more conservative), splaying at 15 degrees relative the outbound segment nominal track until it intersects the outbound segment boundary lines.

Step 1b: Where WS2 lies within the outbound segment secondary boundary, construct the OEA boundary using WS1, WS2, and a line (from the point WS2 is parallel to the outbound segment nominal track), splaying at 15 degrees relative the outbound segment nominal track until it intersects the outbound segment boundary line. Continue WS2 and the tangent 30-degree converging line to establish the inner primary/secondary boundary.

(3) CASE 3: Larger turn using more than 2 WSs. (Not applicable to Turn-at-Fix due to 90 degree turn limit). For turns nearing or greater than 180 degrees (such as a missed approach to a holding fix at the IF).

Step 1: Construct the WS3 baseline perpendicular to the straight MA track along CD-extended toward the turn side. See section 5, figure 8-5-15.

Step 2: To determine WS3 necessity, locate its center on the WS3 baseline at distance R from point C. See section 5, figure 8-5-15.

Step 3: Construct WS3 from point C in the direction of turn until tangent to the WS/WS, or WS/Segment connecting line from section 5, table 8-5-2. See section 5, figure 8-5-15.

Step 4: Where WS3 intersects, or is outside WS2 construction, include WS3 in the OEA construction. Otherwise revert to the dual WS construction. See section 5, figure 8-5-15.

Step 5: Connect WS2 and WS3 with a line tangent to both. See section 5, figure 8-5-15.

Note: The WS2 & WS3 tangent line should parallel a line between the WS center points.

CASE 3-1: Turn-at-Altitude: (WS3 ends when tangent to a line direct to fix)

Step 1: Construct the OEA outer primary and secondary boundary lines parallel to this track (0.5-1.5-1.5-0.5 segment width). See section 5, figure 8-5-15.

Step 2: Construct a line from the WS3 tangent point, splaying at 15 degrees from the WS3-to-fix track until it intersects the parallel boundary lines or reaches the segment end. See section 5, figure 8-5-15.

(4) Outside Turn Secondary Area. Outbound segment secondary areas following wind spirals begin where either the 30-degree converging line crosses the secondary and primary boundaries from outside the segment, or the 15-degree splay line crosses the primary boundary from inside the segment.

c. **Second MA Turn WS Construction (DF/TF FO).** To accommodate the two inbound tracks in the DF leg, the second MA turn DF/TF (fly-over) construction uses two WS baselines, PP' and P'P''.

Note: Apply section 5, table 8-5-2 PP' location information for each baseline (formula is identical).

(1) CASE 1: Small angle turn using 1 WS for each inbound DF track.

Step 1: Construct the WS1 baseline, (P'P'') perpendicular to the DF track nearer the outside of the DF/TF turn, at the late-turn-point. See section 5, table 8-5-2 for line PP' location.

Step 1a: Construct the WS2 baseline, (PP') perpendicular to the DF track nearer the inside of the DF/TF turn, at the late-turn-point. See section 5, table 8-5-2 for line PP' location.

Step 2: Locate the WS1 center on P'P'' at distance R (no-wind turn radius, using section 5, formula 5-2b; see section 5, figure 8-5-5) from the intersection of P'P'' and the inbound-segment outer-boundary extension.

Step 2a: Locate the WS2 center on PP' at distance R (no-wind turn radius, using section 5, formula 5-2b; see section 5, figure 8-5-5) from the intersection of PP' and the inbound-segment inner-boundary extension.

Step 3: Construct WS1 from this outer boundary point in the direction of turn until tangent to the WS/Segment connecting line from section 5, table 8-5-2.

Step 3a: Construct WS2 from this inner boundary point in the direction of turn until tangent to the WS/Segment connecting line from section 5, table 8-5-2.

Step 4: Where WS2 intersects WS1 construction, include WS2 in the OEA construction, and connect WS1 to WS2 with a tangent line. Otherwise revert to the single WS construction.

CASE 1-1: WS1 and/or WS2 lie outside the outbound segment boundary.

Step 1: Construct the OEA outer boundary using WS1 and/or WS2 and the tangent 30-degree converging line until it crosses the outbound segment boundaries . See section 5, figure 8-5-22.

CASE 1-2: WS1 and WS2 lie inside the outbound segment boundary.

Step 1: Where WS1 and/or WS2 lie inside the outbound segment primary boundary, construct the OEA outer boundary using WS1 and/or WS2 and a line (from the point WS1 or WS2 is parallel to the outbound segment nominal track), splaying at 15 degrees relative the outbound segment nominal track until it intersects the outbound segment boundary lines.

Step 1a: Where WS1 and/or WS2 lie inside the outbound segment secondary boundary, construct the OEA outer boundary using WS1 and/or WS2 and a line (from the point WS1 or WS2 is parallel to the outbound segment nominal track), splaying at 15 degrees relative the outbound segment nominal track until it intersects the outbound segment boundary line. Continue the final WS and 30 degrees converging line to establish the primary/secondary boundary.

8.5.6. **Missed Approach Climb Gradient.** Where the MA standard OCS is penetrated and a CG is required, specify a missed approach CG to clear the penetrating obstruction. MA starting ROC is 100 ft (plus adjustments). ROC increases at 96 ft/NM, measured parallel to the MA track to TIA end (Turn-at-Altitude), or early-turn point (Turn-at-Fix), then shortest primary distance to the next fix. Apply fix-to-fix distance for subsequent segments. Where a part-time altimeter is in use, consider the helicopter SOC altitude to be the MDA associated with the local altimeter (ensures adequate CG is applied).

Step 1: Calculate the ROC, the altitude at which the ROC for the obstacle is achieved, and the required CG (ft/NM) using section 5, formula 5-3.

Step 2: Apply the CG to:

- The altitude which provides appropriate ROC, or
- The point/altitude where the subsequent MA OCS clears all obstacles.

Step 2a: Where a RASS adjustment is applicable for climb-to-altitude operations (prior to turn, terminate CG, etc.), apply the CG associated with the lower MDA (section 5, formula 5-3). Where there is a local altimeter, to establish the RASS-based climb-to-altitude, add the difference between the local altimeter-based MDA and the RASS-based MDA to the climb-to-altitude and round to the next higher 100-ft increment (see TP308/GPH209, Volume 1, chapter 3 for further details).

Formula 5-3: ROC/CG/Minimum Altitude/OCS

STEP 1	$$ROC_{obs} = ROC_{start} + 96 \cdot d$$ Where: ROC_{start} = SOC ROC (100 ft for NVGP); d = distance (NM) CG origin (SOC) to obstacle
ROC_{start}+96*d	
STEP 2	$$Alt_{min} = O_{elev} + ROC_{obs}$$ Where: ROC_{obs} = Step 1 result; O_{elev} = Obstacle Elevation (MSL)
O_{elev}+ROC_{obs}	
STEP 3	$$CG = \frac{r}{d} \cdot \ln\left(\frac{(r + Alt_{min})}{(r + Copter_{SOC})}\right)$$ Where: Alt_{min} = Step 2 result; $Copter_{SOC}$ = Helicopter altitude (MSL) at CG origin; d = distance (NM), CG origin (SOC) to obstacle
r/d*ln((r+ALT_{min})/(r+$Copter_{SOC}$))	

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SECTION 6: HELICOPTER INSTRUMENT DEPARTURE DESIGN CRITERIA

8.6. Helicopter Instrument Departure Design Criteria.

8.6.1. General. See section 1, paragraph 8.1.

8.6.2. Terms. These terms/variables are common to all formulas:

$\boldsymbol{\beta}$ is magnitude of heading change in degrees
$\boldsymbol{\theta}$ is glidepath angle in degrees
alt is altitude AMSL
ATT is along-track tolerance
DA is decision altitude specified AMSL
$\mathbf{d_{FauxOrigin}}$ is the distance from RDP to the phantom LTP for OEA construction
FTE means .Flight Technical Error.
HAS is the height in feet above the surface beneath (within 5,200 radius of) RDP
LTP means .landing threshold point.
MSL in this document is synonymous with AMSL
$\mathbf{OBS_{elev}}$ is the obstacle AMSL elevation
$\mathbf{OBS_x}$ is the along-track distance from reference datum point
$\mathbf{PFAF_{alt}}$ is the minimum AMSL altitude at the PFAF
RDP means .reference datum point.

Functions and Constants
$$\left\{\begin{array}{l} \text{deg} = \text{radians}\times\frac{180}{\pi} \\ \text{fpnm} = \frac{1852\,ft}{0.3048\,nm} \\ \max(a,b) = \text{maximum value of a and b} \\ \text{round}(a,b) = \text{rounds a to b decimal places} \\ \text{ceiling}(a) = \text{rounds a to next integer toward positive infinity} \end{array}\right\}$$

8.6.3. Reserved.

8.6.4. PinS Departures.

a. **Background operational information for procedure designers.** The PinS Departure Procedures (DPs) described in this criteria allow a pilot to depart a heliport and visually navigate and avoid obstacles to the Initial Departure Fix (IDF) where IFR obstruction clearance begins. The IDF is a Fly-by (FB) Waypoint (WP). IFR helicopter departure procedures will consist of a defined route in graphic form, published/charted as a Instrument Departure and comply with design and documentation guidelines as specified in this section and NAV CANADA charting instructions.

b. General Procedure Design. Establish the IDF at a distance from 1.5 NM to 5.0 NM from HGC for DPs, and 0.55 NM to 2.0 NM for Restricted DPs. Positive Course Guidance (PCG) and obstruction clearance must be provided from the earliest ATT at the IDF to the latest ATT at the last DP WP (DP termination fix) where the DP joins the enroute structure and an altitude that permits enroute flight.

(1) For General DP Construction. Optimum leg length is 3.0 NM. If the magnitude (**β**) of the first turn is ≤ 70 degrees, the minimum leg length allowed is 3.0 NM. If **β** of the first turn is > 70 degrees the minimum leg length is 3.5 NM. Maximum turn magnitude is 90 degrees and leg length is 10.0 NM.

(2) Restricted DP Construction. The **optimum** leg length for Restricted helicopter DP construction is 3.0 NM. If **β** of the first turn angle is ≤ 30 degrees, the minimum leg length is 2.0 NM, if **β** of the first turn angles are > 30 degrees the minimum leg length increases to 3.0 NM. Maximum value for **β** is 90 degrees and maximum leg length is 10.0 NM.

(3) After the first turn fix, and expanding to full width, apply standard RNAV initial segment OEA construction for Category "A" aircraft. Minimum leg length is the greater of the current RNAV minimum leg length criteria or as construction requires after the first turn fix.

(4) Use Formula 6-1 to determine turn radius (R) and DTA appropriate for **β**. For a general DP, use a design climb airspeed of 80 KIAS and a 13-degree bank angle until the climb trajectory reaches the target departure altitude. After the target departure altitude is reached, design for 140 KIAS and 15-degree bank angle. For a Restricted DP, use the best rate of climb airspeed (V_y), the cruising airspeed (V_c), and the design bank angle for V_y and V_c applicable to the specific design helicopter.

(5) If lower or higher airspeeds are required because of design helicopter performance or equipment operating limitations, publish a speed restriction.

Formula 6-1: Turn Radius/Distance of Turn Anticipation (DTA)

(1) $input\ V_{KIAS},\ bank_{angle},\ turn_{alt},\ \beta,\ HRP_{elev}$

(2) $\mathrm{case}(turn_{alt} - HRP_{elev} > 2000):\ V_{KTW} = round(0.00198 \cdot turn_{alt} + 47, 0)$

$\mathrm{case}(turn_{alt} - HRP_{elev} \le 2000):\ V_{KTW} = 30$

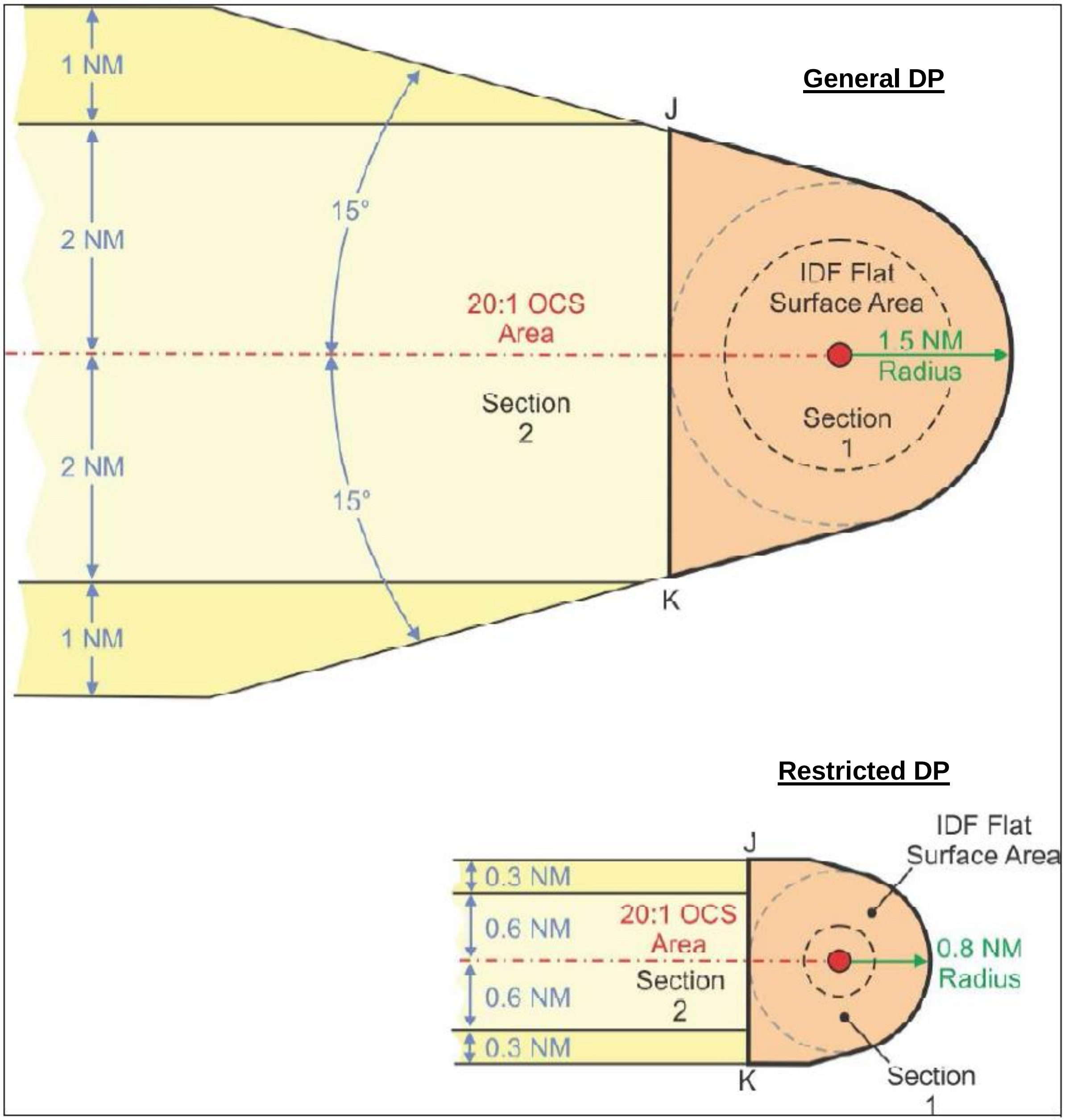
(3) $$V_{KTAS} = \mathrm{round}\left[\frac{V_{KIAS} \cdot 171233 \cdot \sqrt{303 - 0.00198 \times turn_{alt}}}{(288 - 0.00198 \cdot turn_{alt})^{2.628}}, 0\right]$$

(4) $$R = \mathrm{round}\left[\frac{(V_{KTAS} + V_{KTW})^2}{\tan(bank_{angle}) \cdot 68625.4}, 2\right]$$

(5) $$DTA_{NM} = \mathrm{round}\left[R \cdot \tan\left(\frac{\beta}{2}\right), 2\right]$$

8.6.5. **Obstacle Evaluation Area.** The OEA consists of Section 1 (the IDF flat surface area), and Section 2 (the 20:1 sloping OCS), as shown in Figure 8-6-1. The JK line (end of section 1/ beginning of section 2) is a line perpendicular to the initial departure course that is a specified distance from the IDF: 1.5 NM (1 NM ATT + 0.5 NM FTE) for general DPs and 0.8 NM (0.3 NM ATT + 0.5 NM FTE) for Restricted DPs. The construction radius around the IDF is 1 NM ATT + 0.5 NM FTE = 1.5 NM for General DP and 0.3 NM + 0.5 NM FTE = 0.8 NM for a Restricted DP. A 15-degree splay defines the Section 1 and Section 2 outer boundaries as shown in Figure 8-6-1 below. The OEA entry is centered on the IDF and the route is constructed as a series of TF legs to the DP termination fix.

Figure 8-6-1: Section 1 Flat Surface, Section 2 OCS Areas



8.6.6. General PinS Departure Construction. For general DP construction, OEA configuration is dependent on the course change angle at the first turn fix, and the length of the first segment. Some examples are illustrated in Figure 8-6-2 thru Figure 8-6-4. Instructions on how to define these cases (creating the specific OEAs and turn boundaries) are located in steps below:

Figure 8-6-2: General OEA Area Plan View (90-Degree Turn)

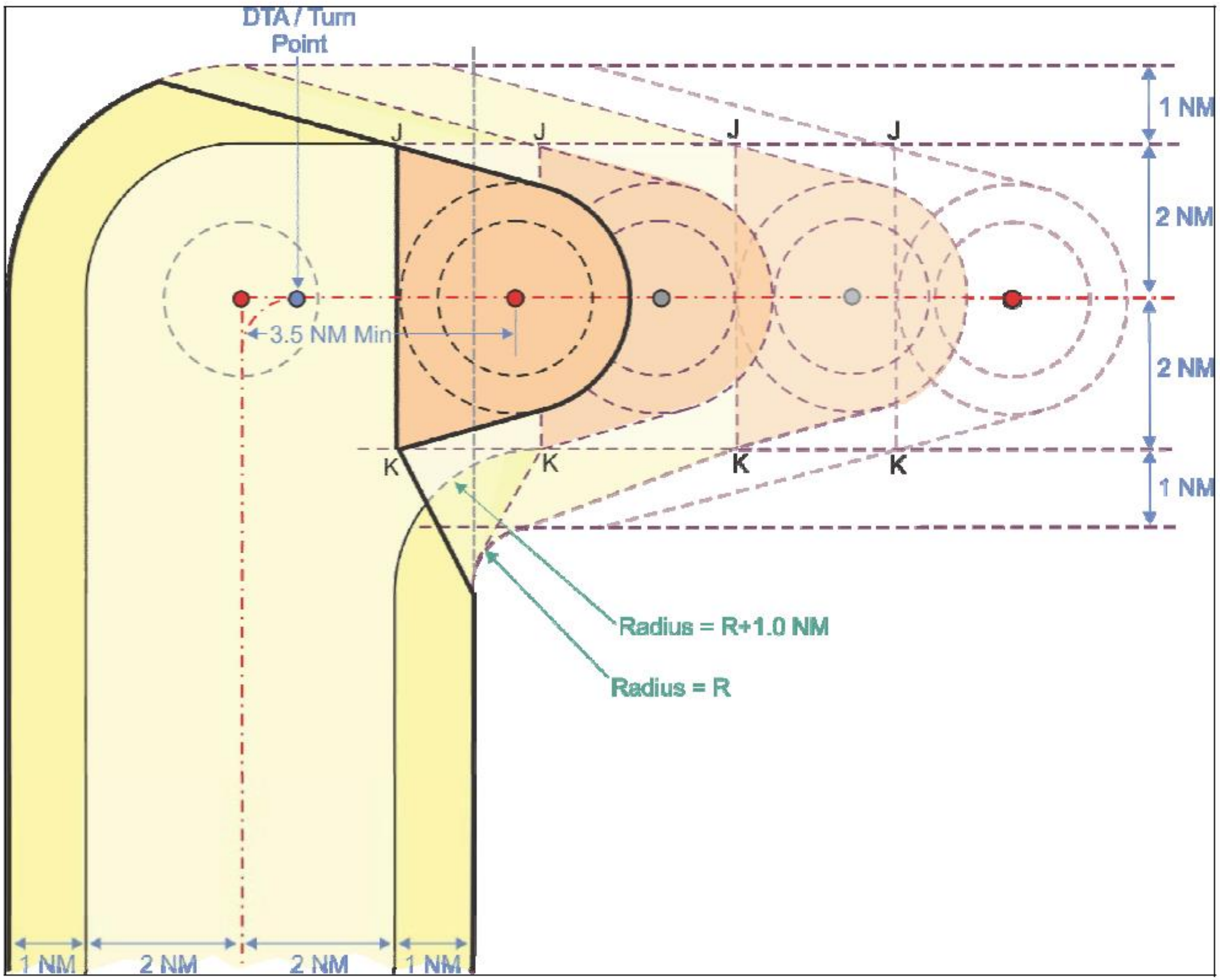


Figure 8-6-3: General OEA Area Plan View (15- and 30-Degree Turns)

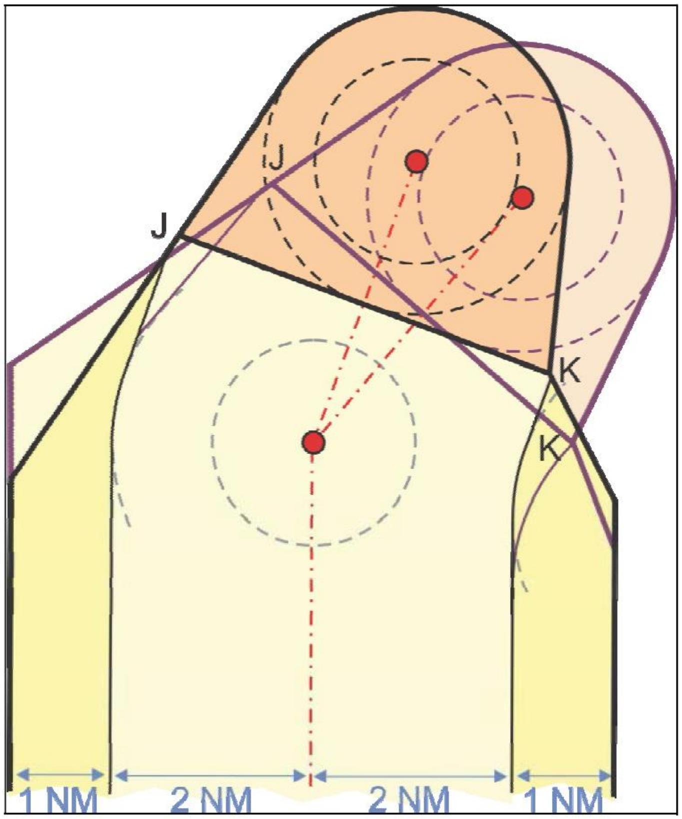
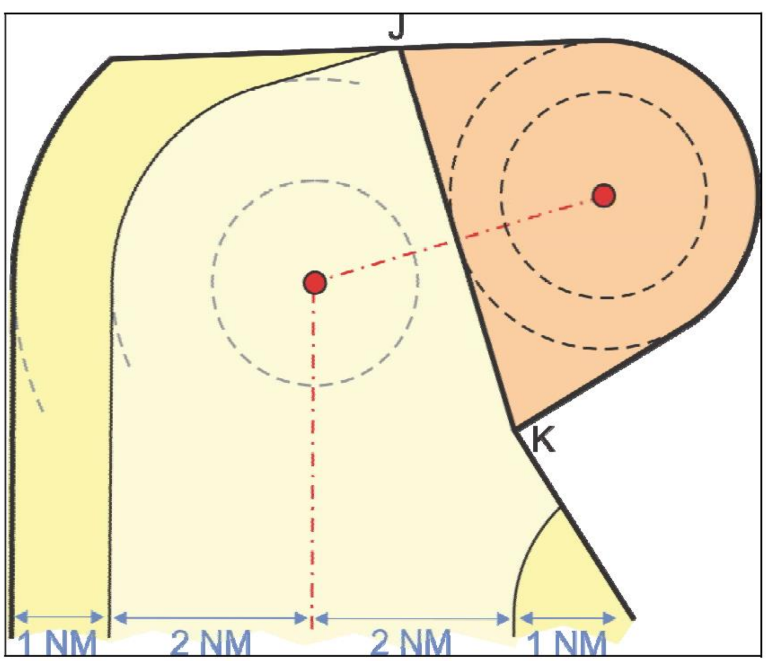


Figure 8-6-4: General OEA Area Plan View (70-Degree Turn)



Step 1: Position the Initial Departure Fix (IDF) as a Fly-By (FB) fix. Use a fix-to-fix distance that is in accordance with paragraph 8.6.4b(1).

Step 2: Construct the IDF Circle as an arc with a 1.5 NM radius centered at the IDF fix.

Step 3: Construct the Designed Turning Flight Path.

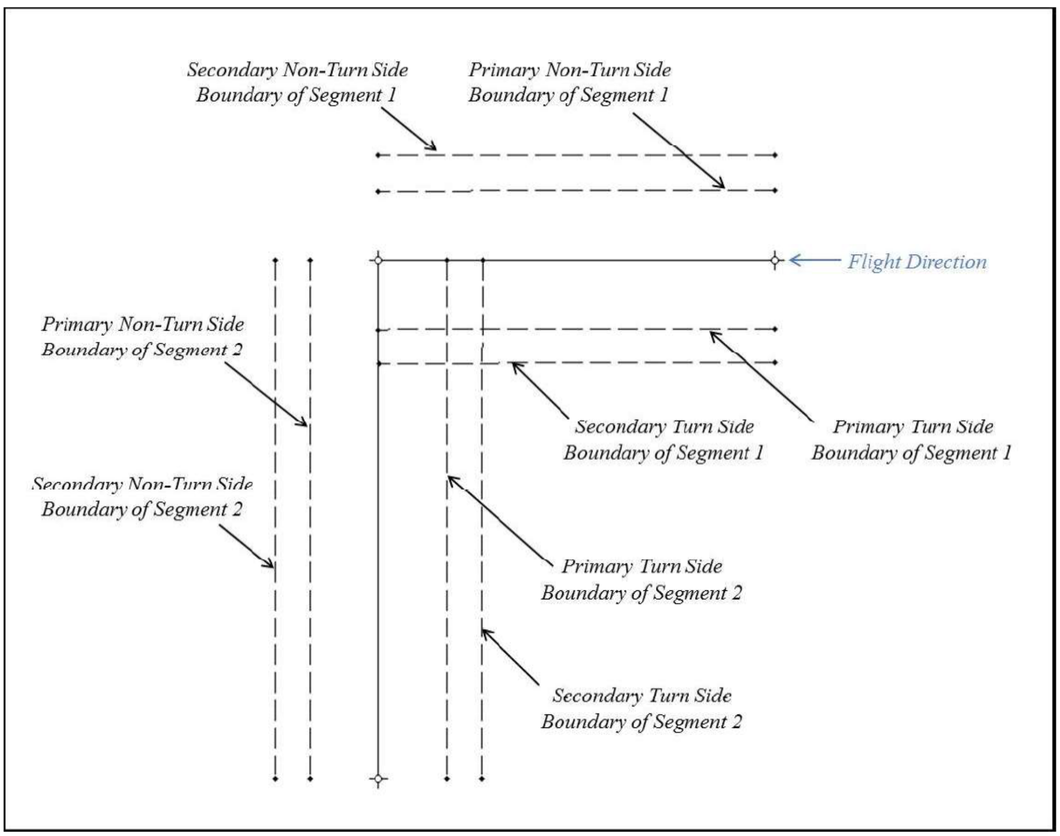
Step 3a: Determine the turn radius (R) utilizing Formula 6-1.

Step 3b: Construct an arc of radius R that lays tangent to Segments 1 and 2.

Step 4: Construct Segment 1 Boundaries. Construct Boundaries of half-widths 1-2-2-1 in reference to Segment 1. They will hereby be referred to as the Secondary Turn Side Boundary of Segment 1, the Primary Turn Side Boundary of Segment 1, the Primary Non-Turn Side Boundary of Segment 1, and the Secondary Non-Turn Side Boundary of Segment 1. These boundaries are depicted in Figure 8-6-5.

Step 5: Construct Segment 2 Boundaries. Construct Boundaries of half-widths 1-2-2-1 in reference to Segment 2. They will hereby be referred to as the Secondary Turn Side Boundary of Segment 2, the Primary Turn Side Boundary of Segment 2, the Primary Non-Turn Side Boundary of Segment 2, and the Secondary Non-Turn Side Boundary of Segment 2. These boundaries are depicted in Figure 8-6-5.

Figure 8-6-5: Construction of the Segment 1 and Segment 2 Boundaries



Step 6: Construct the Turn Side Splay Line (see Figure 8-6-6).

Step 6a: Locate the Splay End Reference Point a distance of 1.5/tan(15°) NM from the IDF along the Segment 1 Course Line.

Step 6b: Locate the Turn Side Splay Line End Point as the Splay End Reference Point projected onto the Secondary Turn Side Boundary of Segment 1.

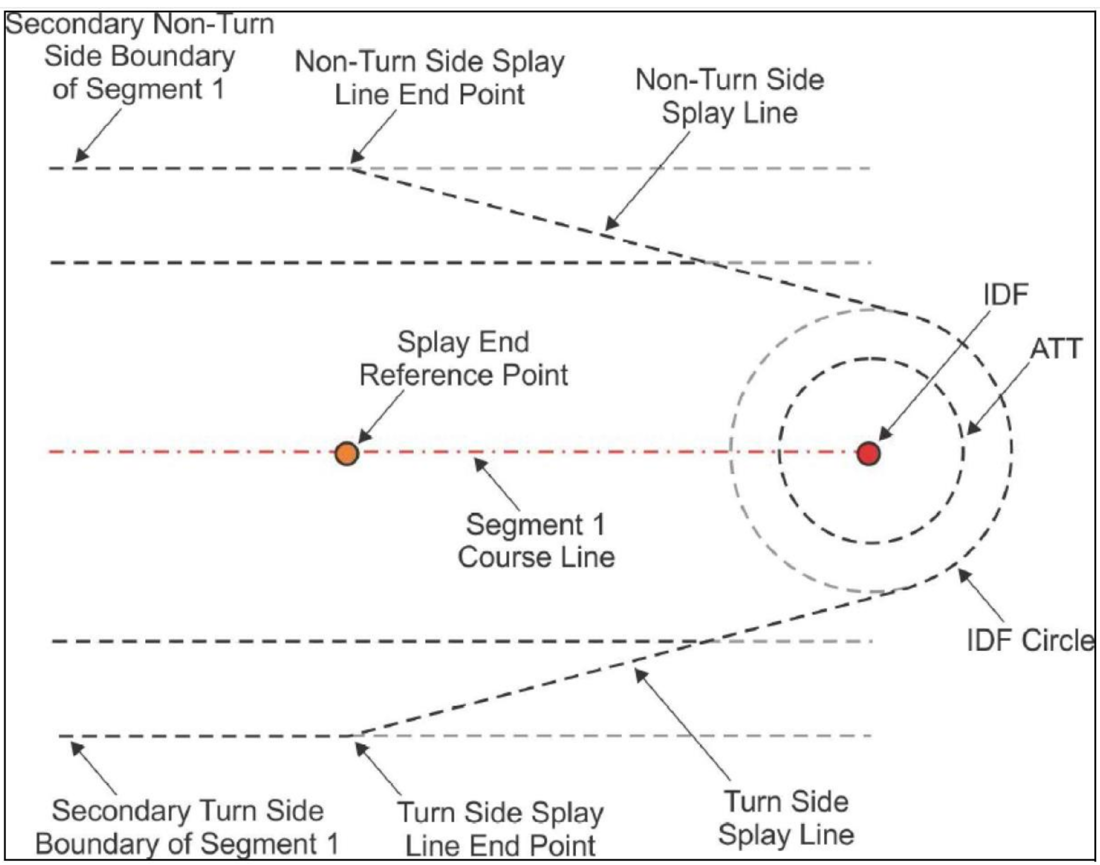
Step 6c: Construct the Turn Side Splay Line as a line that is tangent to the IDF Circle passing through the Turn Side Splay Line End Point.

Step 7: Construct the Non-Turn Side Splay Line (see Figure 8-6-6).

Step 7a: Locate the Non-Turn Side Splay Line End Point as the Splay End Reference Point projected onto the Secondary Non-Turn Side Boundary of Segment 1.

Step 7b: Construct the Non-Turn Side Splay Line as a line that is tangent to the IDF Circle passing through the Non-Turn Side Splay Line End Point.

Figure 8-6-6: Construction of the Splay Lines



Step 8: Construct the IDF Flat Surface Area (see Figure 8-6-7).

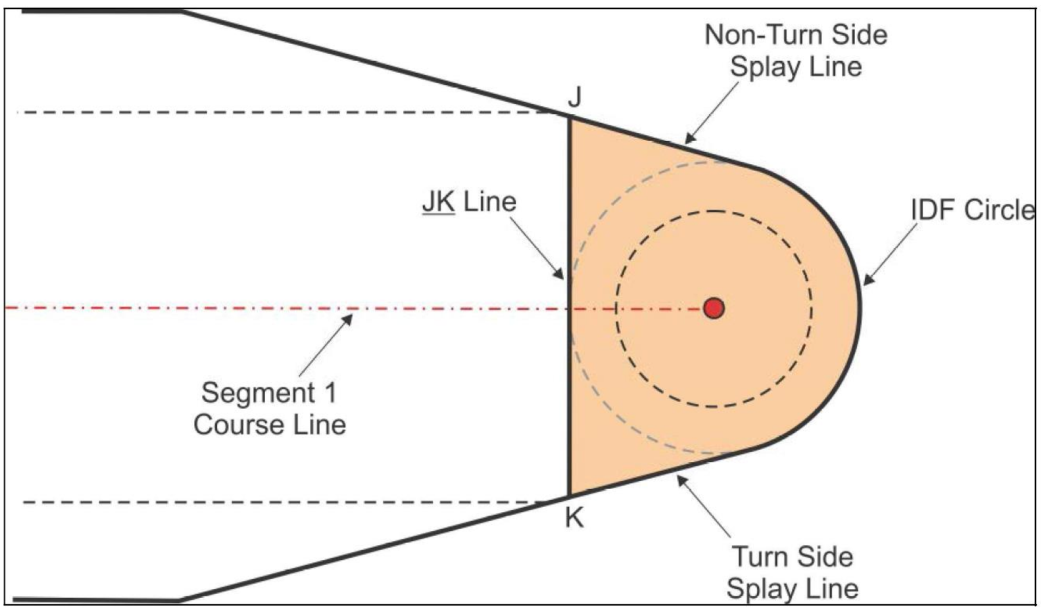
Step 8a: Construct the JK line as a line that lays tangent to the IDF Circle at a point intersecting the Segment 1 Course Line.

Step 8b: Truncate the JK line where it intersects the Turn Side Splay Line and the Non-Turn Side Splay Line.

Step 8c: The IDF Flat Surface Area is the area bounded by the IDF Circle, the Turn Side and Non-Turn Side Splay Lines, and the JK line.

Step 8d: The Turn Side end of the JK line will hereby be referred to as Point K and the Non-Turn Side end of the JK line will hereby be referred to as Point J.

Figure 8-6-7: Construction of the IDF Flat Surface Area

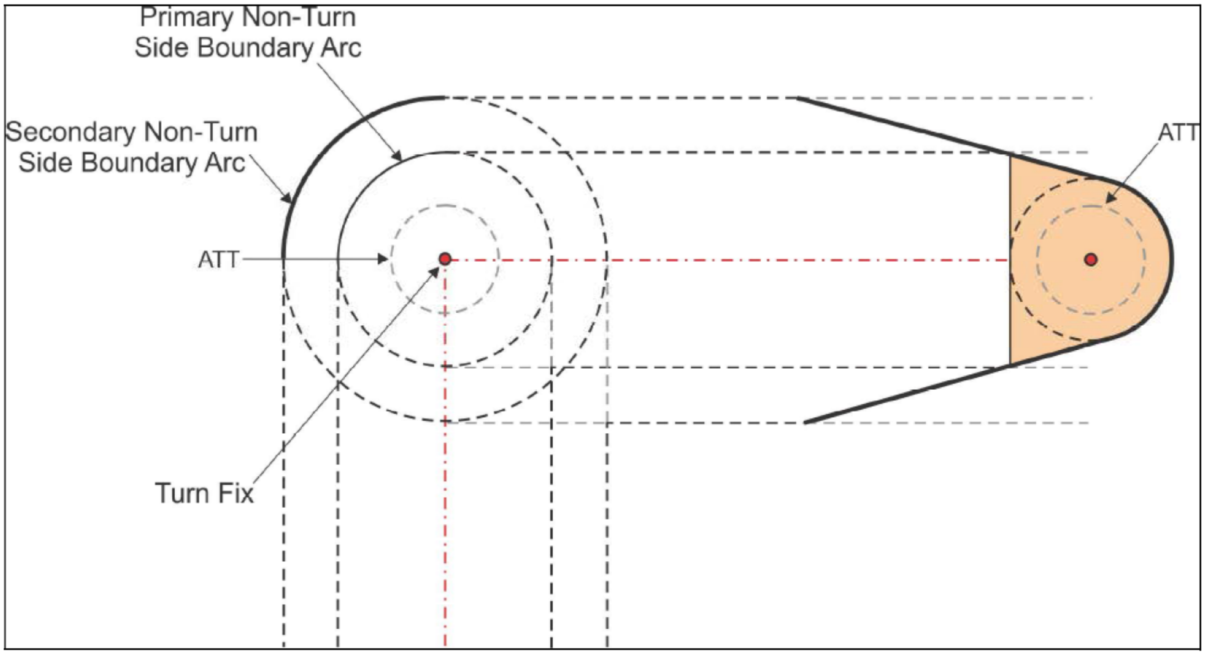


Step 9: Construct Non-Turn Side Boundary Arcs (see Figure 8-6-8).

Step 9a: Construct the Primary Non-Turn Side Boundary Arc centered on the turn fix with a radius equal to the Segment 1 primary half-width.

Step 9b: Construct the Secondary Non-Turn Side Boundary Arc centered on the turn fix with a radius equal to the Segment 1 primary half-width plus the segment secondary width.

Figure 8-6-8: Construction of the Non-Turn Side Boundary Arcs

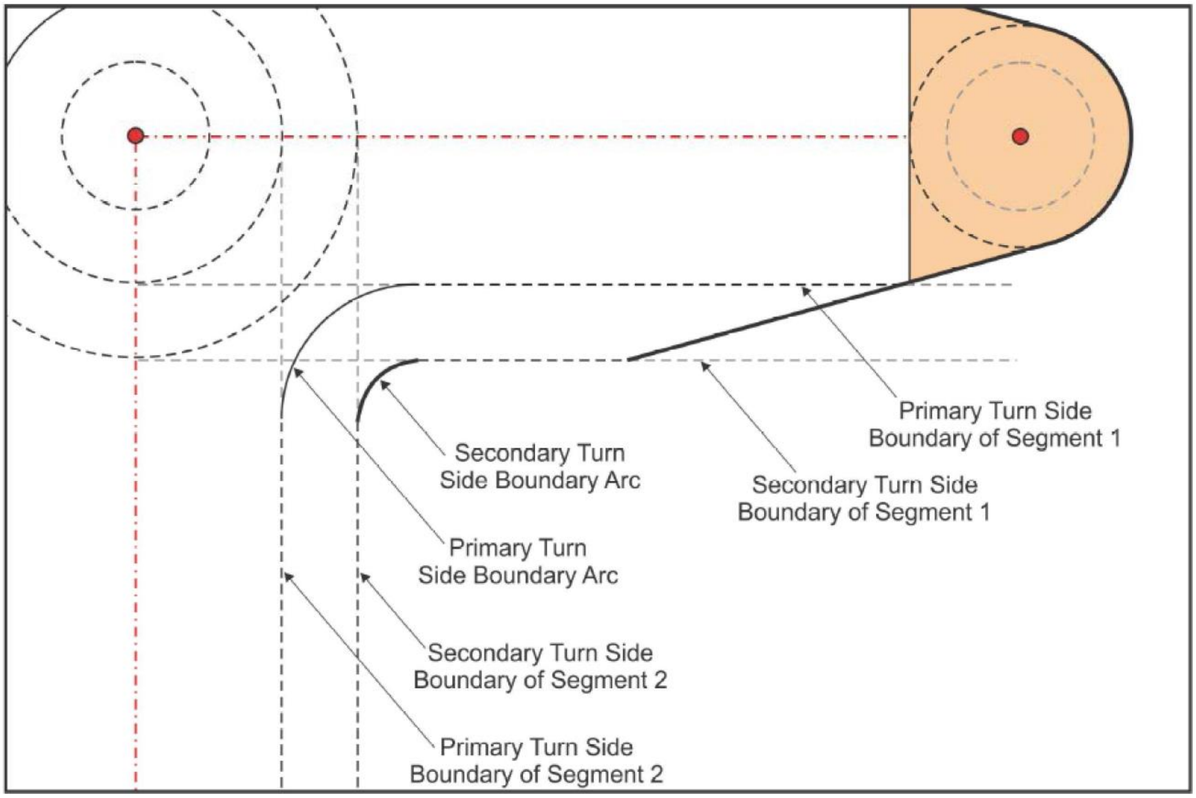


Step 10: Construct Turn Side Boundary Arcs (see Figure 8-6-9).

Step 10a: Construct the Primary Turn Side Boundary Arc tangent to the Primary Turn Side Boundaries of Segments 1 and 2 with a radius equal to R + 1 NM.

Step 10b: Construct the Secondary Turn Side Boundary Arc tangent to the Secondary Turn Side Boundaries of Segments 1 and 2 with a radius equal to R.

Figure 8-6-9: Construction of the Turn Side Boundary Arcs



Step 11: Define and Construct the Non-Turn Side Boundary.

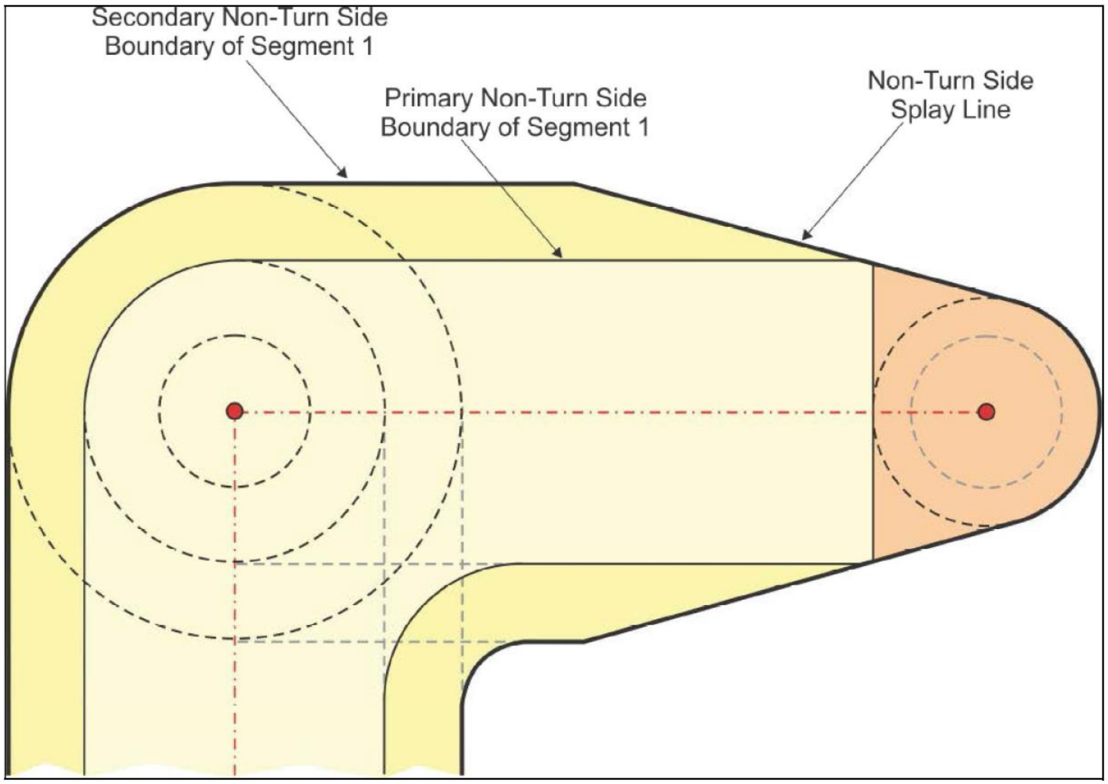
Step 11a: Depending on the course change at the second waypoint and the length of Segment 1, the Non-Turn Side Splay Line will either intersect the Secondary Non-Turn Side Boundary of Segment 1, the Secondary Non-Turn Side Boundary Arc, or the Secondary Non-Turn Side Boundary of Segment 2.

Step 11b: If the Non-Turn Side Splay Line intersects the Secondary Non-Turn Side Boundary of Segment 1 (see Figure 8-6-10), then:

Step 11b (1): Truncate the Secondary Non-Turn Side Boundary of Segment 1 at the intersection, and,

Step 11b (2): Truncate the Primary Non-Turn Side Boundary of Segment 1 where it intersects the Non-Turn Side Splay Line.

Figure 8-6-10: Construction of the Non-Turn Side Boundary, Case 1



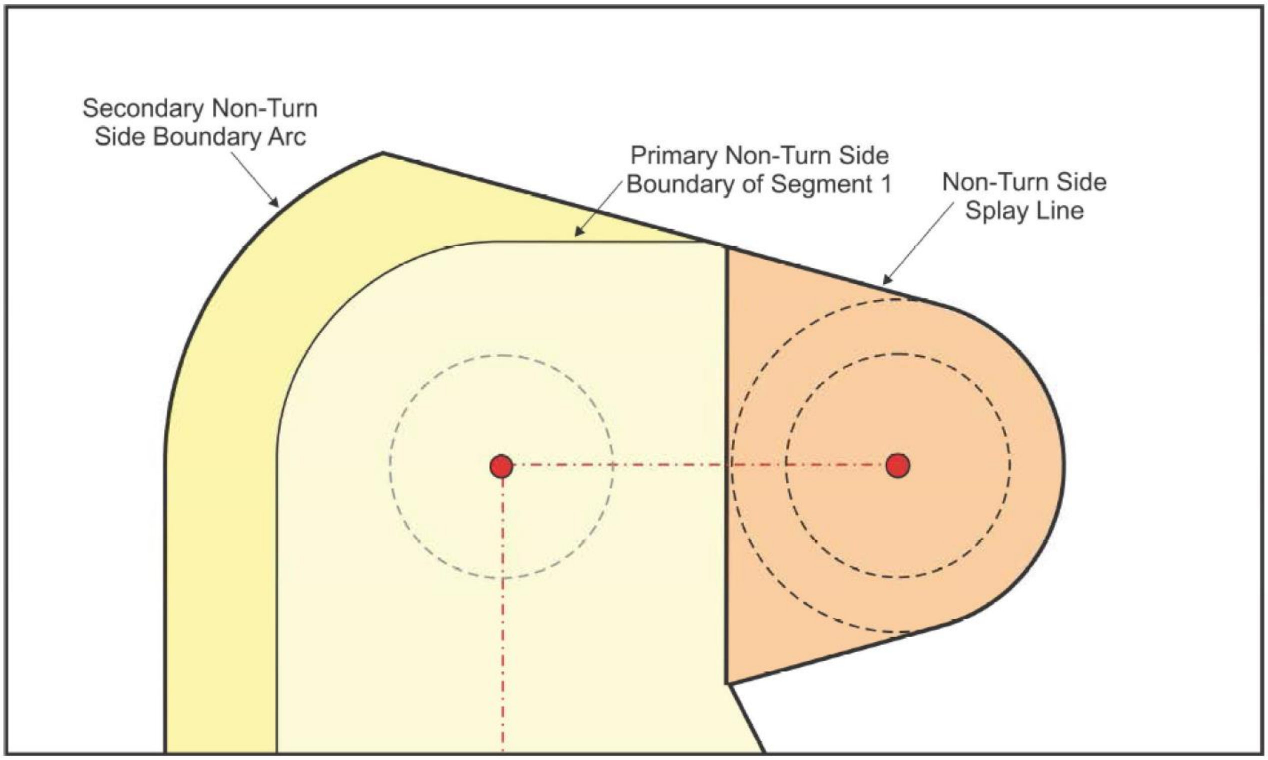
Step 11c: If the Non-Turn Side Splay Line intersects the Secondary Non-Turn Side Boundary Arc (see Figure 8-6-11) then,

Step 11c (1): Remove the Secondary Non-Turn Side Boundary of Segment 1,

Step 11c (2): Truncate the Secondary Non-Turn Side Boundary Arc at the intersection and,

Step 11c (3): Truncate the Primary Non-Turn Side Boundary of Segment 1 where it intersects the Non-Turn Side Splay Line.

Figure 8-6-11: Construction of the Non-Turn Side Boundary, Case 2



Step 11d: If the Non-Turn Side Splay Line intersects the Secondary Non-Turn Side Boundary of Segment 2 (see Figure 8-6-12) then,

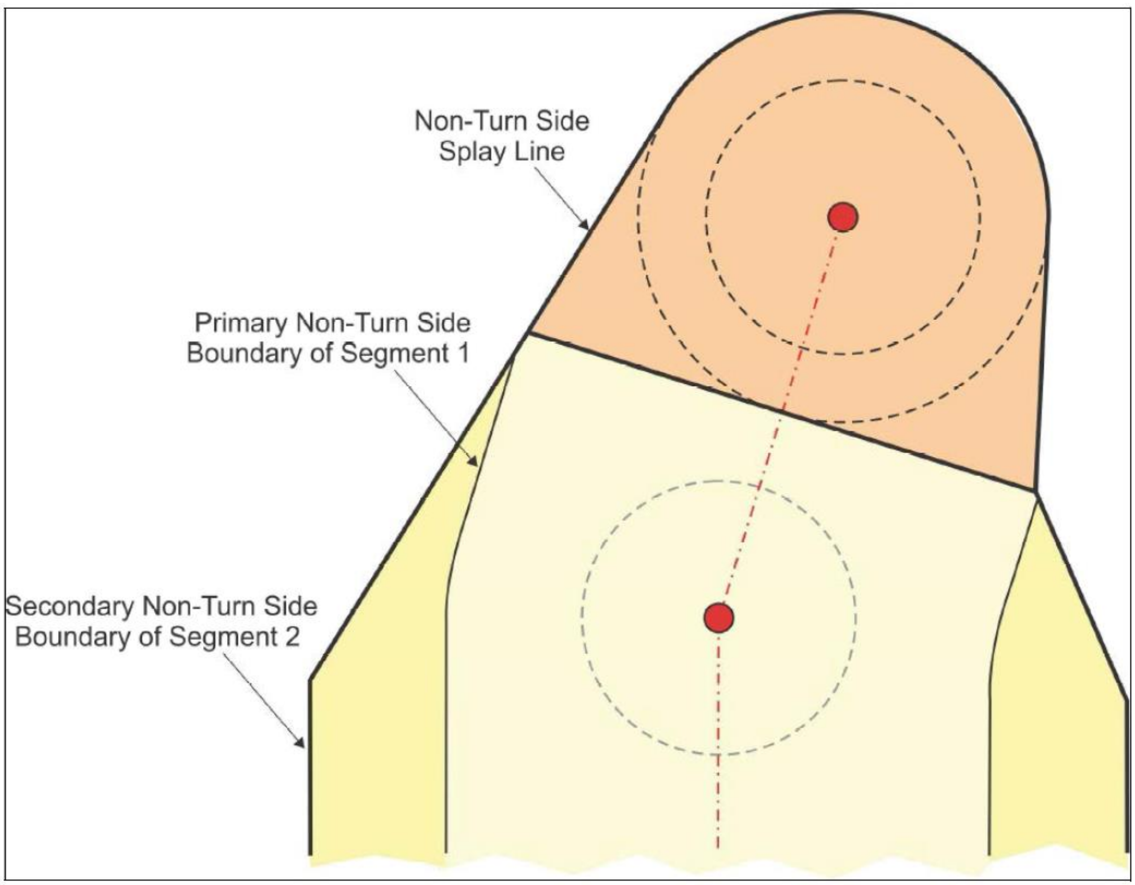
Step 11d (1): Remove the Secondary Non-Turn Side Boundary of Segment 1,

Step 11d (2): Remove the Secondary Non-Turn Side Boundary Arc,

Step 11d (3): Truncate the Secondary Non-Turn Side Boundary of Segment 2 at the intersection and,

Step 11d (4): Truncate the Primary Non-Turn Side Boundary of Segment 1 where it intersects the Non-Turn Side Splay Line.

Figure 8-6-12: Construction of the Non-Turn Side Boundary, Case 3



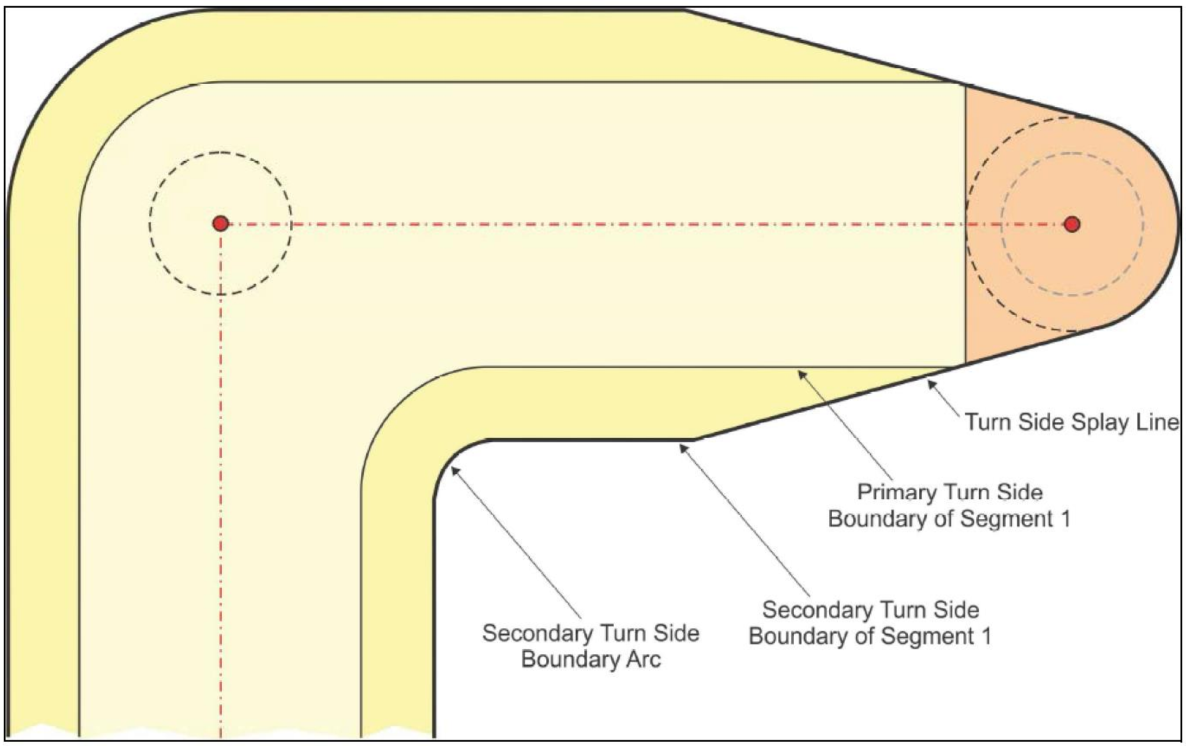
Step 12: Define and Construct the Turn Side Boundary.

Step 12a: If the Turn Side Splay Line intersects the Secondary Turn Side Boundary of Segment 1 before the start of the Secondary Turn Side Boundary Arc (see Figure 6-13) then,

Step 12a (1): Truncate the Primary Turn Side Boundary of Segment 1 at its intersection with the Turn Side Splay Line and,

Step 12a (2): Truncate the Secondary Turn Side Boundary of Segment 1 at its intersection with the Turn Side Splay Line.

Figure 8-6-13: Construction of the Turn Side Boundary, Case 1

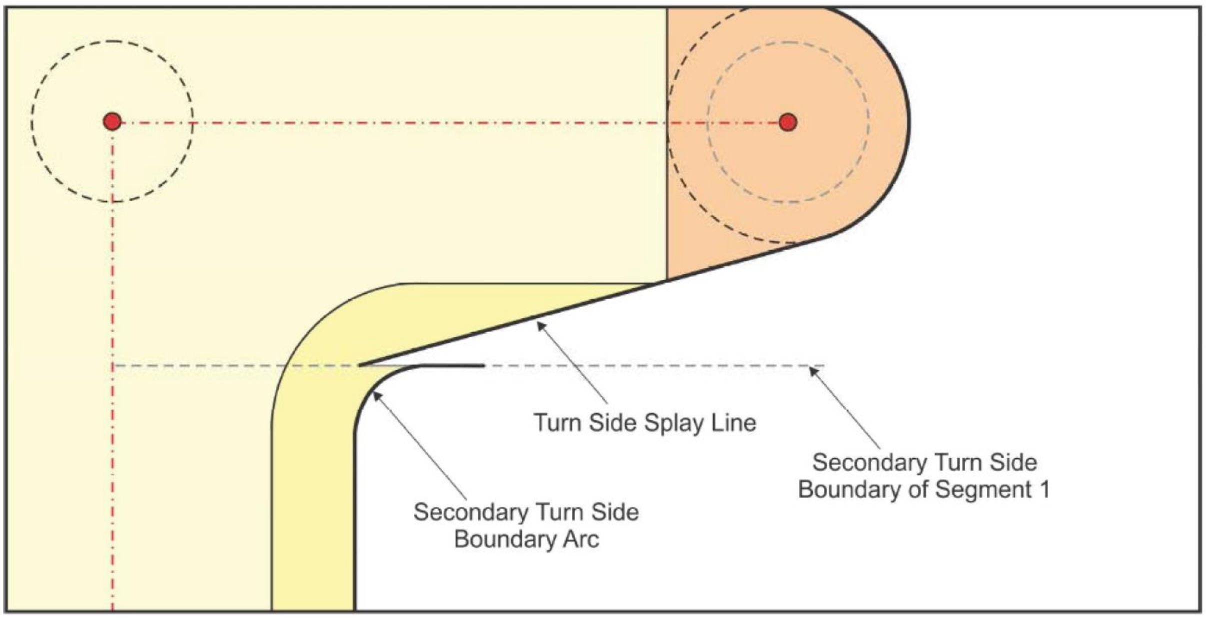


Step 12b: If the Turn Side Splay Line intersects the Secondary Turn Side Boundary of Segment 1 after the start of the Secondary Turn Side Boundary Arc (see Figure 8-6-14) then,

Step 12b (1): Construct the Turn Side Boundary Line as a line that lays tangent to the Secondary Turn Side Boundary Arc and passes through Point K.

Step 12b (1)(a): If the configuration of the procedure is such that this step cannot be performed, forego this step and proceed to Step 12c.

Figure 8-6-14. Construction of the Turn Side Boundary, Case 2 Determination



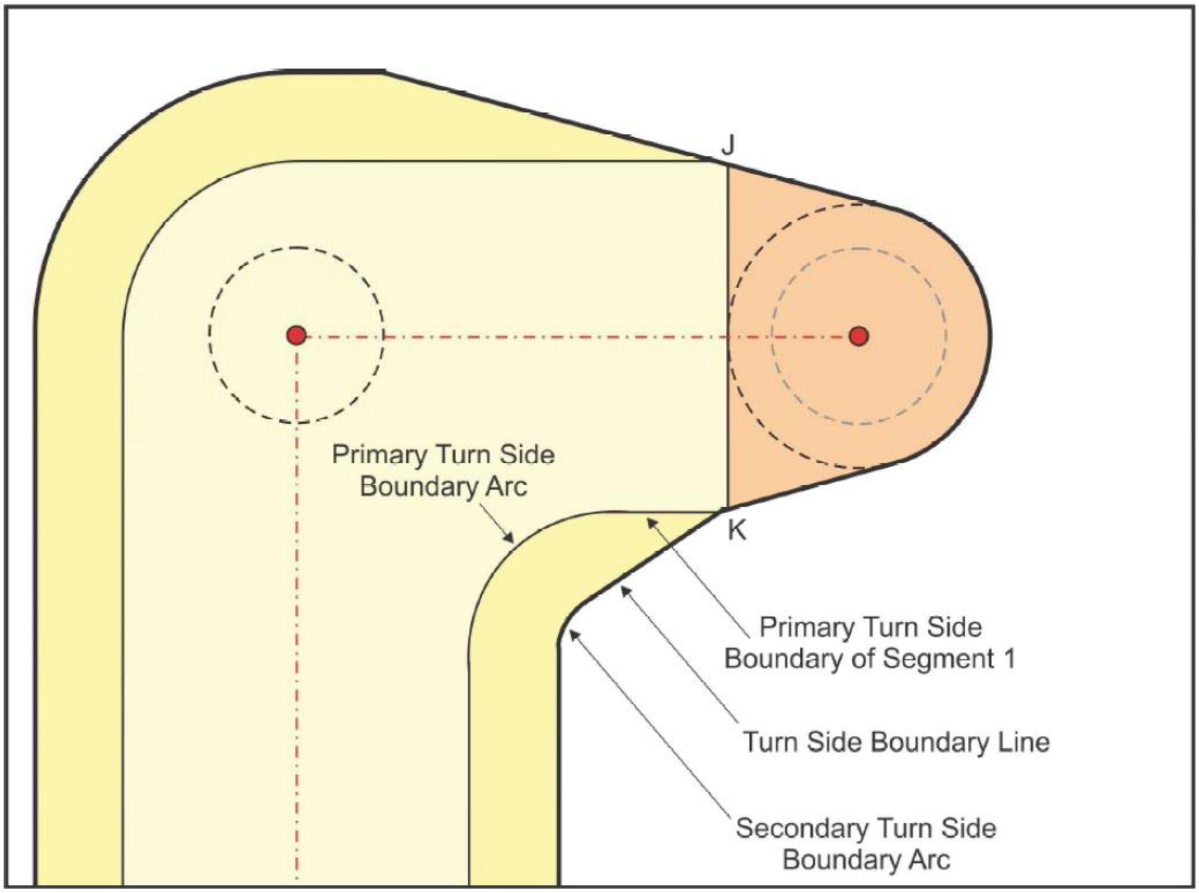
Step 12b (2): If the Turn Side Boundary Line intersects the Primary Turn Side Boundary of Segment 1 (see Figure 8-6-15) then,

Step 12b (2)(a): Truncate the Primary Turn Side Boundary of Segment 1 at its intersection with the Turn Side Boundary Line,

Step 12b (2)(b): Remove the Secondary Turn Side Boundary of Segment 1, and

Step 12b (2)(c): Truncate the Secondary Turn Side Boundary Arc at its point of tangency with the Turn Side Boundary Line.

Figure 8-6-15: Construction of the Turn Side Boundary, Case 2a



Step 12b (3): If the Turn Side Boundary Line intersects the Primary Turn Side Boundary Arc (see Figure 8-6-16) then,

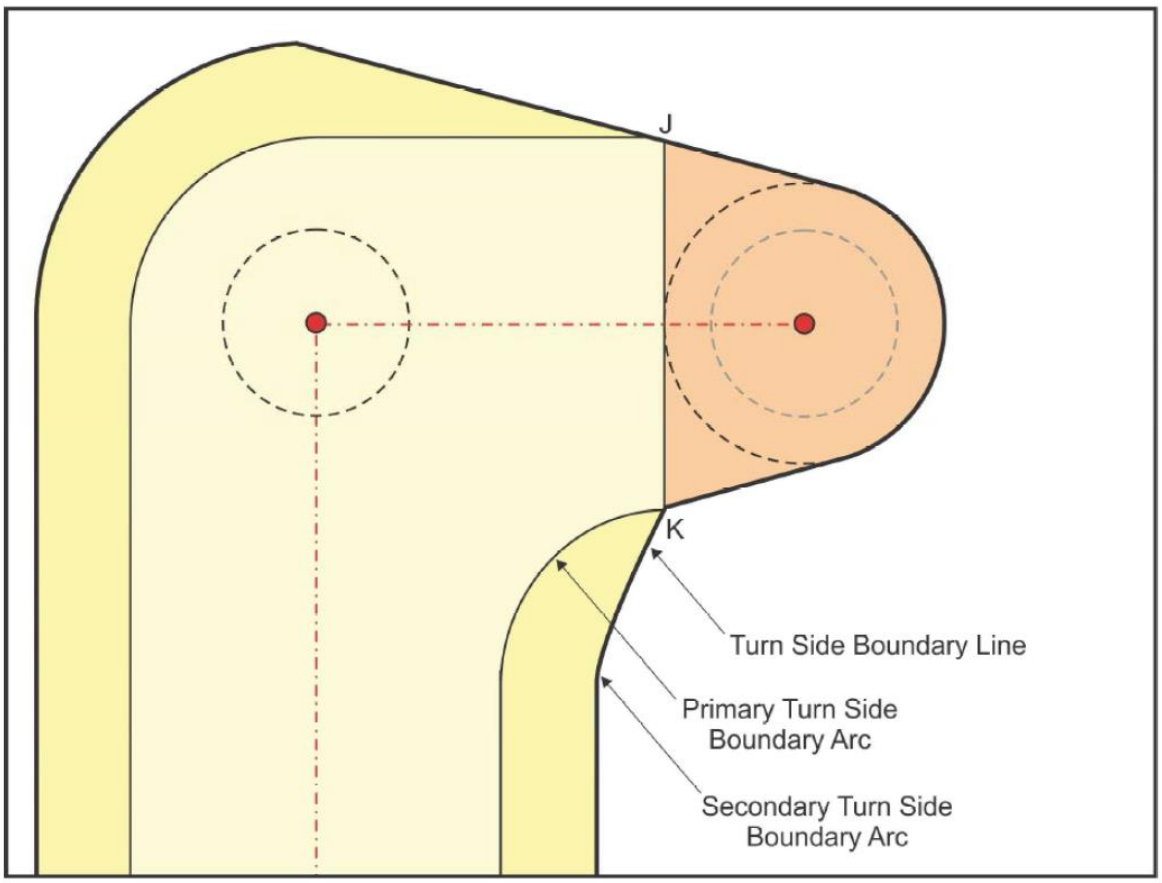
Step 12b (3)(a): Truncate the Primary Turn Side Boundary Arc at its intersection with the Turn Side Boundary Line,

Step 12b (3)(b): Truncate the Secondary Turn Side Boundary Arc at its point of tangency with the Turn Side Boundary Line,

Step 12b (3)(c): Remove the Primary Turn Side Boundary of Segment 1, and

Step 12b (3)(d): Remove the Secondary Turn Side Boundary of Segment 1.

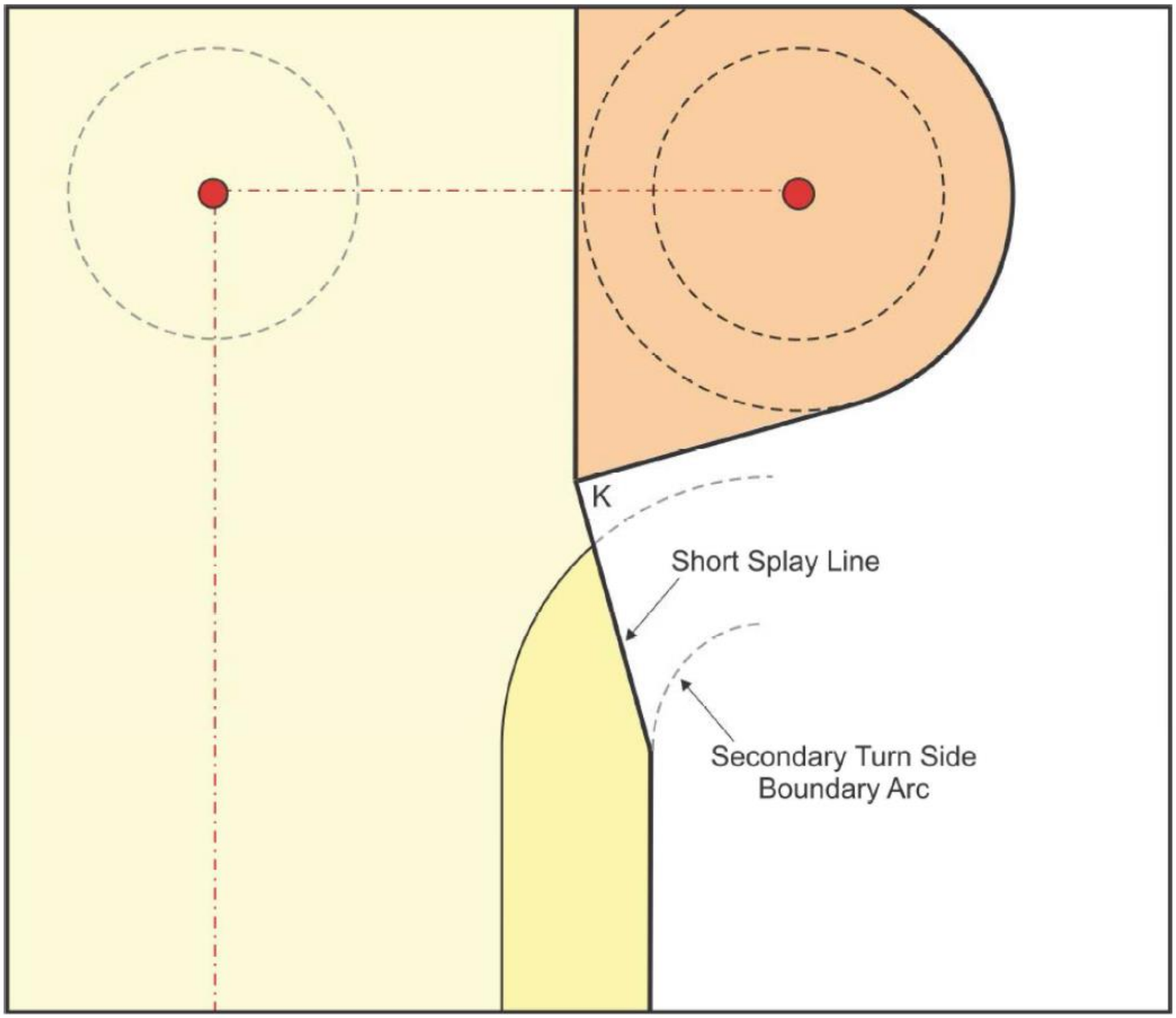
Figure 8-6-16: Construction of the Turn Side Boundary, Case 2b



Step 12c: If full width cannot be achieved in the initial segment [as described in Step 12a], and a tangent line cannot be drawn between Point K and the Secondary Turn Side Boundary Arc [as described in Step 12b(1)(a)],

Step 12c (1): Construct the Short Splay Line as a line that starts at Point K and ends at the end of the Secondary Turn Side Boundary Arc (see Figure 8-6-9).

Figure 8-6-17: Construction of the Turn Side Boundary, Case 3 Determination



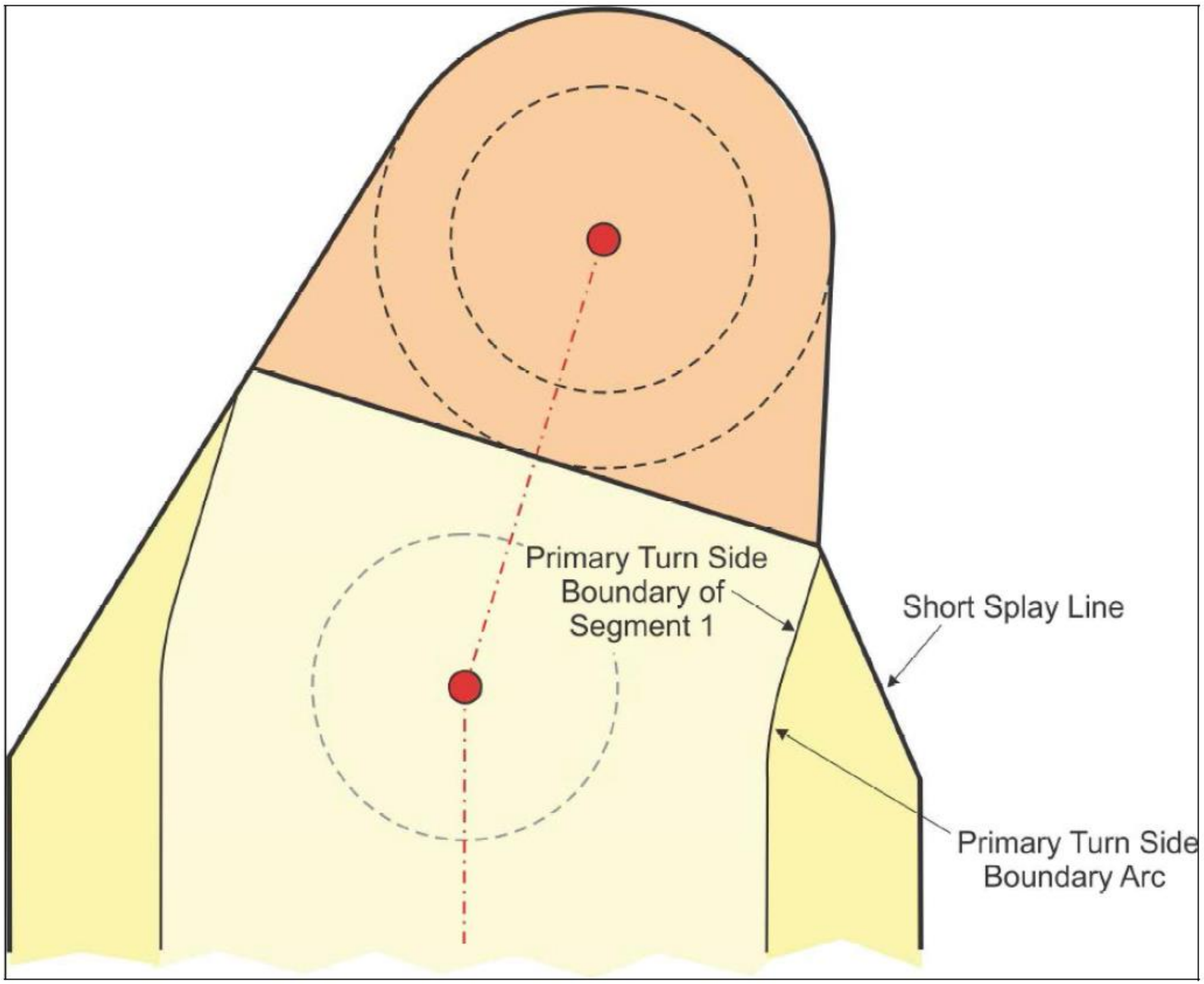
Step 12c (2): If the Short Splay Line intersects the Primary Turn Side Boundary of Segment 1 (see Figure 8-6-18) then,

Step 12c (2)(a): Remove the Secondary Turn Side Boundary of Segment 1,

Step 12c (2)(b): Remove the Secondary Turn Side Boundary Arc, and

Step 12c (2)(c): Truncate the Primary Turn Side Boundary of Segment 1 at its intersection with the Short Splay Line.

Figure 8-6-18: Construction of the Turn Side Boundary, Case 3a



Step 12c (3): If the Short Splay Line intersects the Primary Turn Side Boundary Arc (see Figure 8-6-19) then,

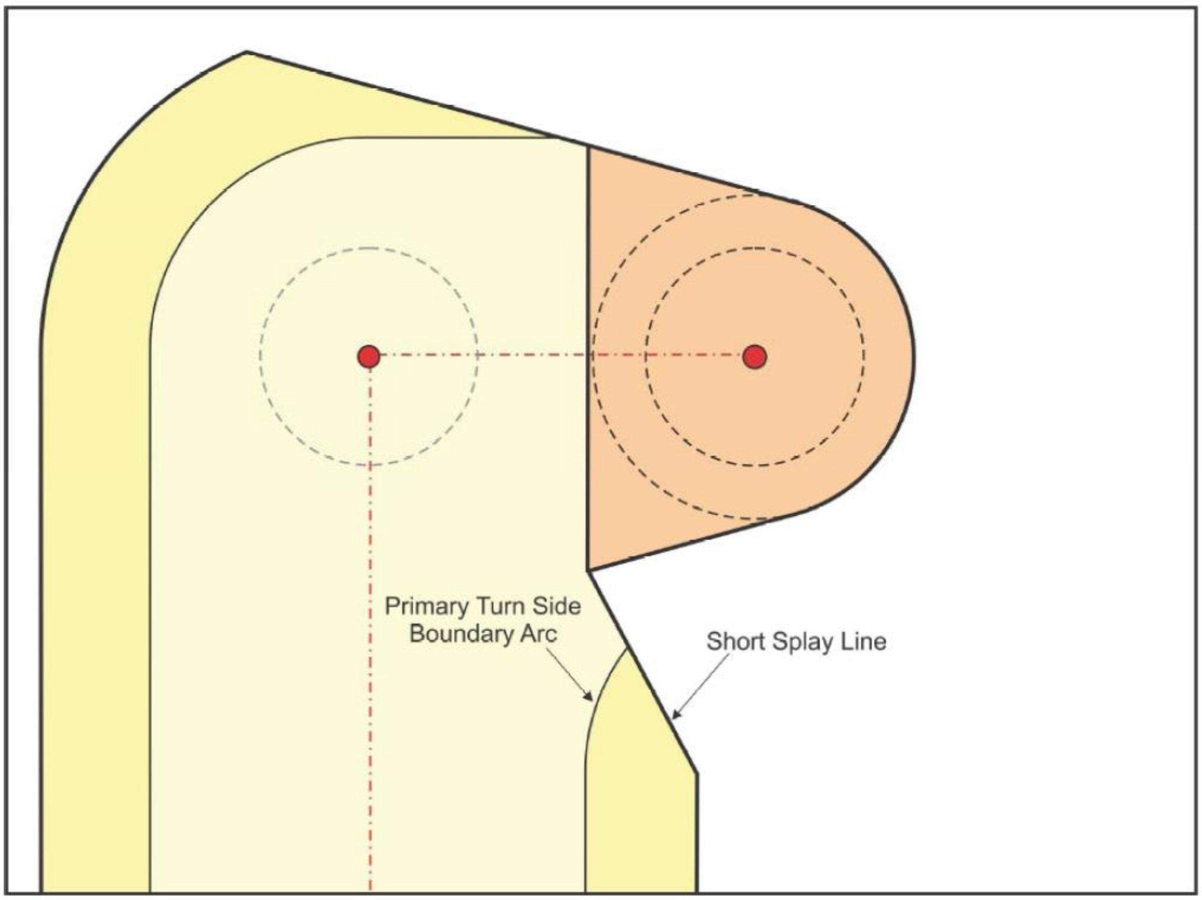
Step 12c (3)(a): Remove the Primary Turn Side Boundary of Segment 1,

Step 12c (3)(b): Remove the Secondary Turn Side Boundary of Segment 1,

Step 12c (3)(c): Remove the Secondary Turn Side Boundary Arc, and

Step 12c (3)(d): Truncate the Primary Turn Side Boundary Arc at its point of intersection with the Short Splay Line.

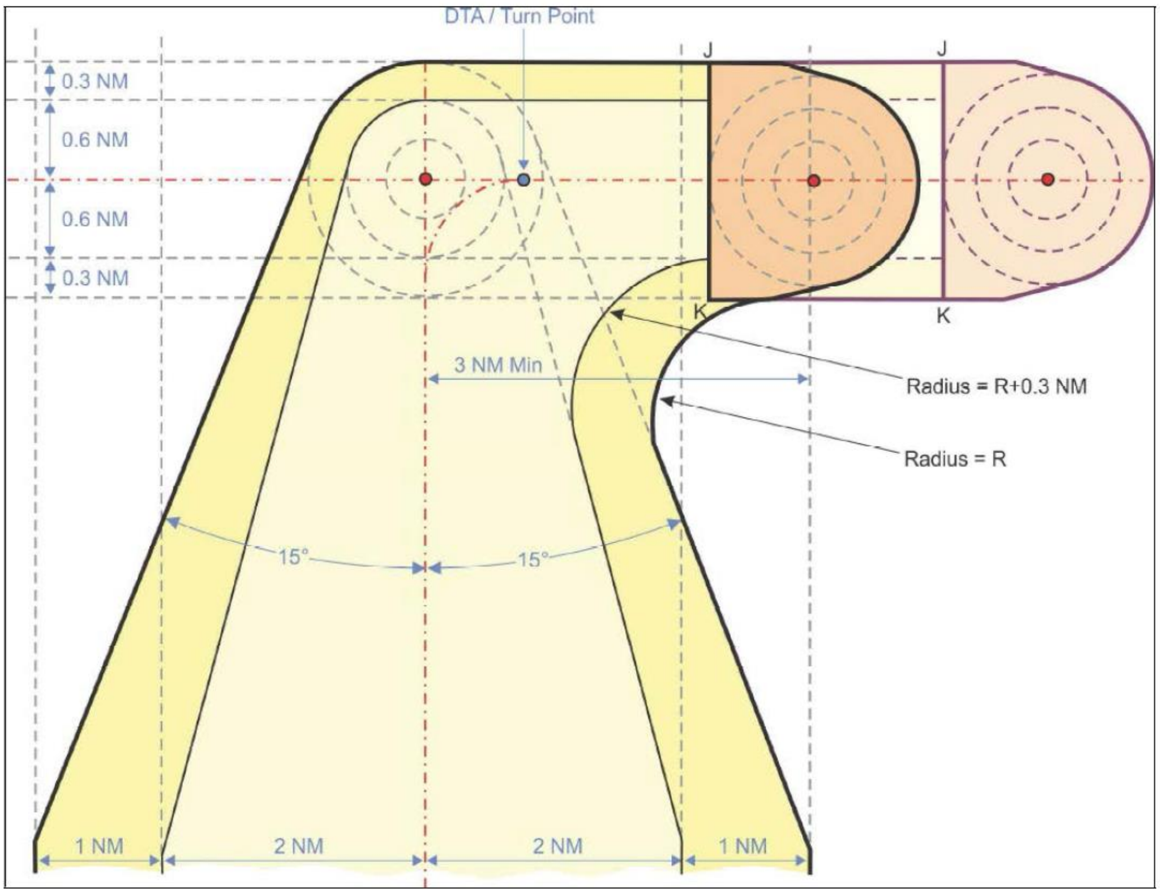
Figure 8-6-19: Construction of the Turn Side Boundary, Case 3b



8.6.7. **Restricted PinS Departure Construction.** When necessary to avoid obstacles, a Restricted DP may be constructed where the initial departure leg (only) is designed with an ATT value of 0.3 NM (e.g. RNP 0.3).

For this construction, multiple OEA configurations can occur that are greatly affected by the course change angle and the length of the first departure segment. Some examples of these different scenarios are illustrated in Figure 8-6-20. Instructions on how to define these cases and create the resulting OEAs are located in this paragraph.

Figure 8-6-20: Restricted OEA Area Plan View (90 Degree Turn)



Step 1: Position the IDF as an FB fix. Use a fix-to-fix distance that is in accordance with paragraph 8.6.4b(2).

Step 2: Construct the IDF Circle as an arc with a 0.8 NM radius centered at the IDF fix.

Step 3: Construct the Designed Turning Flight Path.

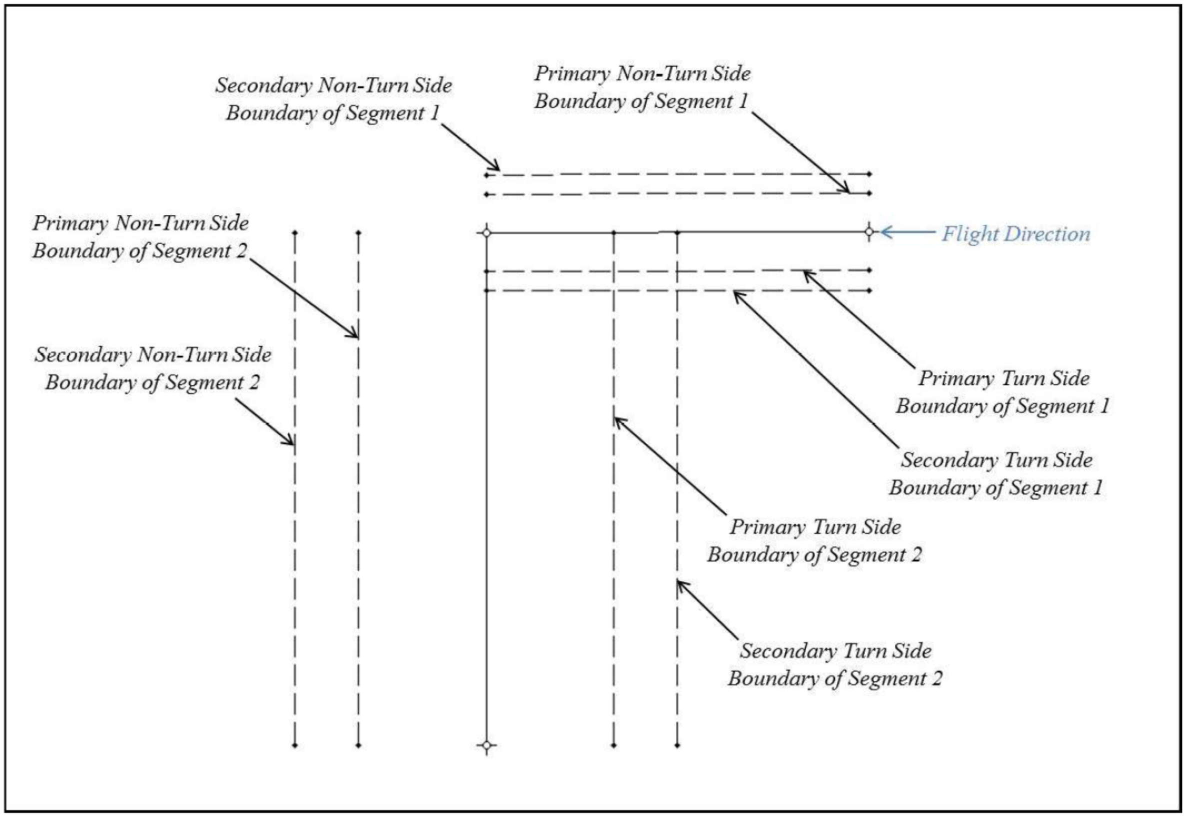
Step 3a: Determine the turn radius (R) utilizing Formula 6-1.

Step 3b: Construct an arc of radius R starting at the early turn point that lays tangent to Segments 1 and 2.

Step 4: Construct Segment 1 Boundaries. Construct Boundaries of half-widths 0.3-0.6-0.6-0.3 in reference to Segment 1. They will hereby be referred to as the Secondary Turn Side Boundary of Segment 1, the Primary Turn Side Boundary of Segment 1, the Primary Non-Turn Side Boundary of Segment 1, and the Secondary Non-Turn Side Boundary of Segment 1. These boundaries are depicted in Figure 8-6-21.

Step 5: Construct Segment 2 Boundaries. Construct Boundaries of half-widths 1-2-2-1 in reference to Segment 2. They will hereby be referred to as the Secondary Turn Side Boundary of Segment 2, the Primary Turn Side Boundary of Segment 2, the Primary Non-Turn Side Boundary of Segment 2, and the Secondary Non-Turn Side Boundary of Segment 2. These boundaries are depicted in Figure 8-6-21.

Figure 8-6-21: Construction of the Segment 1 and Segment 2 Boundaries



Step 6: Construct the Segment 1 Turn Side Splay Line (see Figure 8-6-22).

Step 6a: Locate the Segment 1 Splay End Reference Point a distance of 0.1/tan(15°) NM from the IDF along the Segment 1 Course Line.

Step 6b: Locate the Segment 1 Turn Side Splay Line End Point as the Segment 1 Splay End Reference Point projected onto the Secondary Turn Side Boundary of Segment 1.

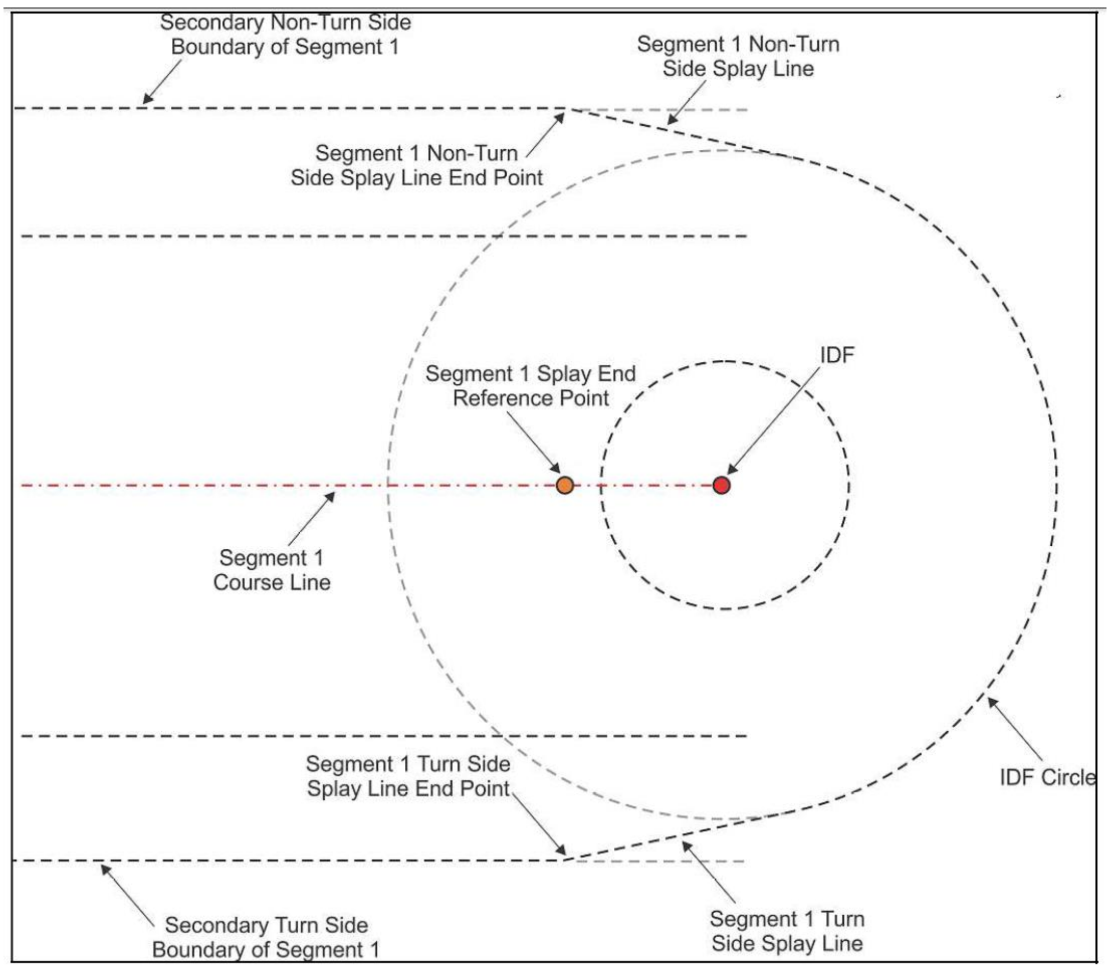
Step 6c: Construct the Segment 1 Turn Side Splay Line as a line that is tangent to the IDF Circle passing through the Segment 1 Turn Side Splay Line End Point.

Step 7: Construct the Segment 1 Non-Turn Side Splay Line (see Figure 8-6-22).

Step 7a: Locate the Segment 1 Non-Turn Side Splay Line End Point as the Segment 1 Splay End Reference Point projected onto the Secondary Non-Turn Side Boundary of Segment 1.

Step 7b: Construct the Segment 1 Non-Turn Side Splay Line as a line that is tangent to the IDF Circle passing through the Segment 1 Non-Turn Side Splay Line End Point.

Figure 8-6-22: Construction of the Splay Lines



Step 8: Construct the IDF Flat Surface Area (see Figure 8-6-23).

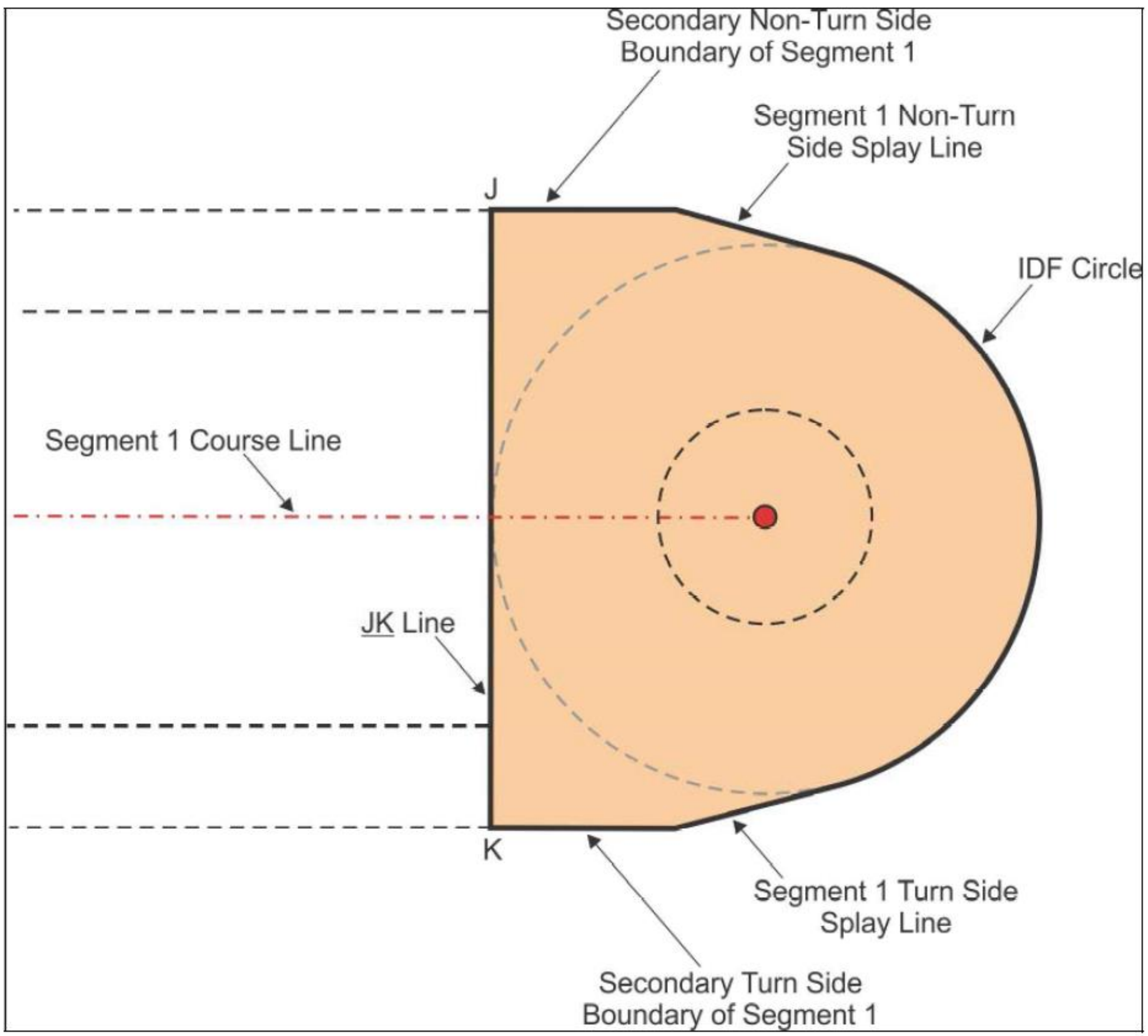
Step 8a: Construct the JK line as a line that lays tangent to the IDF Circle at a point intersecting the Segment 1 Course Line.

Step 8b: Truncate the JK line where it intersects the Secondary Non-Turn Side Boundary of Segment 1 and the Secondary Turn Side Boundary of Segment 1.

Step 8c: The IDF Flat Surface Area is the area bounded by the IDF Circle, the Segment 1 Turn Side and Non-Turn Side Splay Lines, the Secondary Turn Side and Non-Turn Side Boundaries of Segment 1, and the JK line.

Step 8d: The Turn Side end of the JK line will hereby be referred to as Point K and the Non-Turn Side end of the JK line will hereby be referred to as Point J.

Figure 8-6-23: Construction of the IDF Flat Surface Area

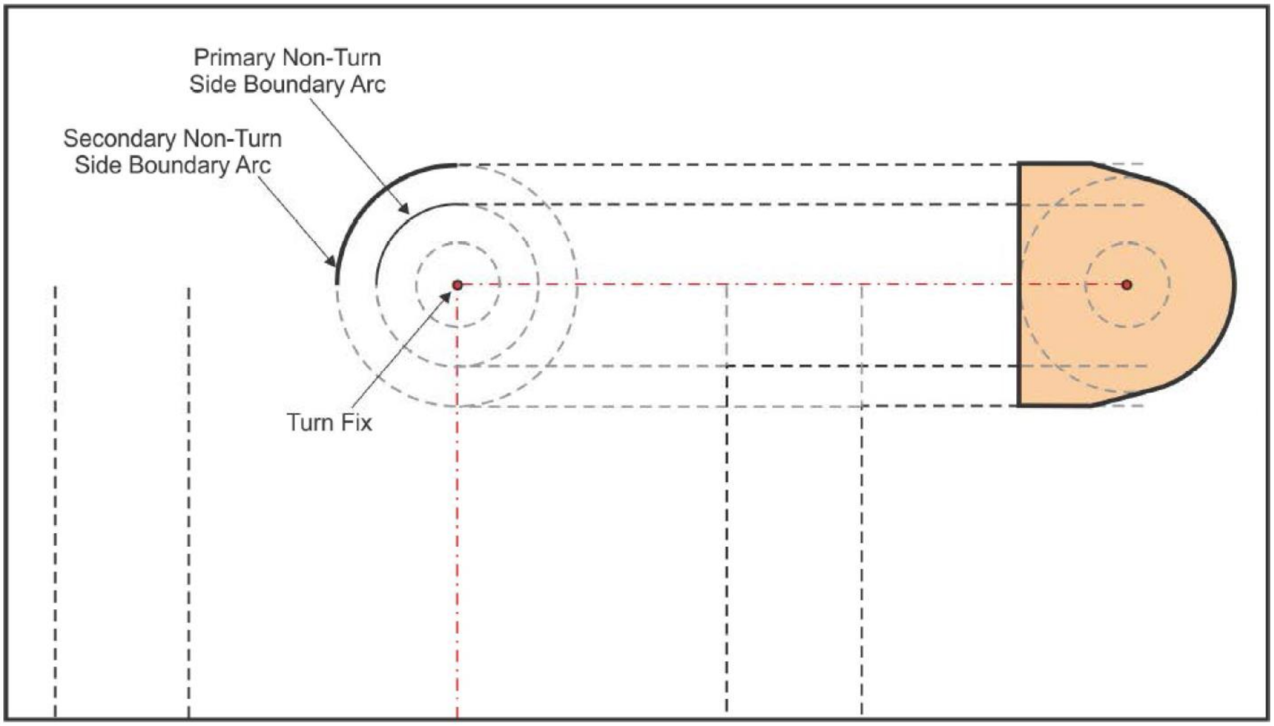


Step 9: Construct Non-Turn Side Boundary Arcs (see Figure 8-6-24).

Step 9a: Construct the Primary Non-Turn Side Boundary Arc centered on the turn fix with a radius equal to the Segment 1 primary half-width.

Step 9b: Construct the Secondary Non-Turn Side Boundary Arc centered on the turn fix with a radius equal to the Segment 1 primary half-width plus the segment secondary width.

Figure 8-6-24: Construction of the Non-Turn Side Boundary Arcs



Step 10: Construct Segment 2 Splay Lines.

Step 10a: Construct Segment 2 Secondary Non-Turn Side Splay Line (see Figure 8-6-25).

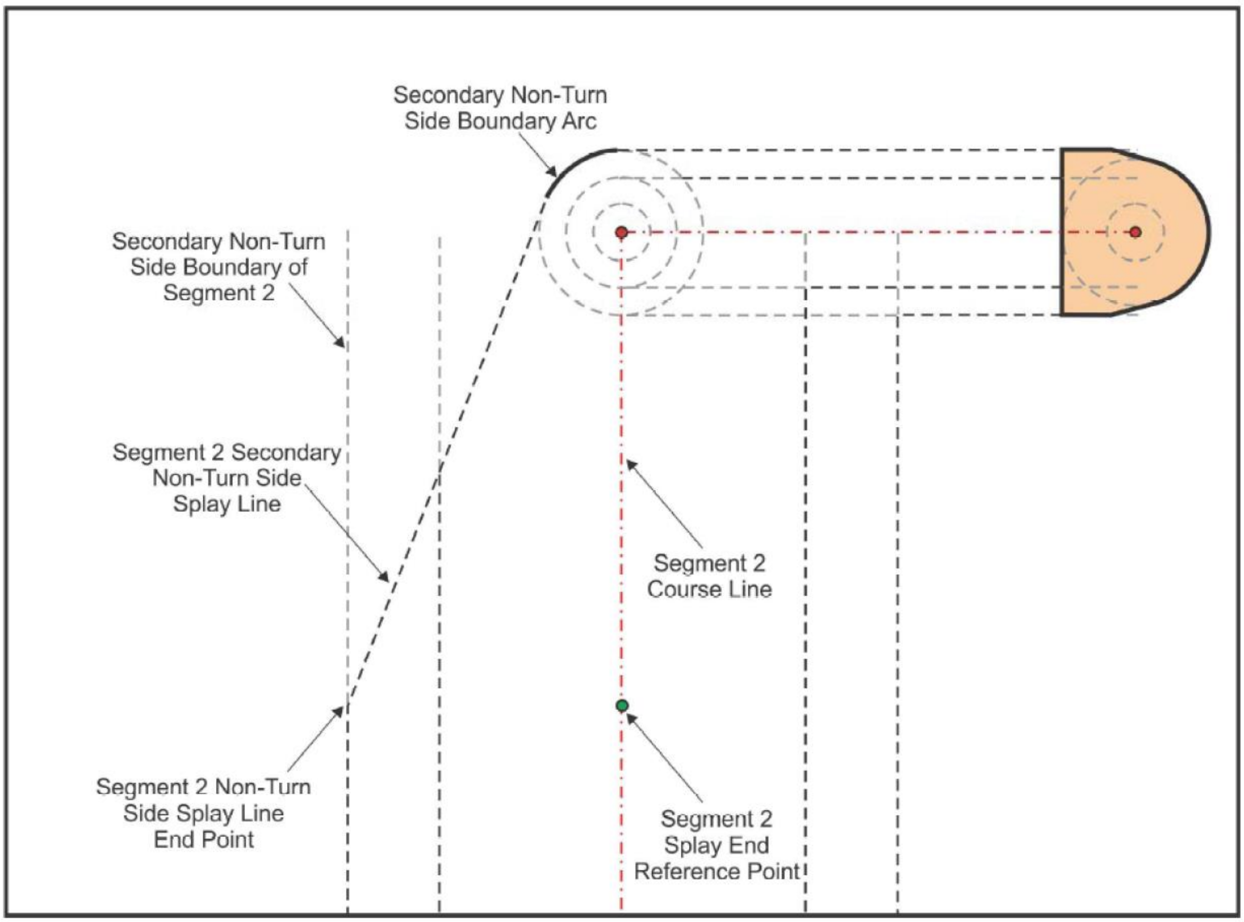
Step 10a (1): Locate the Segment 2 Splay End Reference Point a distance of 2.1/tan(15°) NM from the turn fix along the Segment 2 Course Line.

Step 10a (2): Locate the Segment 2 Non-Turn Side Splay Line End Point as the Segment 2 Splay End Reference Point projected onto the Secondary Non-Turn Side Boundary of Segment 2.

Step 10a (3): Construct the Segment 2 Secondary Non-Turn Side Splay Line as a line that is tangent to the Secondary Non-Turn Side Boundary Arc passing through the Segment 2 Non-Turn Side Splay Line End Point.

Step 10a (4): If Segment 2 is not long enough to allow for a full expansion with a 15-degree splay, utilize a splay angle ≥15 degrees as necessary to reach full expansion at the termination of Segment 2.

Figure 8-6-25: Construction of the Segment 2 Secondary Non-Turn Side Splay Line



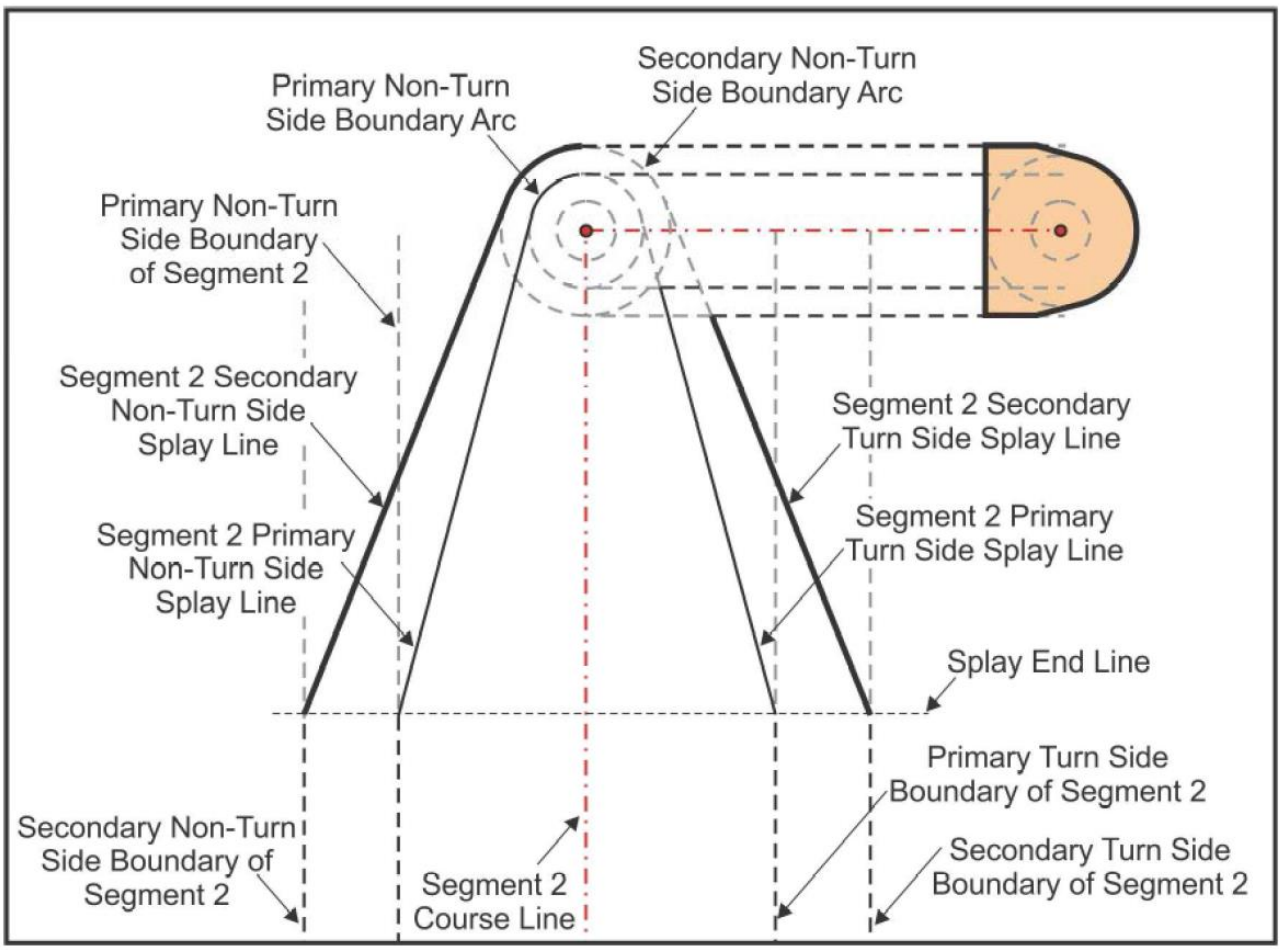
Step 10b: Construct the Splay End Line as an infinite line that is perpendicular to the Segment 2 Course Line and intersects at the end point of the Segment 2 Secondary Non-Turn Side Splay Line. The Splay End Line will be used to determine the end points of the remaining Segment 2 splay lines (see Figure 8-6-26).

Step 10c: Construct the Segment 2 Primary Non-Turn Side Splay Line as a line tangent to the Primary Non-Turn Side Boundary Arc and runs through the intersection of the Splay End Line and the Primary Non-Turn Side Boundary of Segment 2 (see Figure 8-6-26).

Step 10d: Construct the Segment 2 Primary Turn Side Splay Line as a line tangent to the Primary Non-Turn Side Boundary Arc and runs through the intersection of the Splay End Line and the Primary Turn Side Boundary of Segment 2 (see Figure 8-6-26).

Step 10e: Construct the Segment 2 Secondary Turn Side Splay Line as a line tangent to the Secondary Non-Turn Side Boundary Arc and runs through the intersection of the Splay End Line and the Secondary Turn Side Boundary of Segment 2 (see Figure 8-6-26).

Figure 8-6-26: Construction of the Segment 2 Splay Lines



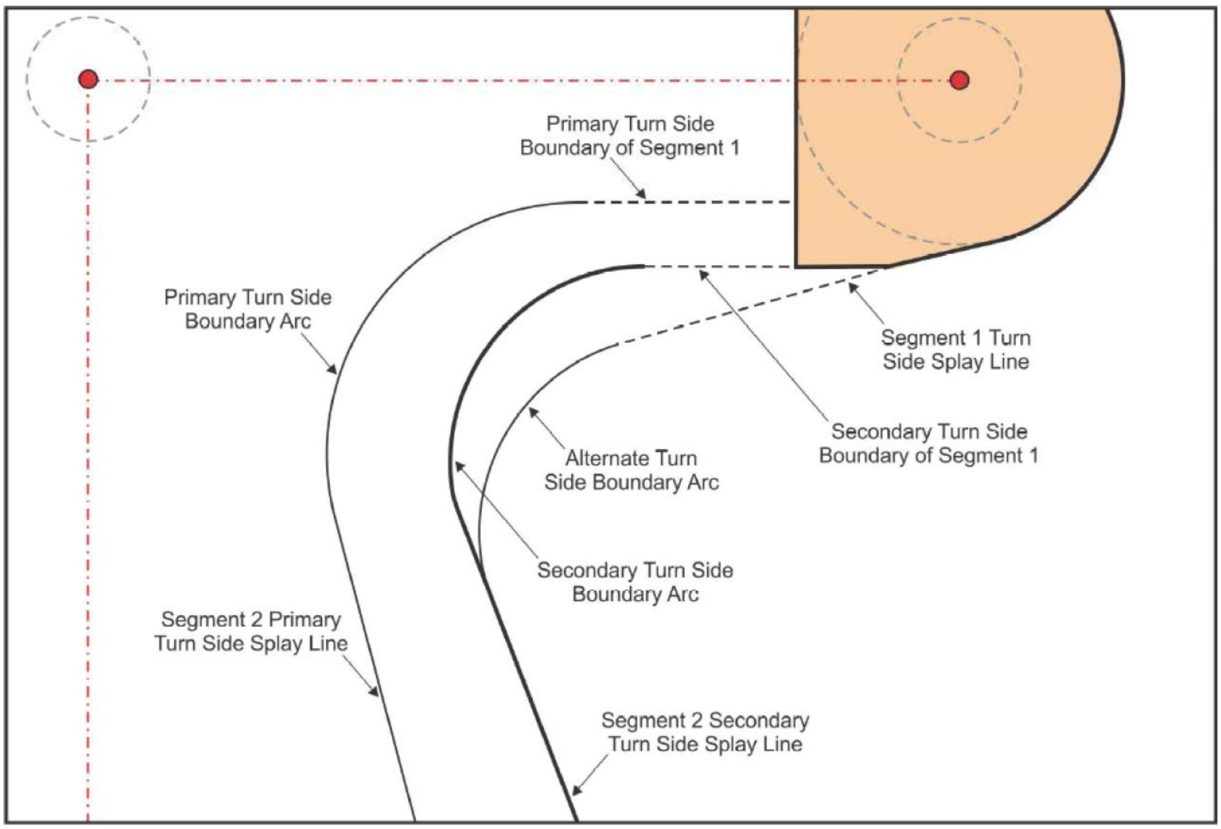
Step 11: Construct Turn Side Boundary Arcs (see Figure 8-6-27).

Step 11a: Construct the Primary Turn Side Boundary Arc as an arc that is tangent to both the Segment 2 Primary Turn Side Splay Line and the Primary Turn Side Boundary of Segment 1 with a radius equal to R + 0.3 NM.

Step 11b: Construct the Secondary Turn Side Boundary Arc an arc that is tangent to both the Segment 2 Secondary Turn Side Splay Line and the Secondary Turn Side Boundary of Segment 1 with a radius equal to R.

Step 11c: Construct the Alternate Turn Side Boundary Arc as an arc that is tangent to both the Segment 2 Secondary Turn Side Splay Line and the Segment 1 Turn Side Splay Line with a radius equal to R.

Figure 8-6-27: Construction of the Turn Side Boundary Arcs

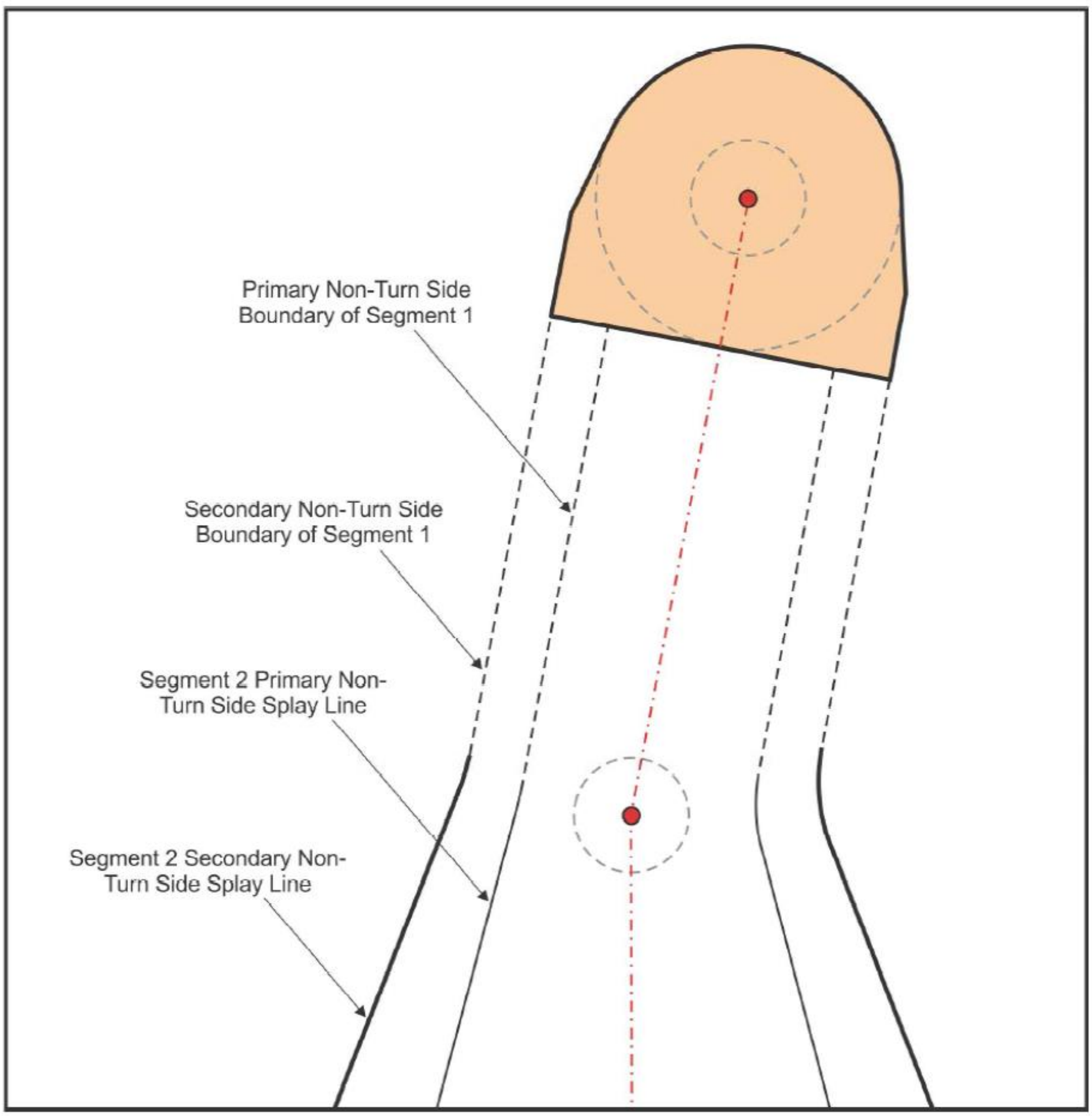


Step 12: Define and Construct the Secondary Non-Turn Side Boundary.

Step 12a: If the Secondary Non-Turn Side Boundary of Segment 1 intersects the Segment 2 Secondary Non-Turn Side Splay Line, as depicted in Figure 8-6-28, then remove the Secondary Non-Turn Side Boundary Arc and truncate the Secondary Non-Turn Side Boundary of Segment 1 and the Segment 2 Secondary Non-Turn Side Splay Line at their intersection.

Step 12b: Otherwise, truncate the Secondary Non-Turn Side Boundary of Segment 1 and the Segment 2 Secondary Non-Turn Side Splay Line at their point of tangency with the Secondary Non-Turn Side Boundary Arc (see Figure 8-6-29).

Figure 8-6-28: Construction of the Non-Turn Side Boundary, Case 1

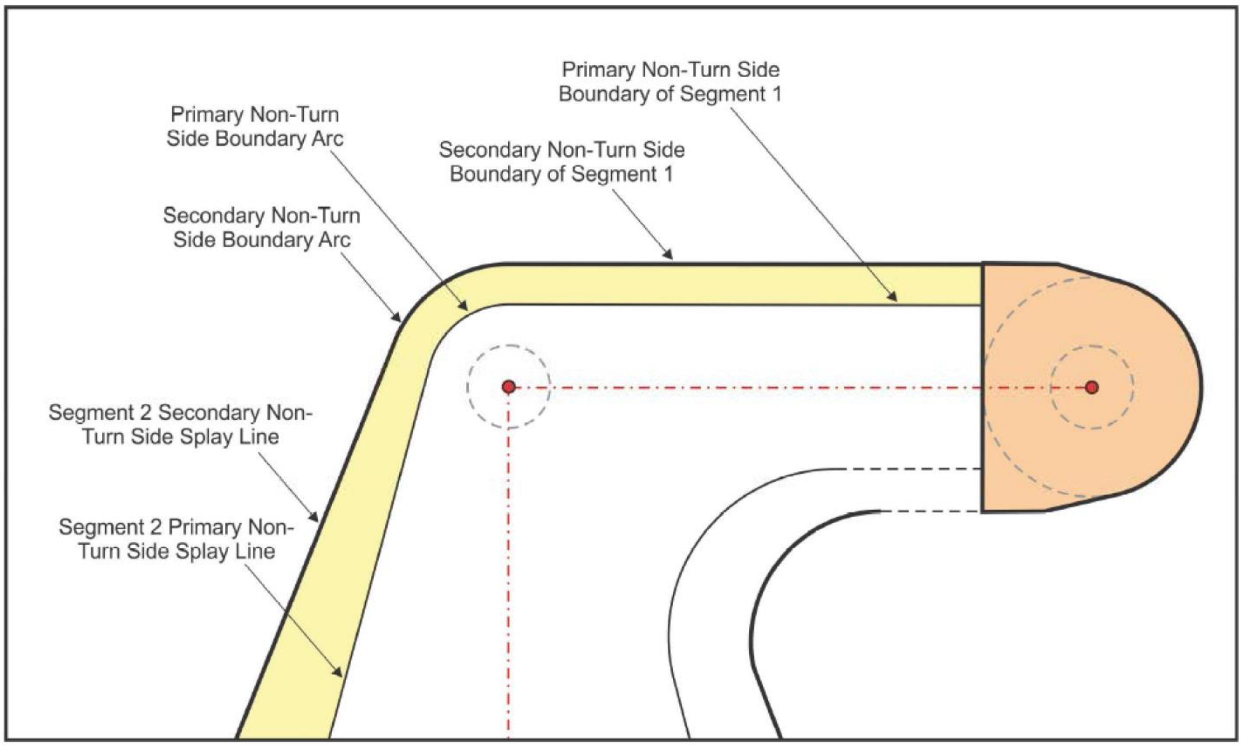


Step 13: Define and Construct the Primary Non-Turn Side Boundary.

Step 13a: If the Primary Non-Turn Side Boundary of Segment 1 intersects the Segment 2 Primary Non-Turn Side Splay Line, as depicted in Figure 8-6-28, then remove the Primary Non- Turn Side Boundary Arc and truncate the Primary Non-Turn Side Boundary of Segment 1 and the Segment 2 Primary Non-Turn Side Splay Line at their intersection.

Step 13b: Otherwise, truncate the Primary Non-Turn Side Boundary of Segment 1 and the Segment 2 Primary Non-Turn Side Splay Line at their point of tangency with the Primary Non-Turn Side Boundary Arc (see Figure 8-6-29).

Figure 8-6-29: Construction of the Non-Turn Side Boundary, Case 2



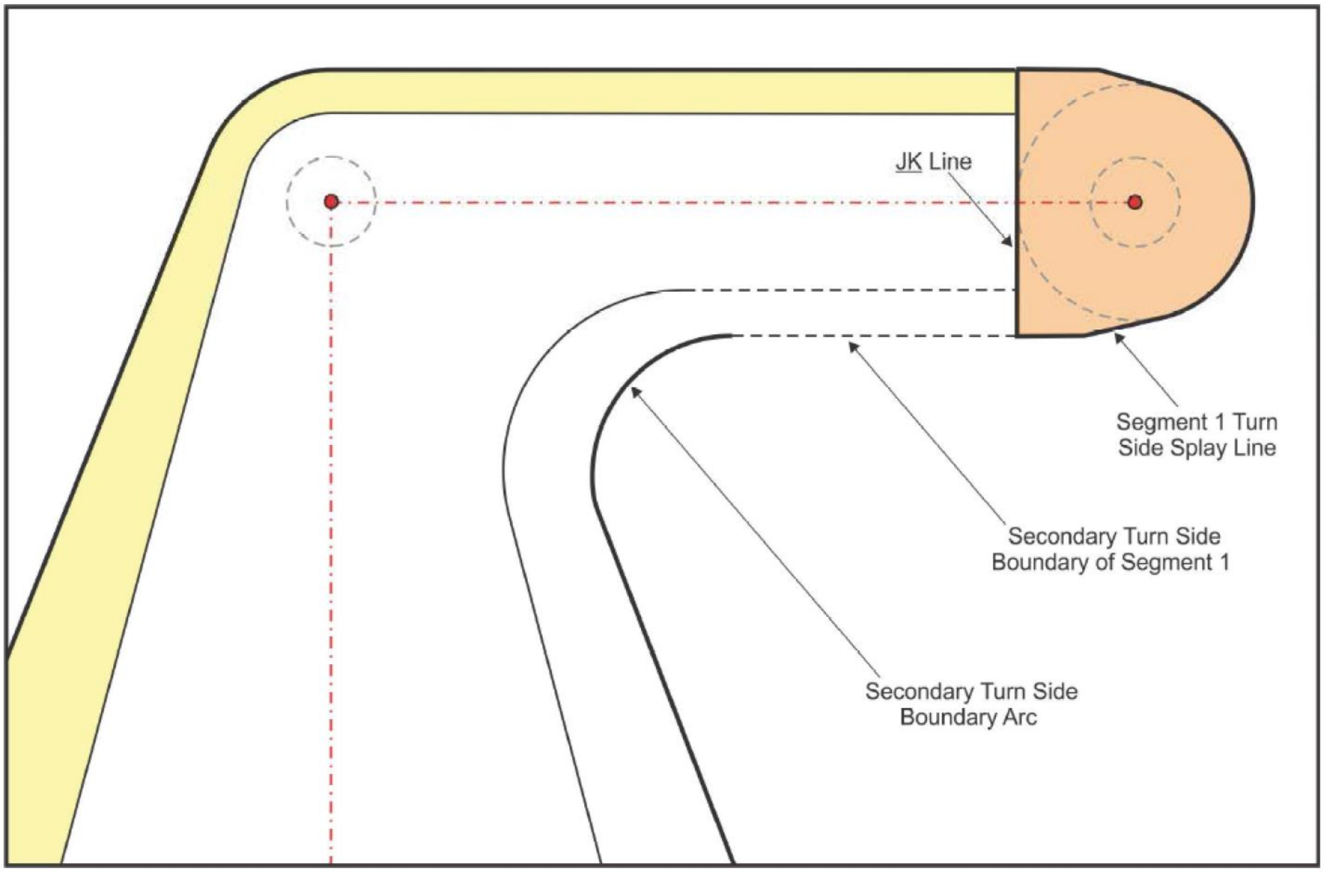
Step 14: Define and Construct the Secondary Turn Side Boundary

Step 14a: If the intersection of the Secondary Turn Side Boundary of Segment 1 and the Segment 1 Turn Side Splay Line occurs before the start of the Secondary Turn Side Boundary Arc (see Figure 8-6-30) then,

Step 14a (1): Remove the Alternate Turn Side Boundary Arc, and

Step 14a (2): Truncate the Secondary Turn Side Boundary of Segment 1 where it intersects the JK line.

Figure 8-6-30: Construction of the Secondary Turn Side Boundary, Case 1



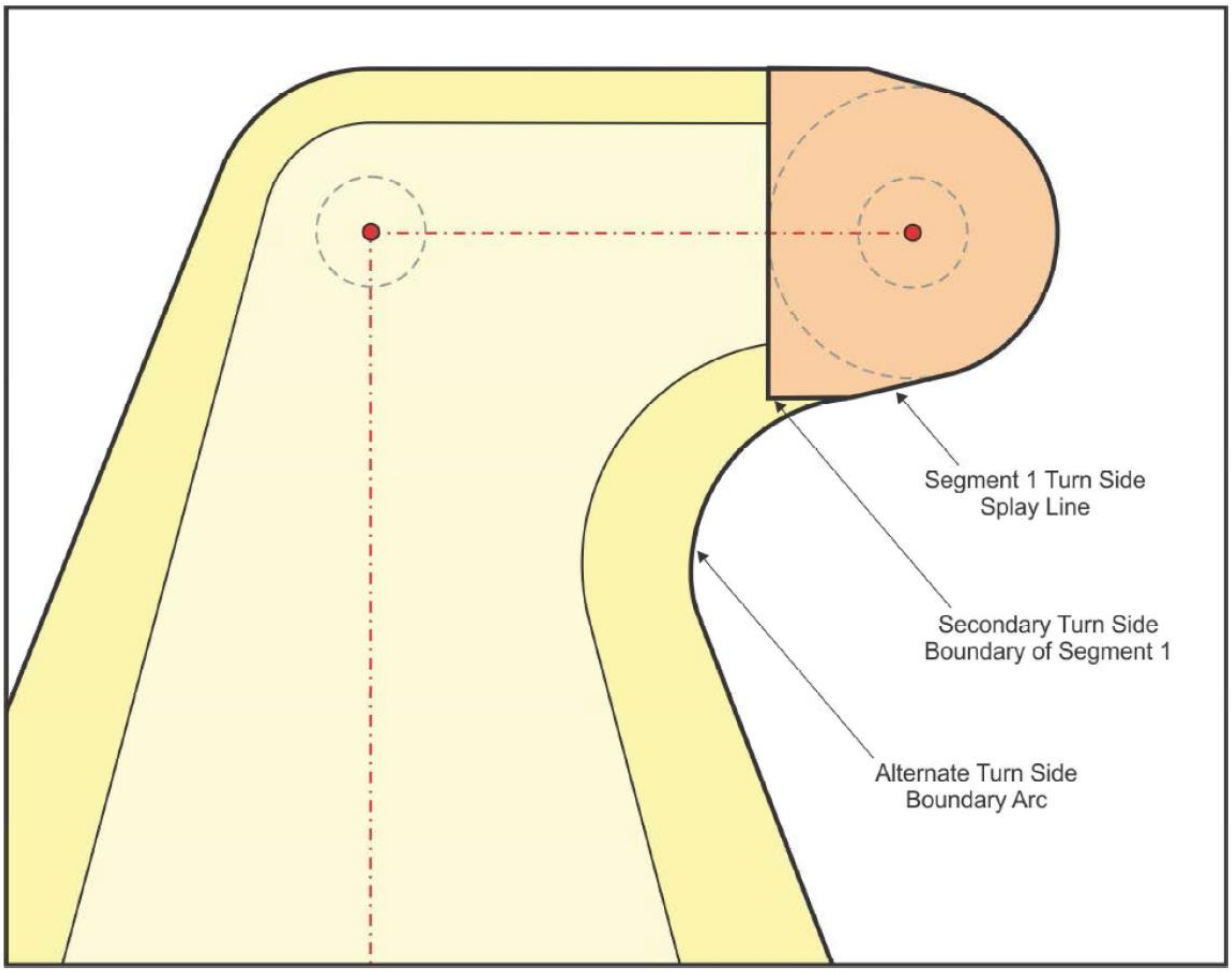
Step 14b: If the intersection of the Secondary Turn Side Boundary of Segment 1 and the Segment 1 Turn Side Splay Line occurs after the start of the Secondary Turn Side Boundary Arc (see Figure 8-6-31) then,

Step 14b (1): Remove the Secondary Turn Side Boundary Arc,

Step 14b (2): Remove the Secondary Turn Side Boundary of Segment 1, and

Step 14b (3): Extend the Segment 1 Turn Side Splay Line to the Alternate Turn Side Boundary Arc.

Figure 8-6-31: Construction of the Secondary Turn Side Boundary, Case 2

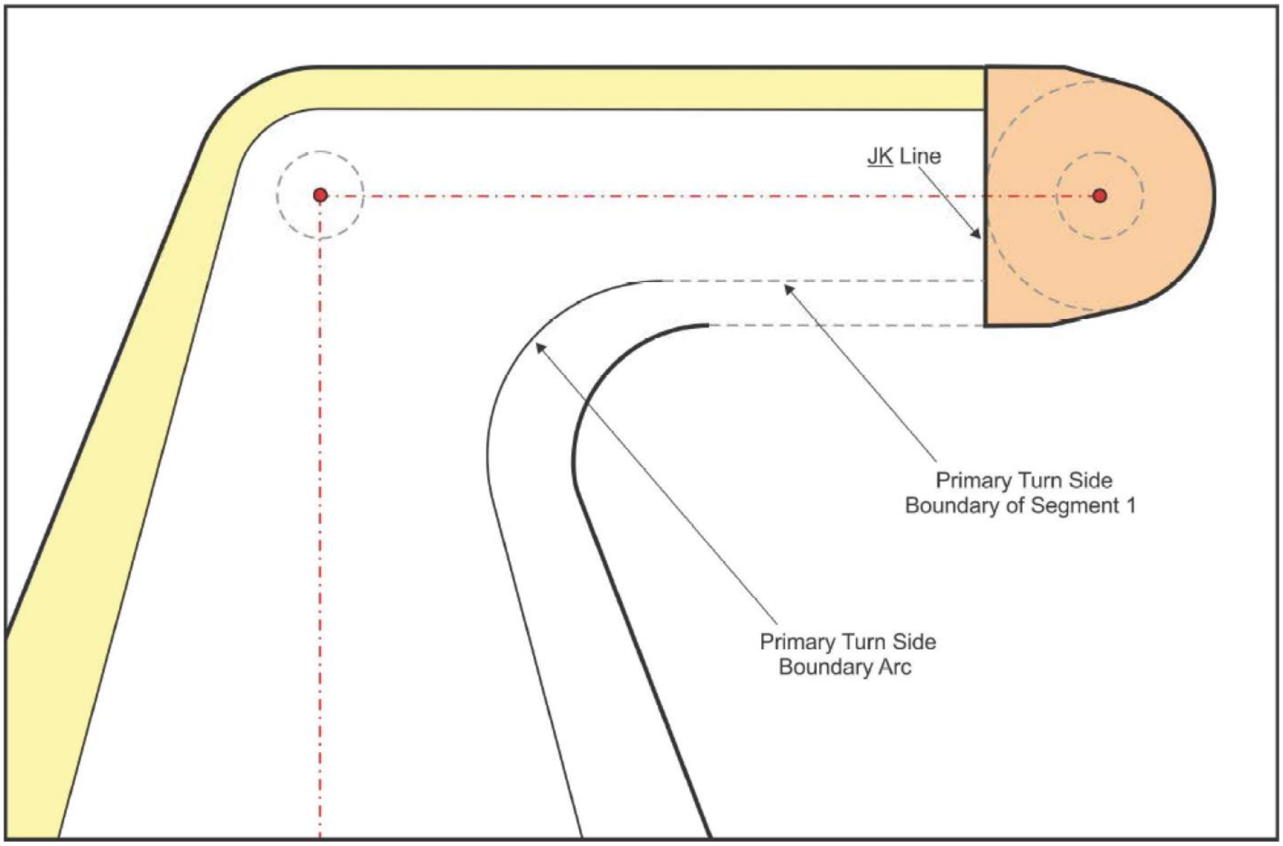


Step 15: Define and Construct the Primary Turn Side Boundary

Step 15a: If the JK line intersects the Primary Turn Side Boundary of Segment 1 (see Figure 8-6-32) then,

Step 15a (1): Truncate the Primary Turn Side Boundary of Segment 1 where it intersects the JK line.

Figure 8-6-32: Construction of the Primary Turn Side Boundary, Case 1

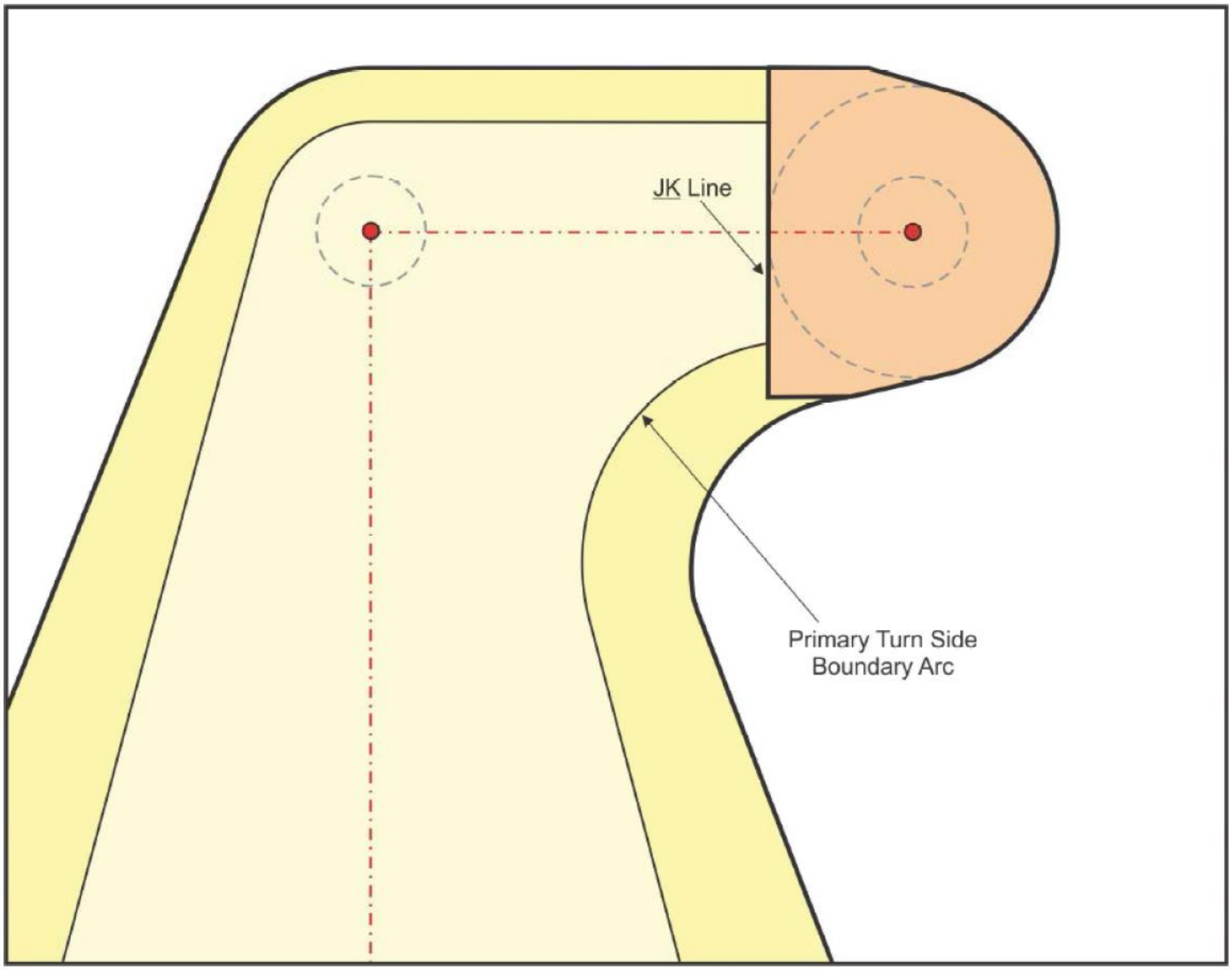


Step 15b: If the JK line intersects the Primary Turn Side Boundary Arc (see Figure 8-6-33) then,

Step 15b (1): Remove the Primary Turn Side Boundary of Segment 1, and

Step 15b (2): Truncate the Primary Turn Side Boundary Arc where it intersects the JK line.

Figure 8-6-33: Construction of the Primary Turn Side Boundary, Case 2



8.6.8. Obstacle Evaluation (OE). Starting at the JK line, apply a 20:1 OCS in the primary OEA, and a 6:1 OCS in the secondary OEA rising perpendicular from the edge of the primary area. Where an obstacle penetrates the primary OCS, or the *secondary OCS throughout the DP, calculate a minimum CG to clear the penetration(s) for all departure segments (legs) or raise the IDF crossing altitude. The highest required CG of all the departure legs is maintained until penetration(s) are cleared, and then the CG may be relaxed. See Figure 8-6-34 for a Climb Area Profile View and Figure 8-6-35/Figure 8-6-36 for a Climb Area Plan View. See paragraph 8.6.9 for assessing ROC, minimum altitude and CG.

***Note:** The elevation of obstacles in the secondary is reduced.

Figure 8-6-34: Climb Area Profile View

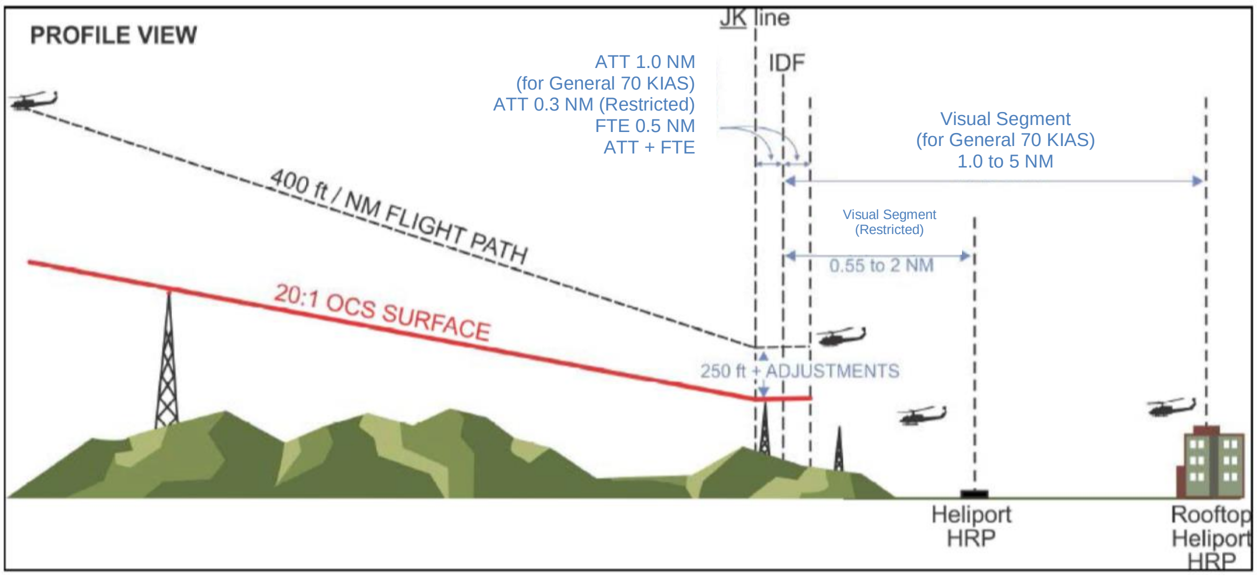


Figure 8-6-35: Departure Climb Area Plan View (General)

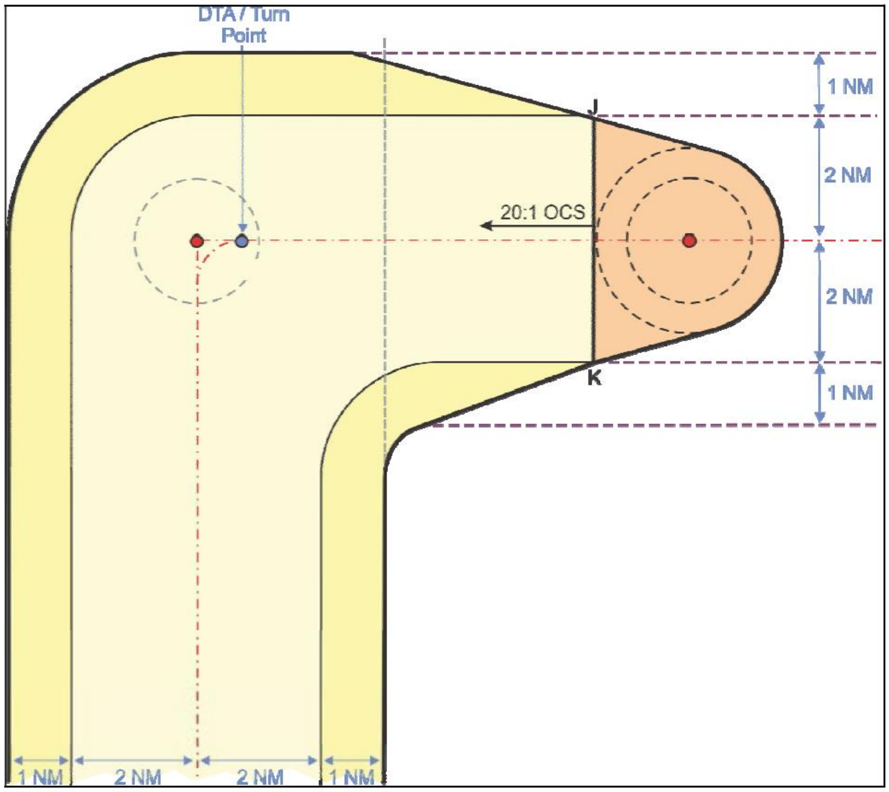
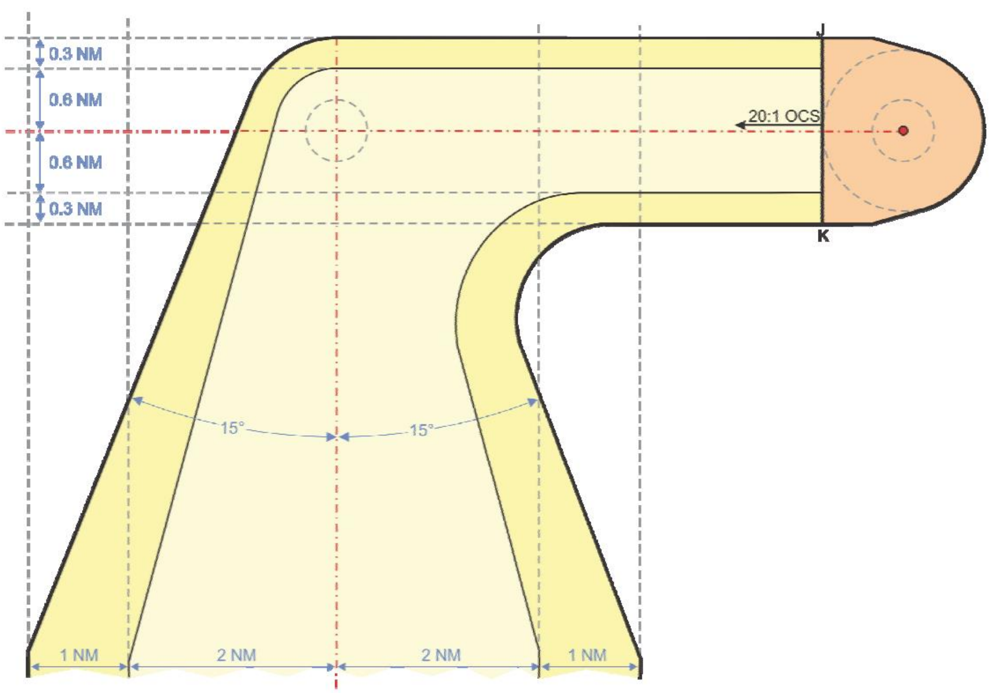


Figure 8-6-36: Departure Climb Area Plan View (Restricted)



8.6.9. **Required Obstacle Clearance (ROC)**

a. Section 1 Obstacle Clearance

(1) The PinS DP minimum ROC at the IDF is 250 ft, plus any adjustments for RASS (when altimeter source greater than 5 NM from the IDF), precipitous terrain, and obstacle accuracy standard.

Note 1: Precipitous terrain apply Section 1 only.
Note 2: IDF altitude must not be lower than the heliport elevation.

(2) ROC is applied within the IDF flat surface area (Section 1), and then rounded to the next higher 100-ft increment. For example, 500 ft remains 500 ft and 501 ft becomes 600 ft. The rounded altitude is the IDF crossing altitude.

(3) Accuracy Standard. Obstacle accuracy standard is 50 ft horizontal/20 ft vertical (Ref: Annex E, 1.1 b (2)) in the IDF flat surface area.

b. Section 2 Obstacle Clearance

(1) Sloping OCS. ROC increases at 96 ft/NM for all climb gradients.

(2) Primary OEA. Apply a 20:1 OCS originating at the JK line in the direction of departure. The OCS origin elevation is equal to the IDF crossing altitude subtracting ROC and any adjustments.

(3) Secondary OEA. Apply a 6:1 OCS from the edge of the primary OEA. The OCS origin elevation is equal to the height of the primary OEA boundary directly abeam the obstacle and perpendicular to the segment track. For obstacles located within a turn OEA (see Figure 8-6-37).

(4) Obstacle evaluation. If the OCS is clear, then the standard CG (400 ft/NM) applies. If the OCS is not clear, then take the following actions:

(a) Publish a CG to clear the penetration(s). If CGs exceeds 600 ft/NM, raise the IDF to an altitude where a CG of 600 ft/NM will clear the penetration.

(b) Alternatively, raise the IDF altitude to clear the penetration(s) to accommodate helicopters that cannot meet the non-standard climb gradient.

Note: This option will increase the ceiling value at the IDF.

(c) Lastly, design another DP over a different route to achieve a lower CG.

(5) Level Surface. The departure OCS continues to increase until reaching 1,000 ft of ROC for non-mountainous regions (2,000 ft or 1500 ft as required for mountainous regions) to the highest obstacle located within the primary OEA (or secondary

equivalent), and round the result to the next higher 100-ft increment. For example, 5,700 ft remains 5,700 ft and 5,701 ft becomes 5,800 ft.

(6) Accuracy standard. The obstacle accuracy for the 20:1 OCS area is 250 ft horizontal/50 ft vertical (Ref: Annex E, 1.1 b (3)).

(7) Calculate the ROC over an obstacle, the altitude at which the ROC is achieved, and the resulting required CG using Formula 6-2.

Formula 6-2: ROC/Min Alt/CG

(1) $\text{input } d,\ d_{secondary},\ OBS_{elev},\ adj,\ aircraft_{SOC}$

(2) $ROC_{OBS} = (250+adj)+\dfrac{96\cdot d}{fpnm}$

(3) $OBS_{elev} = if\left[\left(OBS_{elev}-aircraft_{SOC}-\dfrac{d_{secondary}}{6}\right)\le 0, 0, OBS_{elev}-\dfrac{d_{secondary}}{6}\right]$

(4) $alt_{min} = OBS_{elev}+ROC_{OBS}$

(5) $CG_{minimum} = \text{ceiling}\left[\dfrac{r}{d}\cdot\ln\left(\dfrac{r+alt_{min}}{r+aircraft_{SOC}}\right)\cdot fpnm\right]$

(6) $CG_{required} = \max[400,\ CG_{minimum}]$

(250+adj)+96*d/fpnm
if OBS in secondary, $OBS_{elev}= OBS_{elev}- d_{secondary}/6$
$OBS_{elev}+ROC_{OBS}$
ceiling(r/d*ln((r+alt_{min})/(r+$aircraft_{SOC}$))*fpnm)
max(400,$CG_{minimum}$)

8.6.10. Obstacle Distance Measurement. Obstacle distance (d) is measured using the shortest distance from each primary area obstacle to the JK line as illustrated in Figure 8-6-37 and Figure 8-6-38. Secondary area obstacles that occur during turn expansions have an obstacle distance that begins at the JK line and ends at the point on the edge of the primary boundary closest to the obstacle. Secondary area obstacles that do not occur during turn expansion have an obstacle distance that begins at the JK line and ends at the point of intersection of a line perpendicular to the flight path passing through the obstacle and boundary of the primary area. Secondary area obstacle evaluations are further reduced based on their distances to the primary edge boundary as shown in Formula 6-2. Detailed steps for obstacle distance measurements and calculations are found below:

a. **Obstacle in the Primary evaluation.** Determine obstacle evaluation distance (d), as the shortest distance within the primary area from the obstacle to the JK line.

b. Obstacle in the Secondary evaluation

(1) Determine the intersecting element of a line drawn from the obstacle to the closest point on the flight path.

(a) If the intersecting element is an arc, determine the Obstacle Primary Point as the closest point on the primary boundary to the obstacle.
(b) If the intersecting element is not an arc, determine the Obstacle Primary Point as the point of intersection between a line drawn from the obstacle perpendicular to the flight path and the Primary Boundary.

(2) Determine obstacle evaluation distance (d), as the shortest distance within the primary area to from the Obstacle Primary Point to the JK line.

(3) Determine distance into the secondary ($d_{secondary}$) as the distance from the obstacle to the Obstacle Primary Point.

Figure 8-6-37: Measuring Obstacle Distance (General)

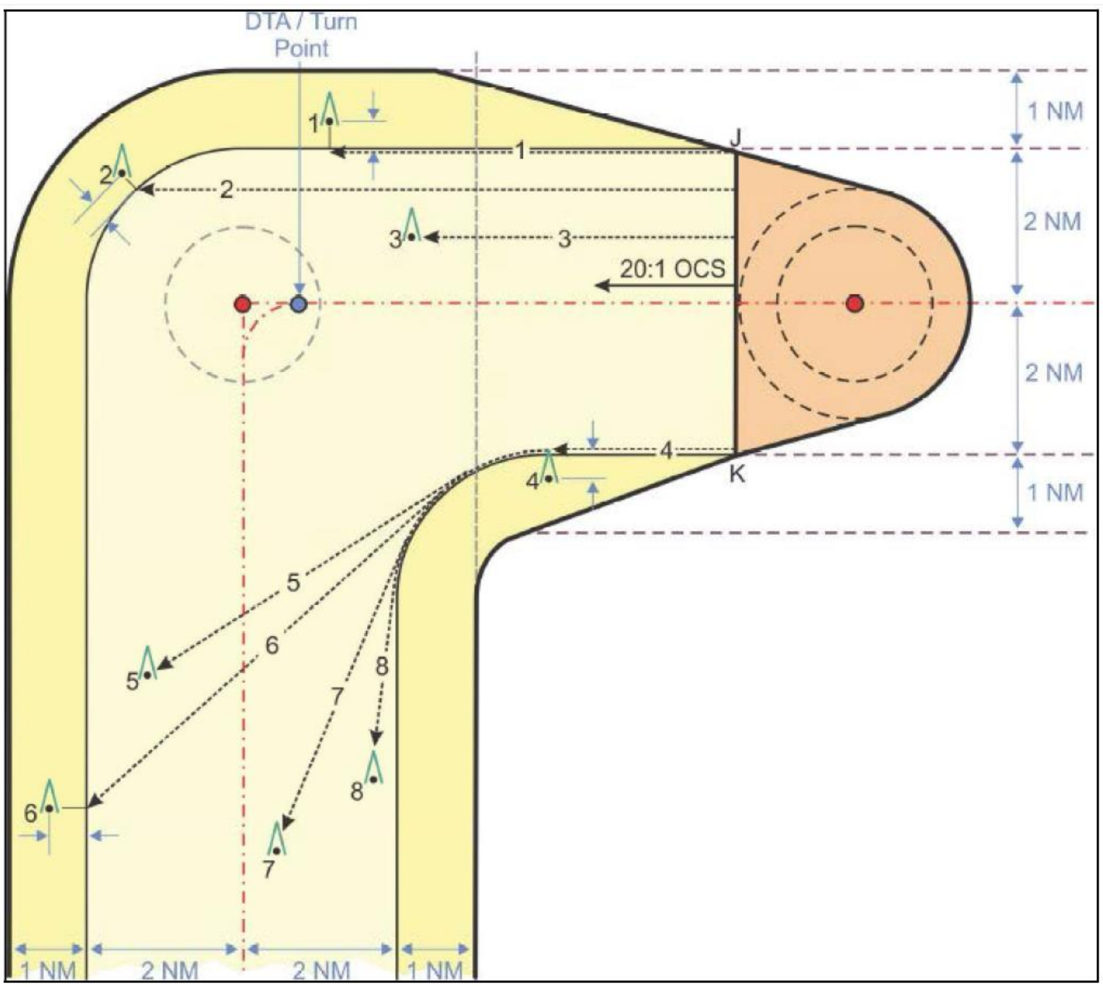
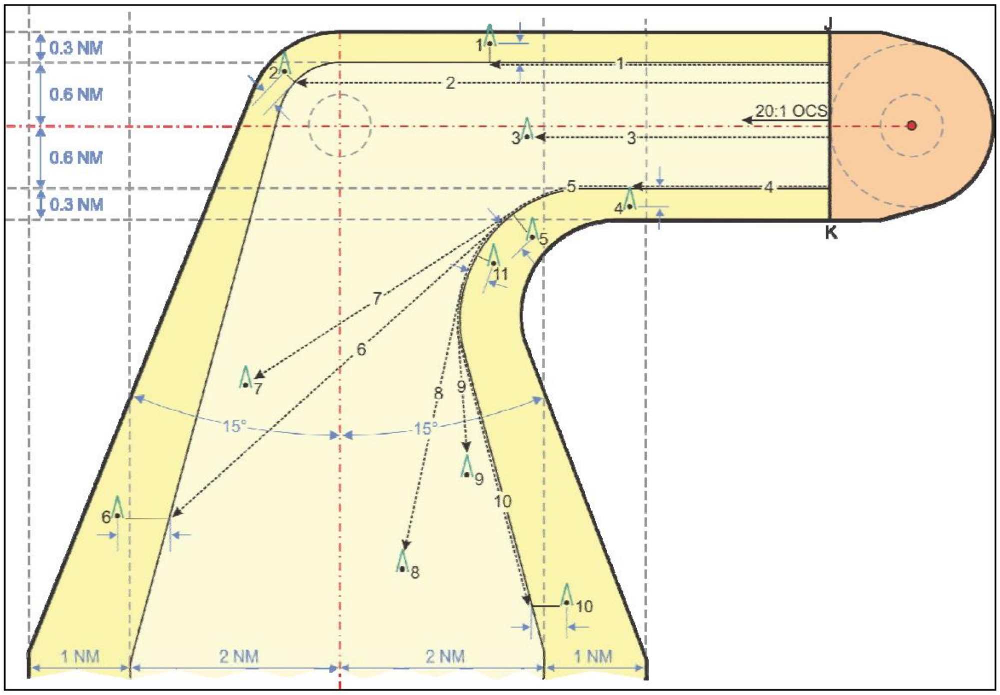


Figure 8-6-38: Measuring Obstacle Distance (Restricted)



8.6.11. **Visual Segment (Restricted only).** To ensure a safe IFR operation from a heliport, it is essential to establish the acceptability of the landing site, to design a safe, flyable departure procedure, and to provide a flight inspection evaluation consistent with the type of operation. This paragraph provides the construction guidance for the visual segment of this type of procedure.

a. **Procedure design.** The restricted procedure provides a measure of obstruction protection/ identification along the visual track from a specific VFR heliport to the IDF.

Note: In most cases the DP will be developed to utilize the waypoints of a corresponding Approach Procedure, resulting in the IDF being in the same location as the MAP.

(1) Alignment. The visual segment connects the helipoint to the IDF. The optimum visual segment is aligned with the FAC. The course change at the IDF must not exceed 30 degrees.

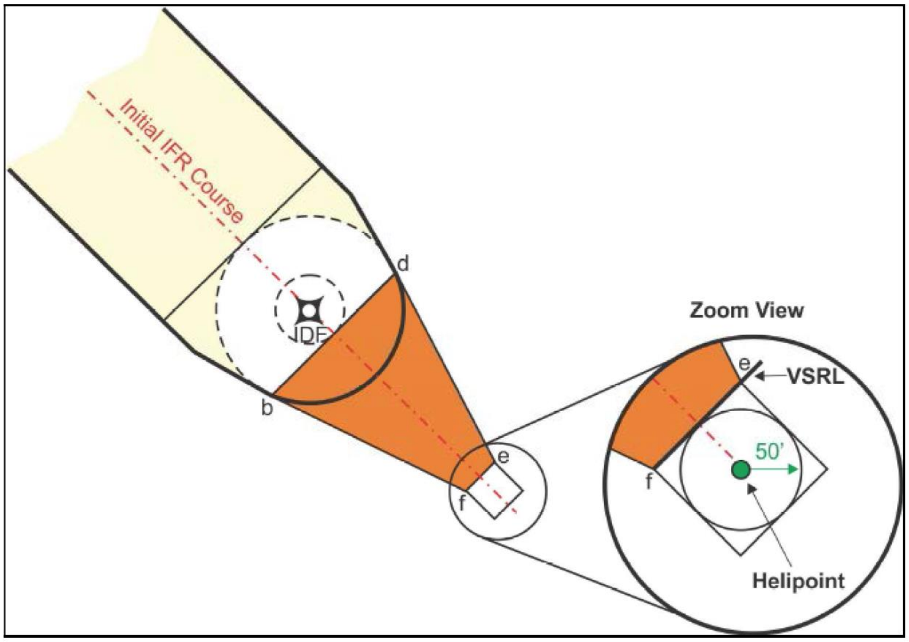
(2) Area.

(a) Length. The visual segment OEA begins at the VSRL and ends at the IDF. The visual segment OEA maximum length is 2 NM, measured from the helipoint to the IDF plotted position. The optimum helipoint to the ATD/IDF fix distance is 0.65 NM.

(b) Width. The visual segment splay begins at the VSRL. It splays from the VSRL endpoints to 0.6 NM either side of the IDF, perpendicular to the Initial IFR course.

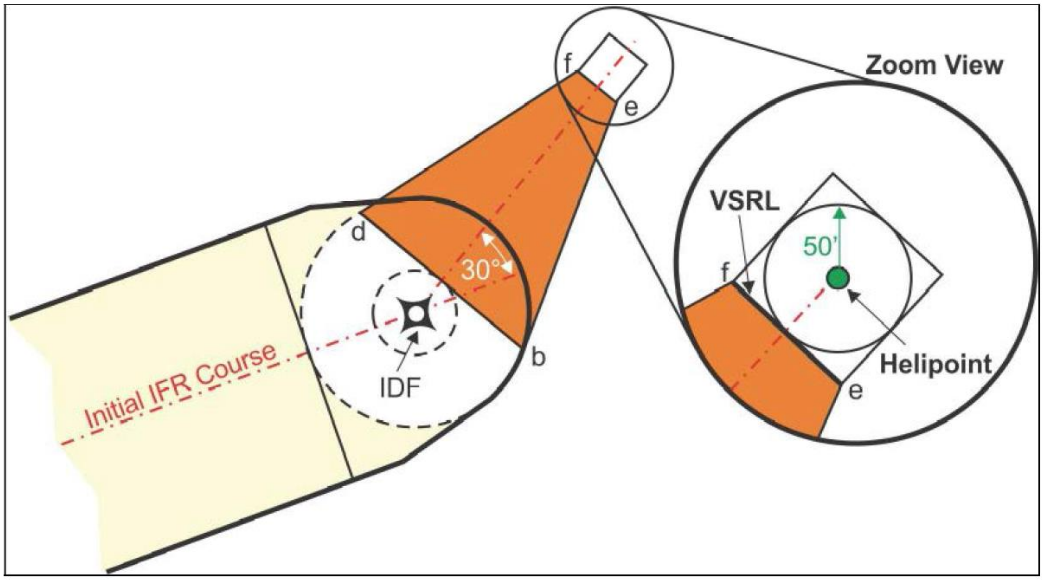
1. Straight Course Construction. Connect the VSRL outer edges (EF) to points B and D - 0.6 NM either side of the IDF, perpendicular to the Initial IFR course (see Figure 8-6-39).

Figure 8-6-39: Straight Visual Segment OEA



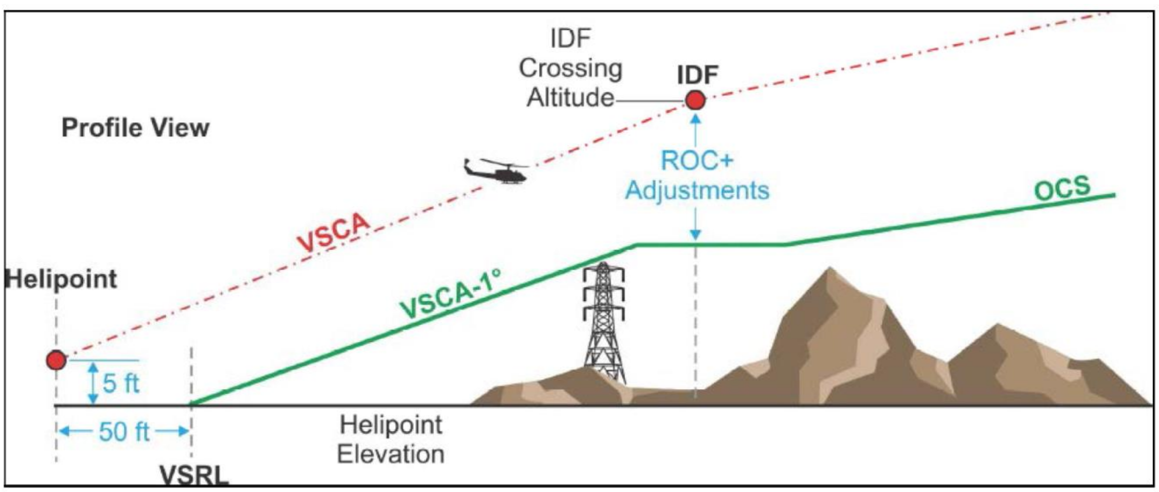
2. Turn at the IDF Construction. Connect the VSRL outer edges (EF) to points B and D - 0.6 NM either side of the IDF, perpendicular to the Initial IFR course (see Figure 8-6-40).

Figure 8-6-40: Visual Segment with Turn at IDF OEA



(c) Visual Segment Climb Angle (VSCA). The VSCA is a developer-specified angle extending from a point 5 to 20 ft directly above the helipoint to the IDF altitude (see Figure 8-6-41).

Figure 8-6-41: VSCA and OIS



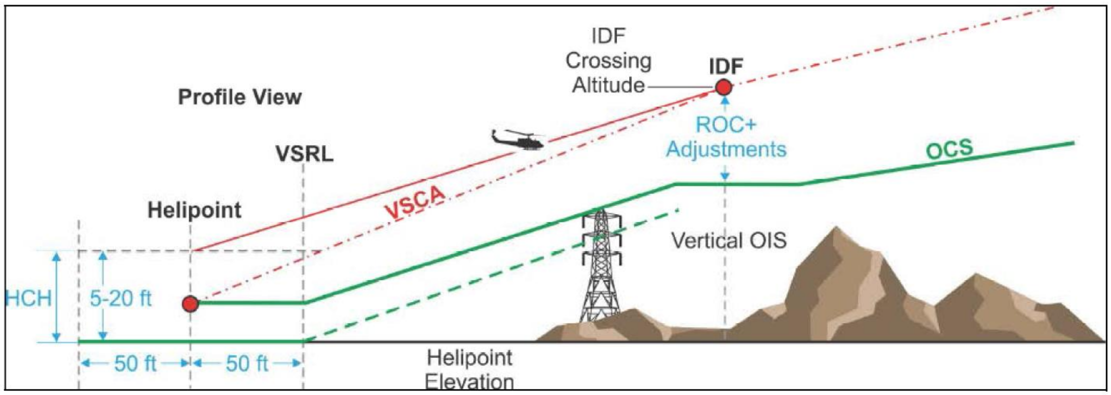
(d) Visual Segment OIS. The OIS begins at the VSRL and extends upward toward the IDF at an angle of (VSCA minus 1 degree). The OIS rises to the point it reaches an altitude equal to the IDF altitude minus the ROC and adjustments, after which it becomes a level surface to the end of the IDF area. Measure obstacles using the shortest distance to the VSRL. Obstacles should not penetrate the OIS; if they penetrate in the initial evaluation; take one of the following actions, listed in preferential order (see Figure 8-6-42):

1. Remove or adjust obstacle location and/or height to eliminate the penetration; or

2. Raise the VSCA (Maximum 8.13°) to achieve an OIS angle that clears the obstacle, (verify that the helicopter meets this new climb performance); or

3. Raise the HCH to ≤ 20 ft. Consult with the operator to determine ability of the helicopter fleet to hover at the adjusted HCH. When this procedure is applied, raise the OIS origin above the helipoint elevation by the amount that the HCH is increased (see Figure 8-6-42).

Figure 8-6-42: VSCA and OIS Evaluation



b. Charting requirements

(1) Publish the VSCA and climb gradient to the IDF.

(2) Chart the obstructions required by the application of the attached criteria.

(3) Annotate the procedure: “Procedure Not Authorized (NA) at night”.

8.6.12. Weather Minimums. Calculate ceiling and visibility weather minimums required for documenting the RNAV PinS DP.

a. **The minimum ceiling will correspond** with the IFR MSL altitude required at the IDF rounded up to the next higher 100-ft increment, or the highest HGC elevation rounded up to the next higher 100-ft increment, whichever is higher. For example, 500 ft remains 500 ft and 501 ft becomes 600 ft.

b. **The visibility for a DP without a visual segment** is in accordance with standard VFR minima. (i.e. “Proceed VFR from heliport to IDF”)

c. **The visibility for a Restricted DP with a visual segment** is the greater of 1 SM or the distance between the HGC and the IDF. Conduct an obstacle evaluation of the visual segment area, ensure that a satisfactory flight validation is accomplished, and obtain Flight Standards approval of the Restricted DP.

SECTION 7: HLPV PINS FINAL APPROACH SEGMENT (FAS) EVALUATION

8.7. HLPV PinS Final Approach Segment (FAS) Evaluation

8.7.1. **General.** Helicopter specific LPV PinS Approach criteria are based on section 2 OEA concepts; however, the LPV and LNAV procedure follows the same ground track and fixes and the along-track location of DA and the LNAV MAP are the same. For procedures annotated .Proceed VFR,. DA must be at least 250 ft above the terrain/surface and obstacles within a radius of 5,280 ft of the latest ATT point of the LNAV/LPV MAP/DA (see Figure 8-7-1 and Figure 8-7-2).

Figure 8-7-1: PinS Approach LPV Reference Datum Point (RDP)

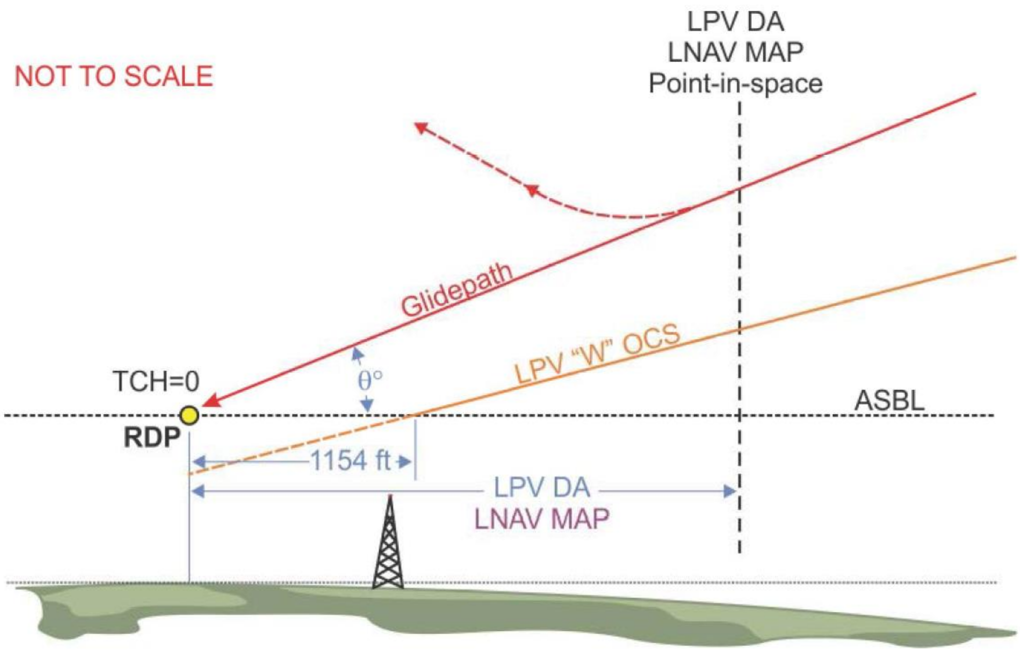
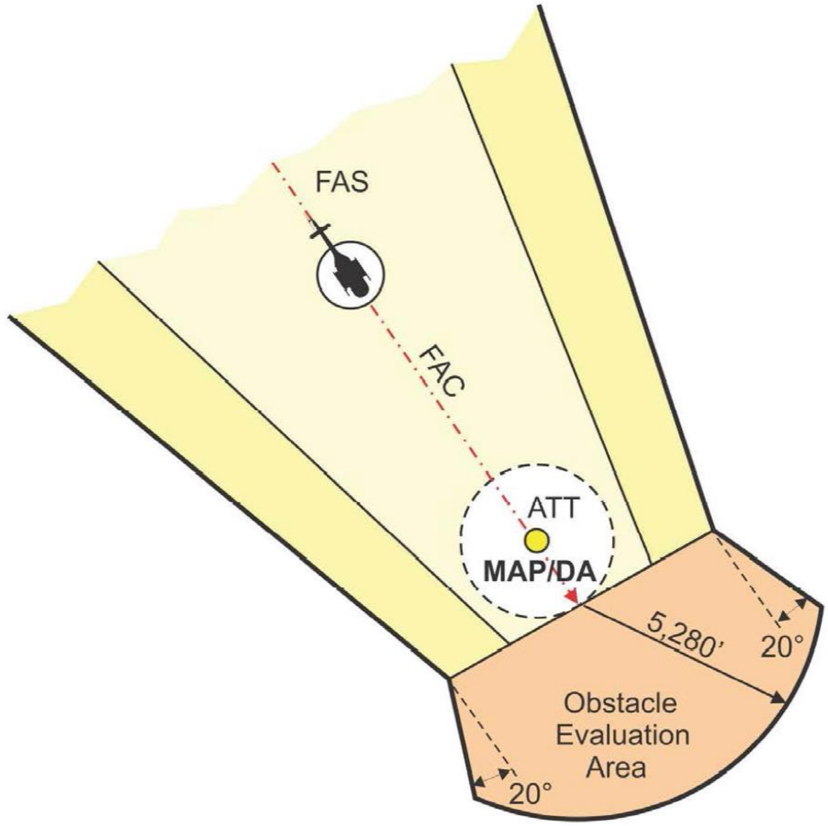


Figure 8-7-2: PinS Approach VFR Area



8.7.2. **Final Segment Obstruction Evaluation Area (OEA).** The HLPV PinS Approach final segment begins at the distance 1,154 ft from the RDP and extends to GPIP. The OEA protection extends the along-track segment dimension by the ATT value (40 m, 131.234 ft) at each end (see Figure 8-7-3 and Figure 8-7-4).

Figure 8-7-3: PinS Approach OEA Plan View

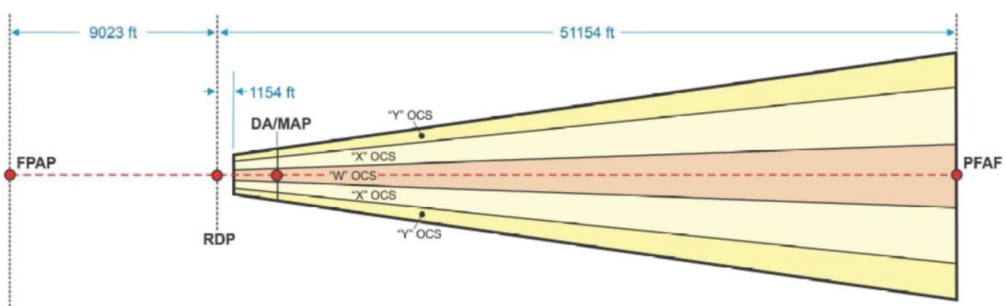
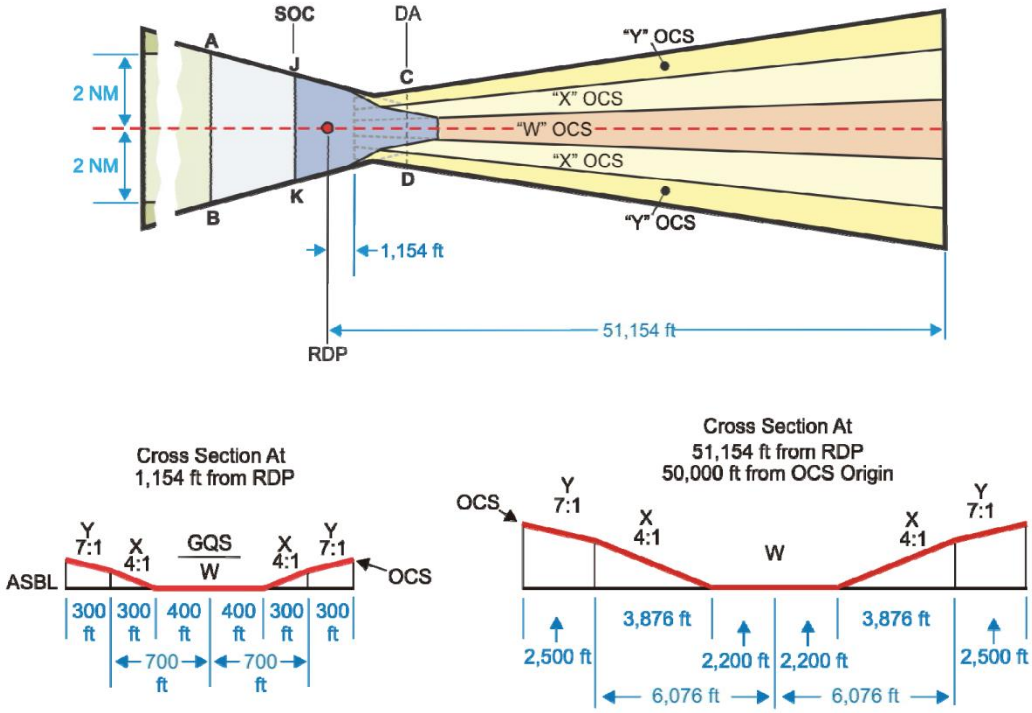


Figure 8-7-4: GPIP

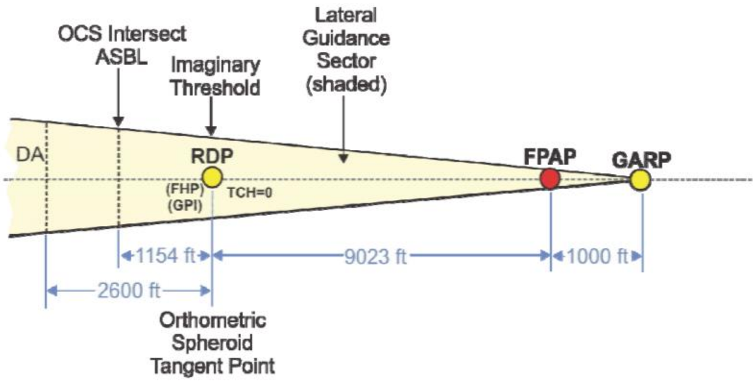


a. **Calculate the distance from RDP to PFAF using Formula 2-15 (coincident with LNAV PFAF).** Minimum length is 3 NM and maximum 10 NM. When using Formula 2-15 replace HCH with 0, and $\mathrm{HGC_{elev}}$ with $\mathrm{RDP_{elev}}$.

b. **Locate the FPAP 9,023 ft from RDP on a continuation of the final approach course (FAC), see Figure 8-7-5.** The following are values entered into the procedure FAS data block (see paragraph 8.7.11).

Distance RDP to FPAP = 9,023 ft
Distance FPAP to GARP = 304.8 m (1,000 ft)
Course Width at RDP = 106.75 m (350 ft)

Figure 8-7-5: FPAP



c. **OEA Alignment.** The FAC is nominally aligned with landing site approach track extended ($\pm$ 0.03°). Where a unique operational requirement indicates a need to offset the track from DA/MAP to the landing site from the track of the FAC, the offset must not exceed 30 degrees measured at DA.

d. **OCS Slope**. In this document, OCS slope is expressed as run over rise; e.g., 22.667:1. Determine the OCS slope (OCS_{slope}) associated with a specific $\boldsymbol{\theta}$ using Formula 7-1.

Formula 7-1: OCS Slope

$$(1)\ \text{input}\ \theta$$

$$(2)\ OCS_{slope} = \text{round}\left[\frac{102}{\theta},3\right]$$

round(102/θ ,3)

e. **OCS Origin and Elevation.** For obstacle evaluation, the OCS originates 1,154 ft from (prior to) the RDP at the same elevation. Along-track distance measurements in the final segment OEA are from RDP.

8.7.3. **W OCS.** All final segment OCS (W, X, and Y surfaces) obstacles are evaluated relative to the height of the W surface based on their along-track distance (OBS_X) from RDP, perpendicular distance (OBS_Y) from the FAC centerline, and MSL elevation (OBS_{elev}) adjusted for earth curvature and X/Y surface rise if appropriate. This adjusted elevation is termed obstacle effective elevation (O_{EE}) and is covered in paragraph 8.7.3.b.

a. **Half-Width**. (Perpendicular distance from FAC centerline to surface boundary.) The perpendicular distance ($W_{boundary}$) from FAC centerline to the boundary is 400 ft at the point 1,154 ft from RDP and expands uniformly to 2,200 ft at a point 51,154 ft from RDP then remains constant. Calculate $W_{boundary}$ for any distance from RDP using Formula 7-2.

Formula 7-2: W OCS Half-Width

$$(1)\ \text{input}\ \ OBS_X$$

$$(2)\ W_{boundary} = 0.036 \cdot (OBS_X - 954) + 392.8$$

$$\text{Where } OBS_X = \text{any along-track distance from RDP} \leq 51{,}154\ ft$$

0.036*(OBS_X-954)+392.8

b. Height. Calculate the MSL height (ft) of the W OCS (W_{elev}) at any distance from RDP using Formula 7-3.

Formula 7-3: W OCS MSL Elevation

(1) input DA, θ, OBS_X

(2) $$W_{eLev} = \frac{(r+DA)\cdot\cos\left(\operatorname{atan}\left(\frac{\theta}{102}\right)\right)}{\cos\left(\frac{OBS_X - 1154}{r} + \operatorname{atan}\left(\frac{\theta}{102}\right)\right)} - r$$

(r+DA)*cos(atan(θ/102))/cos((OBS$_X$-1154)/r+atan(θ/102))-r

The glide path is a straight line in space extending from RDP. The OCS is; therefore, a flat plane (does not follow earth curvature) to protect the straight-line glide path. The elevation of the OCS at any point is the elevation of the OCS at the FAC centerline abeam it. Since the earth's surface curves away from these surfaces as distance from RDP increases, the MSL elevation (OBS_{elev}) of an obstacle is reduced to account for earth curvature. This reduced value is termed the obstacle effective elevation (O_{EE}). Calculate O_{EE} using Formula 7-4 with adjustment "Q" for "X" or "Y" surface rise (0 if in W Surface).

Formula 7-4: Calculation of O_{EE}

(1) input OBS_{eLev}, DA, OBS_Y, Q

(2) $$O_{EE} = OBS_{eLev} - \left((r+DA)\cdot\left(\frac{1}{\cos\left(\frac{OBS_Y}{r}\right)} - 1\right) + Q\right)$$

OBS$_{elev}$-((r+DA)*(1/cos(OBS$_y$/r)-1)+Q)

c. **W OCS Evaluation.** Compare the obstacle O_{EE} to W_{elev} at the obstacle location. Lowest minimums are achieved when the W surface is clear. To eliminate or avoid a penetration, take one or more of the following actions listed in the order of preference.

(1) Remove or adjust the obstruction location and/or height.

(2) Raise the GPA (see paragraph 8.7.7) up to a maximum GPA of 9 degrees.

(3) Adjust DA (for existing obstacles only) see paragraph 8.7.6.

(4) Raise RDP elevation.

(5) Adjust Final Approach Course.

8.7.4. X OCS

a. **Width.** Calculate the perpendicular distance ($X_{boundary}$) from the FAC centerline to the X surface boundary using Formula 7-5.

Formula 7-5: Perpendicular Distance to "X" Boundary

$$(1)\ input\ OBS_X$$

$$(2)\ X_{boundary} = 0.10752 \cdot (OBS_X - 954) + 678.496$$

0.10752*(OBS$_X$-954)+678.496

b. **X Surface Obstacle Elevation Adjustment (Q).** The X OCS begins at the height of the W surface and rises at a slope of 4:1 in a direction perpendicular to the FAC. The MSL elevation of an obstacle in the X surface is adjusted (reduced) by the amount of surface rise. Use Formula 7-6 to determine the obstacle height adjustment (Q) for use in Formula 7-4. Evaluate the obstacle under paragraphs 8.7.3.b and 8.7.3.c.

Formula 7-6: X OCS Obstacle Height Adjustment

$$(1)\ input\ OBS_Y,\ W_{boundary}$$

$$(2)\ Q = \frac{OBS_Y - W_{boundary}}{4}$$

(OBS$_y$-W$_{boundary}$)/4

8.7.5. Y OCS

a. **Width.** Calculate the perpendicular distance ($Y_{boundary}$) from the FAC centerline to the Y surface boundary using **Formula** 7-7.

Formula 7-7: Perpendicular Distance to "Y" Boundary

$$(1)\ input\ OBS_X$$

$$(2)\ Y_{boundary} = 0.15152 \cdot (OBS_X - 954) + 969.696$$

0.15152*(OBS$_X$-954)+969.696

b. **Y Surface Obstacle Elevation Adjustment (Q).** The Y OCS begins at the height of the X surface and rises at a slope of 7:1 in a direction perpendicular to the FAC. The MSL elevation of an obstacle in the Y surface is adjusted (reduced) by the amount of X and Y surface rise. Use Formula 7-8 to determine the obstacle height adjustment

(Q) for use in Formula 7-4. Evaluate the obstacle under paragraphs 8.7-3b and 8.7-3c.

Formula 7-8: Y OCS Obstacle Height Adjustment

$$(1)\quad input\ X_{boundary}, W_{boundary}, OBS_Y$$

$$(2)\quad Q = \frac{X_{boundary} - W_{boundary}}{4} + \frac{OBS_Y - X_{boundary}}{7}$$

$(X_{boundary}-W_{boundary})/4+(OBS_y-X_{boundary})/7$

8.7.6. **HAS and DA.** Where the OCS is clear, the minimum HAS is the greater of 250 ft.

a. **DA Calculation (Clear OCS).** The minimum DA value is 250 ft above the highest obstruction (terrain+obstacle or vegetation) rounded to the next higher 1-ft increment.

b. **DA Adjustment to mitigate OCS Penetration.** Calculate the adjusted DA for an obstacle penetration of the OCS using Formula 7-9.

Formula 7-9: Adjusted DA

$$(1) input\ \theta°, DA, O_{EE}$$

$$(2)\ D_{adjusted} = r \cdot \left(\frac{\pi}{2} - atan\left(\frac{\theta°}{102}\right) - asin\left(\frac{cos\left(atan\left(\frac{\theta°}{102}\right)\right) \cdot \left(r + DA - 954 - \frac{\theta° \cdot 954}{102}\right)}{r + O_{EE}} \right) \right)$$

$$(3) DA_{adjusted} = \textbf{ceiling} \left\lceil \frac{(r + DA - 954) \cdot cos(\theta°)}{cos\left(\frac{D_{adjusted}}{r} + \theta°\right)} - r \right\rceil$$

8.7.7. **Revising Glide Path Angle ($\theta_{adjusted}$) for OCS Penetrations.** Raising the θ may eliminate OCS penetrations. To determine θ adjusted, use Formula 7-10.

Formula 7-10: Glide Path Angle Adjustment $(\theta_{adjusted})$

(1) input OBS_X, OBS_{elev}, RDP_{elev}

(2) $s = (r + RDP_{elev})^2 + (r + OBS_{elev})^2 - 2 \cdot (r + RDP_{elev}) \cdot (r + OBS_{elev}) \cdot \cos\left(\frac{OBS_X - 1154}{r}\right)$

(3) $b = \text{acos}\left(\frac{(r + RDP_{elev})^2 + s - (r + OBS_{elev})^2}{2 \cdot (r + RDP_{elev}) \cdot \sqrt{s}}\right) - \frac{\pi}{2}$

(4) $OCS_{adjusted\_slope} = \text{round}\left(\frac{1}{\tan(b)}, 2\right)$

(5) $\theta_{adjusted} = \text{round}\left(\frac{102}{OCS_{adjusted\_slope}}, 2\right)$

(r+RDP$_{elev}$)^2+(r+OBS$_{elev}$)^2-2*(r+RDP$_{elev}$)*(r+OBS$_{elev}$)*cos((OBS$_X$-1154)/r)
acos(((r+RDP$_{elev}$)^2+s-(r+OBS$_{elev}$)^2)/(2*(r+RDP$_{elev}$)*sqrt(s)))-π/2
OCS$_{adjusted_slope}$=round(1/tan(b),2)
θ$_{adjusted}$=round(102/OCS$_{adjusted_slope}$,2)

The descent rate of the adjusted glidepath angle should not exceed 800 ft/min. Descent rate is heavily dependent on airspeed. Determine the airspeed that yields 800 ft/min ($V_{KIAS\_800ft\_min}$) for the adjusted glidepath angle using Formula 7-11. If $V_{KIAS\_800ft\_min}$ is less than the normal approach speed, publish a final approach airspeed restriction of $V_{KIAS\_800ft\_min}$. The minimum adjusted glidepath angle should not be less than three degrees.

Formula 7-11. Descent Rate Indicated Airspeed

(1) input $\theta°_{adjusted}$, DA

(2) $V_{KIAS\_800*ft/min} = \text{round}\left[\left(\frac{800*}{101.26859 \cdot \sin(\theta°_{adjusted})} - 10\right) \cdot \frac{(288 - 0.00198 \cdot DA)^{2.628}}{171233 \cdot \sqrt{303 - 0.00198 \cdot DA}}, 0\right]$

*1000 when the airspeed limit is required for 1000 ft/min

8.7.8. **Adjusting TCH to Reduce/Eliminate OCS Penetrations.** NA for PinS Approach LPV procedures.

8.7.9. **Missed Approach Section 1 (Height Loss and Initial Climb).** Section 1 begins at DA (CD line) and ends at the AB line. It accommodates height loss and establishment of missed approach climb gradient. Obstacle protection is based on an assumed minimum climb gradient of 400 ft/NM (≈15.19:1 slope). Section 1 is centered on a continuation of the FAC and is subdivided into sections 1a and 1b (see Figures 8-7-6 and 8-7-7).

Figure 8-7-6: Section 1 3D Perspective

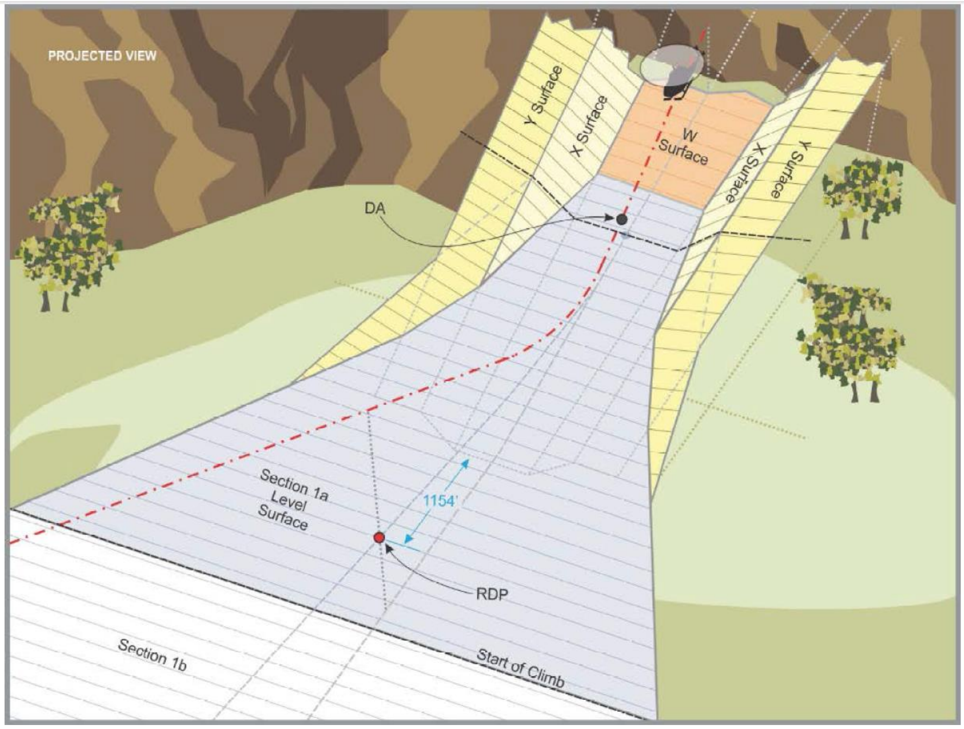
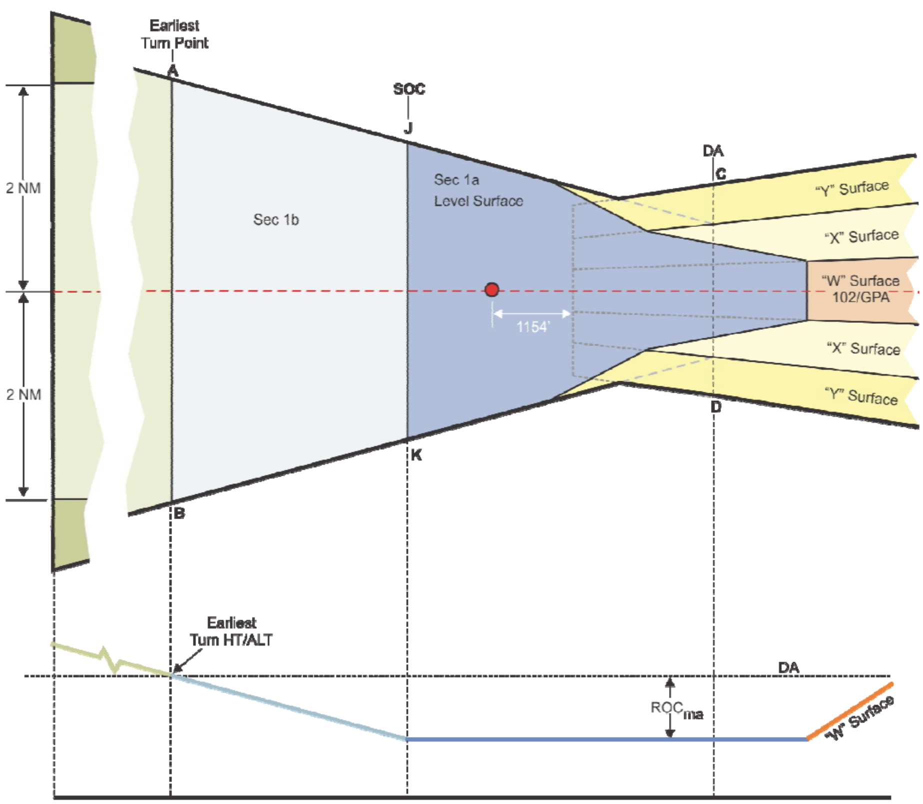


Figure 8-7-7: Section 1 (a/b) 2D Perspective



a. **Missed Approach Section 1.** Section 1 begins at DA (CD line) and ends at the JK line which is the Start-Of-Climb (SOC) point. It accommodates reconfiguration, inherent height loss, and establishing required missed approach climb gradient (CG_{MA}) of 400 ft/NM (20:1 slope), unless higher climb gradients and the appropriate slope adjustments are authorized. Section 1 is subdivided into sections 1a and 1b, and is centered on a continuation of the FAC. These surfaces must not be penetrated. Section 1a, is protected by a level surface that provides required ROC (ROC_{sec_1a}) based on glide path angle and airspeed. ROC is 115 ft for glide path angles up to 3.2 degrees. Apply ROC adjustments for glide path angles exceeding 3.2 degrees, for RDP elevations greater than 3,000 ft., and for final indicated airspeed. Calculate section 1a ROC (ROC_{sec_1a}) and the level surface MSL elevation (sec_1a_{elev}) using Formula 7-12.

Formula 7-12: MA Beginning ROC

(1) input DA, RDP_{elev}, θ, V_{KIAS}

(2) if (θ > 3.2) then

$$\theta_{adjustment} = 0.05 \cdot 25 \cdot \frac{\theta - 3.2}{0.1}$$

else

$$\theta_{adjustment} = 0$$

end if

(3) if (RDP_{elev} > 3000) then

$$Elev_{adjustment} = 0.02 \cdot 25 \cdot \frac{RDP_{elev}}{1000}$$

else

$$Elev_{adjustment} = 0$$

end if

(4) $ROC_{sec\_1a} = 115 + \theta_{adjustment} + Elev_{adjustment} - 25 \cdot \frac{90 - V_{KIAS}}{90}$

(5) $Level\_sfc_{elev} = DA - ROC_{sec\_1a}$

0.05*25*(θ -3.2)/0.1
0.02*25*RDP_{elev}/1000
115+$\theta_{adjustment}$+$Elev_{adjustment}$-25*(90-V_{KIAS})/90
DA- ROC_{sec_1a}

(1) Section 1a. Section 1a length varies with altitude, airspeed, and glide path angle. The 1a surface splays at 15 degrees relative the FAC extension, from X boundary at its beginning (CD line) until reaching the JK line. Calculate X width at section 1a start point using the final segment X width. Calculate section 1a length ($Length_{sec1a}$) using Formula 7-13.

Formula 7-13: Section 1a Length

$$(1)\quad input\ \theta°,\ V_{KTAS}$$

$$(2)\quad anpe = 1.225 \cdot \frac{40}{0.3048}$$

$$(3)\quad wpr = 60 \cdot \tan(\theta)$$

$$(4)\quad fte = \frac{75}{\tan(\theta)}$$

$$(5)\quad d1 = 10 \cdot \frac{(V_{KTAS} + 10) \cdot fpnm}{3600}$$

$$(6)\quad Length_{sec1a} = \mathbf{round}\left[d1 + \frac{4}{3} \cdot \sqrt{anpe^2 + wpr^2 + fte^2}, 0\right]$$

(a) Calculate the 1a surface half-width ($½width_{sec1a}$) at any along-track distance (d_{1a}) from DA assuming a beginning half-width of the final segment "X" surface at DA ($½X_{sfc\_DA}$) using Formula 7-14.

Formula 7-14: Section 1a Width

$$(1)\quad input\ d_{1a},\ DA,\ RDP_{elev},\ \theta°$$

$$(2)\quad \tfrac{1}{2}width_{sec1a} = d_{1a} \cdot \tan(15) \quad + 0.036 \cdot \left(\frac{DA - RDP_{elev}}{\tan(\theta°)} - 954\right) + 398.2$$

(b) Obstacles within the lateral boundaries of the flat surface that underlie the X or Y surfaces may be evaluated against the higher of: (1) the W surface abeam the obstacle, or (2) the flat surface elevation. Conduct the evaluation using the .Obstacle Effective Elevation. (O_{EE}).

(2) Section 1b. Section 1b provides initial climb protection from SOC at the specified CG_{MA} until minimum turn height/altitude (alt_{turn}) is attained. Its lateral boundaries continue the section 1a splay until alt_{turn} is reached or until reaching full width, whichever occurs first. Calculate section 1b length using Formula 7-15.

Formula 7-15: Section 1b Length

$$(1)\quad input\ \ alt_{turn},\ Level\_sfc_{elev},\ CG_{MA}$$

$$(2)\quad Length_{sec1b} = \frac{r \cdot fpnm \cdot \ln\left[\frac{r + alt_{turn}}{r + Level\_sfc_{elev}}\right]}{CG_{MA}}$$

r*fpnm*ln((r+alt_{turn})/(r+$Level\_sfc_{elev}$))/CG_{MA}

(a) Calculate the width of the section 1b surface ($\frac{1}{2}width_{sec1b}$) at any distance d_{sec1a_end} from the end of section 1a using Formula 7-16.

Formula 7-16: Section 1b Width

$$(1)\quad input\ d_{sec1a\_end},\ \tfrac{1}{2}width_{sec1a}$$

$$(2)\quad \tfrac{1}{2}width_{sec1b} = d_{sec1a\_end} \cdot \tan(15) + \tfrac{1}{2}width_{sec1a}$$

d_{sec1a_end}*tan(15)+1/2$width_{sec1a}$

(b) The surface rises at a rate related to the assigned CG_{MA} from sec_1a_{elev}. Determine the 1b MA surface elevation ($OCS\_1b_{OBS\_x}$) at any section 1b obstacle distance (d), and the elevation of the OCS at section 1b end ($OCS\_1b_{end\_elev}$) using Formula 7-17.

Formula 7-17: MA Slope and Section 1b Elevation

$$(1)\quad input\ CG_{MA},\ d_{sec1b\_end},\ Level\_sfc_{elev},\ OBS_x$$

$$(2)\quad MA_{slope} = \frac{fpnm}{CG_{MA} - 96}$$

$$(3)\quad OCS\_1b_{end\_elev} = \frac{d_{sec1b\_end}}{MA_{slope}} + Level\_sfc_{elev}$$

$$(4)\quad OCS\_1b_{OBS\_x} = \frac{OBS_x}{MA_{slope}}$$

fpnm/(CG_{MA}-96)
$d_{sec1b\ end}$/MA_{slope}+$Level\_sfc_{elev}$
OBS_X/MA_{slope}

b. **Section 2.** See section 5.

8.7.10. Surface Height Evaluation

a. **Section 1a.** Obstacles that penetrate these surfaces are mitigated during the final segment OCS evaluation. However, missed approach segment penetrations are not allowed and must be mitigated by:

(1) Removing or reducing obstruction height.

(2) Adjusting RDP elevation.

(3) Adjusting the FAC.

(4) Adjusting DA (for existing obstacles).

(5) A combination of the above mitigations.

b. **Section 1b/Section 2 Surface Penetration.** The CG_{MA} may be increased, (if operationally feasible) in addition to the options listed in paragraph 8.7.11.a. Climb gradients above 600 ft/NM is a Non-Standard Procedure as per TP308/GPH209. Volume 1, paragraph 141.

Note: See formula 5-3 to determine CG_{MA} increase method.

c. **End of Section 1 Values.** Calculate the assumed aircraft MSL altitude at the end of section 1b ($acft_{1b\_alt}$), the OCS MSL elevation at the end of section 1b (OCS_{1b_elev}), and the **ROC** at section 1b end (ROC_{end_1b}) using Formula 7-18.

Formula 7-18: Section 1b End Values

$$(1)\quad input\ DA,\ OCS\_1a_{elev},\ Length_{sec1b},\ CG_{MA}$$

$$(2)\quad MA_{slope} = \frac{fpnm}{CG_{MA} - 96}$$

$$(3)\quad acft_{1b\_alt} = DA + \left(CG_{MA} \cdot \frac{Length_{sec1b}}{fpnm}\right)$$

$$(4)\quad OCS_{1b\_elev} = OCS\_1a_{elev} + \frac{Length_{sec1b}}{MA_{slope}}$$

$$(5)\quad ROC_{end\_1b} = acft_{1b\_alt} - OCS_{1b\_elev}$$

$fpnm/(CG_{MA}-96)$
$DA+(CG_{MA}*Length_{sec1b}/fpnm)$
$OCS\_1a_{elev}+ Length_{sec1b}/MA_{slope}$
$acft_{1b\_alt}-OCS_{1b\_elev}$

8.7.11. **Final Approach Segment (FAS) Data Requirements.** Values are as indicated unless otherwise specified.

a. **Operation type:** 0

b. **Service Provider Identifier:** 0

c. **Airport Identifier:** Use the heliport identifier. If the heliport does not have an identifier one must be obtained. For procedures serving multiple heliports, the identifier for the primary heliport should be used.

d. **Runway Number:** Final approach track rounded to nearest 10 degrees and enter as a two digit number.

e. **Runway Letter:** Leave blank.

f. **Approach Performance Designator:** 0

g. **Route Indicator:** The route indicator coding shall match the duplicate procedure indicator used in the chart title. The first procedure to a runway end shall be coded as “Z”, except when there is only a single procedure to the runway end. In this case, the field is coded as a blank.

h. **Reference Path Data Selector (RPDS):** 0

i. **Reference Path Identifier**: [W] [Final approach track rounded to nearest 10 degrees (2 digits)] [.A. first procedure, “B” second procedure, etc.] EXAMPLE: W23A.

j. **LTP/RDP Latitude:** WGS-84 Latitude of RDP entered to five ten-thousandths of an arc second. The last digit must be rounded down to either a 0 or 5. EXAMPLE: 225436.2128N (11 characters) is entered for 22°54’36.2125”N.

k. **LTP/RDP Longitude:** WGS-84 Longitude of RDP entered to five ten-thousandths of an arc second. The last digit must be rounded to either a 0 or 5. EXAMPLE: 1093247.8783E (12 characters) is entered for 109°32’47.8780”E.

l. **LTP/RDP height above ellipsoid (HAE):** HAE value for RDP. The value is entered in meters using 5 characters. The first character is a + or . and the resolution value is in tenths of a meter. EXAMPLE: +00356 (+35.6 m), -00022 (-2.2 m).

m. **Flight Path Alignment Point (FPAP) Latitude:** WGS-84 Latitude of FPAP using the same requirements as paragraph 8.7.11.j.

n. **Flight Path Alignment Point (FPAP) Longitude:** WGS-84 Longitude of FPAP using the same requirements as paragraph 8.7.11.k.

o. **TCH:** 0000.0

p. **TCH Units Selector:** F (feet) or M (Meters)

q. **Glidepath Angle:** Specify in degrees, resolution of hundredths of a degree using 4 characters. EXAMPLE: 04.50

r. **Course Width at Threshold:** 106.75

s. **∆Offset:** 0

t. **Horizontal Alert Limit (HAL):** 40

u. **Vertical Alert Limit (VAL):** 50

v. **Final Approach Segment CRC Remainder:** 32 bit cyclic redundancy check (CRC) appended to the end of each FAS Data Block in order to ensure approach data integrity. The CRC word is calculated on the entire data block.

Appendix A. TERPS Standard Formulas for Geodetic Calculations

1.0 Purpose

The ellipsoidal formulas contained in this document must be used in determining RNAV flight path (GPS, RNP, WAAS, LAAS) fixes, courses, and distance between fixes.

Notes:

Algorithms and methods are described for calculating geodetic locations (latitudes and longitudes) on the World Geodetic System of 1984 (WGS-84) ellipsoid, resulting from intersections of geodesic and non-geodesic paths. These algorithms utilize existing distance and azimuth calculation methods to compute intersections and tangent points needed for area navigation procedure construction. The methods apply corrections to an initial spherical approximation until the error is less than the maximum allowable error, as specified by the user.

Several constants are required for ellipsoidal calculations. First, the ellipsoidal parameters must be specified. For the WGS-84 ellipsoid, these are:

$$a = \text{semi-major axis} = 6{,}378{,}137.0 \text{ m}$$
$$b = \text{semi-minor axis} = 6{,}356{,}752.314245 \text{ m}$$
$$1/f = \text{inverse flattening} = 298.257223563$$

Note that the semi-major axis is derived from the semi-minor axis and flattening parameters using the relation $b = a(1-f)$.

Second, an earth radius is needed for spherical approximations. The appropriate radius is the geometric mean of the WGS-84 semi-major and semi-minor axes. This gives

$$SPHERE\_RADIUS\ (r) = \sqrt{ab} = 6{,}367{,}435.679716 \text{ m}.$$

Perform calculations with at least 15 significant digits.

For the purpose of determining geodetic positions, perform sufficient iterations to converge within 1 cm in distance and 0.002 arc seconds in bearing.

2.0 Introduction

The algorithms needed to calculate geodetic positions on the earth for the purpose of constructing and analyzing Terminal Instrument Procedures (TERPS) require the following geodetic calculation process some of which are illustrated in Figure A-1:

Process 1: Find the destination latitude and longitude, given starting latitude and longitude as well as distance and starting azimuth (often referred to as the “direct” or “forward” calculation).

Process 2: Compute the geodesic arc length between two points, along with the azimuth of the geodesic at either point (often referred to as the “inverse” calculation).

Process 3: Given a point on a geodesic, find a second geodesic that is perpendicular to the given geodesic at that point.

Process 4: Given two geodesics, find their intersection point. (Labeled “4”)

Process 5: Given two constant-radius arcs, find their intersection point(s). (Labeled “5”)

Process 6: Given a geodesic and a separate point, find the point on the geodesic nearest the given point. (Labeled “6”)

Process 7: Given a geodesic and an arc, find their intersection point(s). (Labeled “7”)

Process 8: Given two geodesics and a radius value, find the arc of the given radius that is tangent to both geodesics and the points where tangency occurs. (Labeled “8”)

Process 9: Given an arc and a point, determine the geodesic(s) tangent to the arc through the point and the point(s) where tangency occurs. (Labeled “9”)

Process 10: Given an arc and a geodesic, determine the geodesic(s) that are tangent to the arc and perpendicular to the given geodesic and the point(s) where tangency occurs. (Labeled “10”)

Process 11: Compute the length of an arc.

Process 12: Determine whether a given point lies on a particular geodesic.

Process 13: Determine whether a given point lies on a particular arc.

The following algorithms have been identified as required for analysis of TERPS procedures that use locus of points curves:

Process 14: Given a geodesic and a locus, find their intersection point.

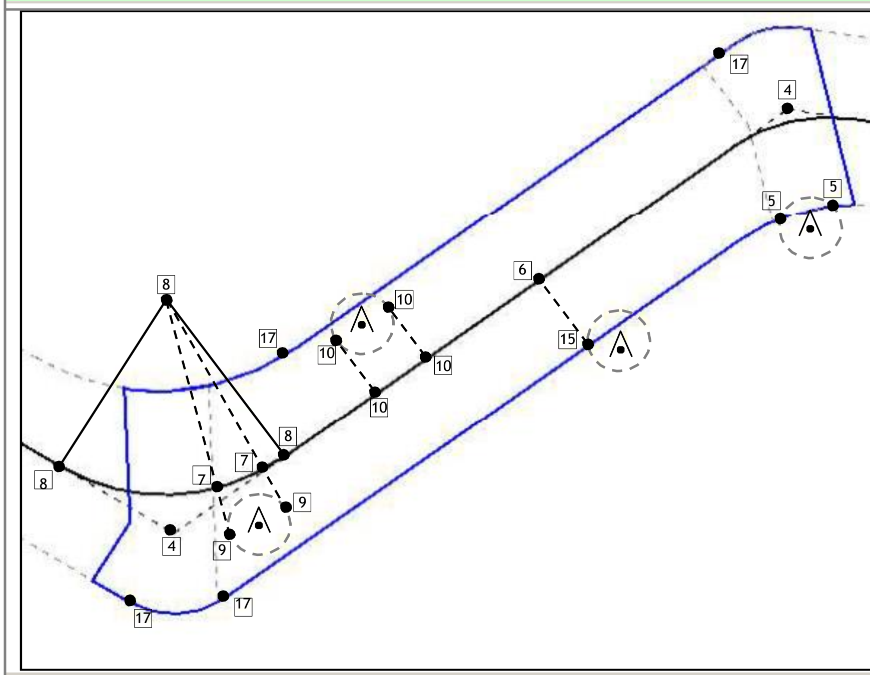
Process 15: Given a fixed-radius arc and a locus, find their intersection point(s). (Labeled "15")

Process 16: Given two loci, find their intersection.

Process 17: Given two loci and a radius, find the center of the arc tangent to both loci and the points of tangency. (Labeled "17")

The algorithm prototypes and parameter descriptions are given below using a C-like syntax. However, the algorithm steps are described in pseudo-code to maintain clarity and readability.

Figure A-1. Typical Geodetic Constructions for TERPS.



Note: Numbers refer to the algorithm in the list above that would be used to solve for the point.

2.1 Data Structures

2.1.1 Geodetic Locations

For convenience, one structure is used for both components of a geodetic coordinate. This is referred to as an **LLPoint**, which is declared as follows using C syntax:

```
typedef struct        {
              latitude;
              longitude;
     } LLPoint;
```

2.1.2 Geodesic Curves

A geodesic curve is the minimal-length curve connecting two geodetic locations. Since the planar geodesic is a straight line, we will often informally refer to a geodesic as a "line." Geodesics will be represented in data using two **LLPoint** structures.

2.1.3 Fixed Radius Arc

A geodetic arc can be defined by a center point and radius distance. The circular arc is then the set (or locus) of points whose distance from the center point is equal to the radius. If an arc subtends an angle of less than 360 degrees, then its start azimuth, end azimuth, and orientation must be specified. The orientation is represented using a value of ±1, with +1 representing a counterclockwise arc and -1 representing a clockwise arc. The distance between the start and end points must be checked. If it is less than a predetermined tolerance value, then the arc will be treated like a complete circle.

2.1.4 Locus of Points Relative to a Geodesic

A locus of points relative to a geodesic is the set of all points such that the perpendicular distance from the geodesic is defined by a continuous function w(P) which maps each point P on the geodesic to a real number. For the purposes of procedure design, will be either a constant value or a linear function of the w (P) distance from to geodesic start point. In the algorithms that follow, a locus of points P is represented using the following C structure:

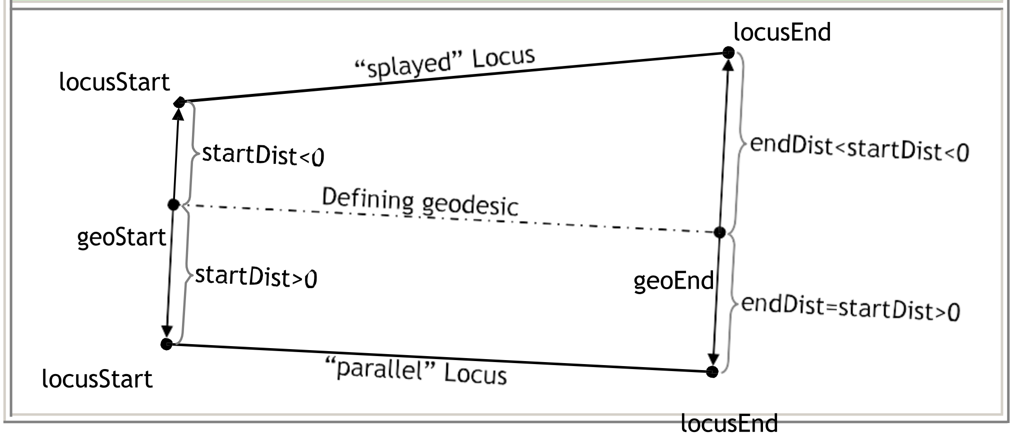
```
typedef struct  {
     LLPoint goeStart;          /* start point of geodesic       */
     LLPoint geoEnd;            /* end point of geodesic         */
     LLPoint locusStart;        /* start point of locus          */
     LLPoint locusEnd;          /* end point of locus            */
     double startDist;          /* distance from geodesic        *
                                 *  to locus at geoStart         */
     double endDist;            /* distance from geodesic        *
                                 *  to locus at geoEnd           */
    Int      lineType;          /* 0, 1 or 2                     */
}  Locus;
```

The **startDist** and **endDist** parameters define where the locus lies in relation to the defining geodesic. If **endDist=StartDist**, then the locus will be described as being "parallel" to the geodesic, while if **endDist≠startDist**, then the locus is "splayed." Furthermore, the sign of the distance parameter determines which side of the geodesic the locus is on. The algorithms described in this paper assume the following convention: if the distance to the locus is positive, then the locus lies to the right of the geodesic; if the distance is negative, then the locus lies to the left. These directions are relative to the direction of the geodesic as viewed from the **geoStart** point. See Figure A-2 for an illustration.

If memory storage is limited, then either the **startDist/endDist** or **locusStart/locusEnd** elements may be omitted from the structure, since one may be calculated from the other. However, calculating them once upon initialization and then storing them will reduce computation time.

The **lineType** attribute is used to specify the locus's extent. If it is set to 0 (zero), then the locus exists only between **geoStart** and **geoEnd** If **lineType=1**, then the locus begins at **geoStart** but extends beyond **geoEnd**. If **lineType=2**, then the locus extends beyond both **geoStart** and **geoEnd**.

Figure A-2. Two Examples Loci Defined Relative To A Single Geodesic.



3.0 Basic Calculations

3.1 Iterative Approach

For most of the intersection and projection methods listed below, an initial approximation is iteratively improved until the calculated error is less than the required accuracy. The iterative schemes employ a basic secant method, relying upon a linear approximation of the error as a function of one adjustable parameter.

To begin the iteration, two starting solutions are found and used to initialize a pair of two-element arrays. The first array stores the two most recent values of the parameter being adjusted in the solution search. This array is named **distarray** when the search parameter is the distance from a known point. It is named **crsarray** when the search parameter is an angle measured against the azimuth of a known geodesic. The second array (named **errarray** in the algorithms below) stores the error values corresponding to the two most recent parameter values. Thus, these arrays store a linear representation of the error function. The next solution in each iteration is found by solving for the root of that linear function using used **findLibearRoot** function:

```
static double findLinearRoot (double* x, double* y,
                         long* err) {
if ( x [0]  = = x [1] )  {
  /* function has duplicate x values, no root */
  return x [0]  ;
}
else if (y [0]  = = y [1]  {
  if (y [0] * y [1]  = = 0.0)  {
  return x [0]  ;
}
/* duplicate y values in root function */
return 0.5* (x [0]  + x [1] ;
}
  return  - y [0] *( x [1]  - x [0]  )/ (y [1]- y [0]) + x [0]
}
```

This function returns the value of the search parameter for which the linear error approximation is zero. The returned root is used as the next value in the adjustable parameter and the corresponding error value is calculated. Then the parameter and error arrays are updated and another new root is found.

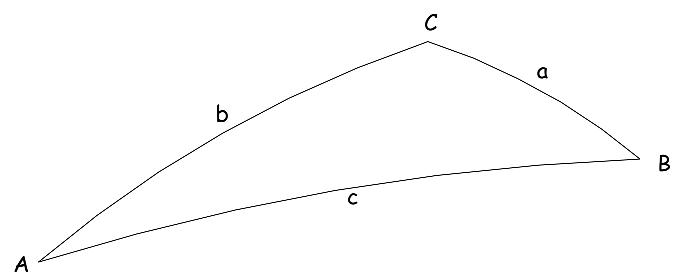
This iteration scheme works well for the algorithms described in this paper. Convergence is achieved very quickly because each starting solution is very close to the final solution, where the error is well approximated by a linear function.

3.2 Starting Solutions

Starting solutions must be provided to start iterating toward a precise solution. Initial solutions may be found in all cases by using spherical triangles to approximate the geodetic curves being analyzed, and then solve for unknown distance and azimuth values using spherical trigonometry formulas.

3.2.1 Spherical Direction Intersect

Given two points A and B and two bearings A to C and B to C, find C.



Run Inverse to find arc length from A to B and bearings A to B and B to A. Compute differences of bearings to find angles A and B of the spherical triangle ABC.

More than one valid solution may result. Choose the solution closest to the original points.

Apply the spherical triangle formulas to find the angle C and arc lengths from A to C and from B to C:

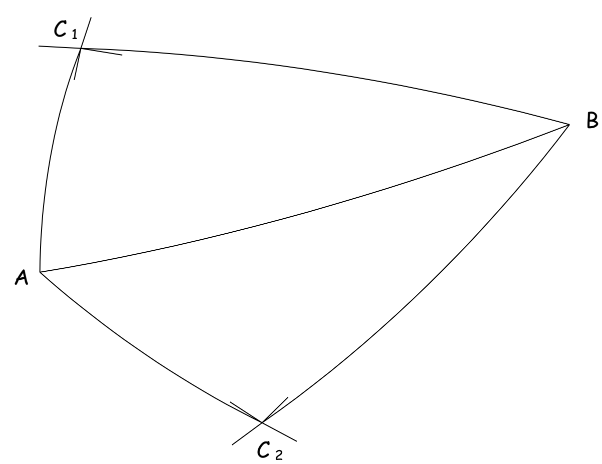
$$C = cos^{-1}\left(-\cos(A)\cdot\cos(B) + \sin(A)\cdot\sin(B)\,cos\left(\frac{c}{R}\right)\right),$$

$$a = R\cdot cos^{-1}\left(\frac{\cos(A) + \cos(B)\cdot\cos(C)}{\sin(B)\cdot\sin(C)}\right), \qquad b = R\cdot cos^{-1}\left(\frac{\cos(B) + \cos(A)\cdot\cos(C)}{\sin(A)\cdot\sin(C)}\right)$$

Note: If distances a or b result from a reciprocal bearing, assign appropriate negative sign(s).

Run Direct from A to find C. Use given bearing and computed length b.

3.2.2 Spherical Distance Intersection



Given A, B and distances AC and BC, find C_1 and C_2.

Run Inverse to find length and bearings between A and B.

Use spherical triangles to find angles A =BAC_1 = BAC_2, B =ABC_1 = ABC_2, and C = BC_1A = BC_2A:

$$A = cos^{-1}\left(\frac{\cos\left(\frac{a}{R}\right) - \cos\left(\frac{b}{R}\right)\cdot\cos\left(\frac{c}{R}\right)}{\sin\left(\frac{b}{R}\right)\cdot\sin\left(\frac{c}{R}\right)}\right), B = cos^{-1}\left(\frac{\cos\left(\frac{b}{R}\right) - \cos\left(\frac{a}{R}\right)\cdot\cos\left(\frac{c}{R}\right)}{\sin\left(\frac{a}{R}\right)\cdot\sin\left(\frac{c}{R}\right)}\right),$$

and $C = cos^{-1}\left(\frac{\cos\left(\frac{c}{R}\right) - \cos\left(\frac{a}{R}\right)\cdot\cos\left(\frac{b}{R}\right)}{\sin\left(\frac{a}{R}\right)\cdot\sin\left(\frac{b}{R}\right)}\right)$

Run Direct from A to find C_1 and C_2.

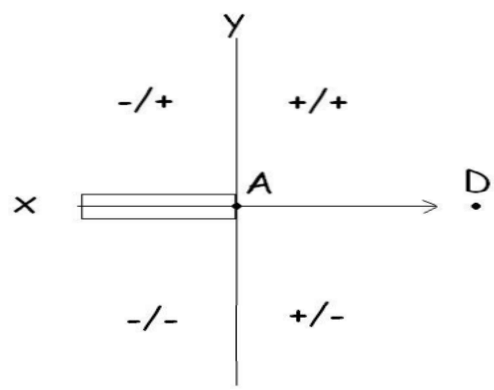
To compute the bearing from A to $C_{1,}$ start with the bearing from A to B and subtract angle A.

To compute the bearing from A to $C_{2,}$ start with the bearing from A to B and add angle A.

Use Inverse and spherical triangle formulas to get remaining bearings.

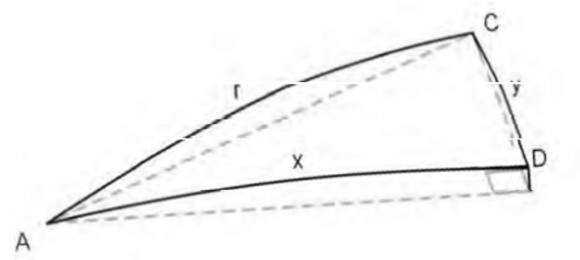
3.2.3 Spherical Tangent Point

In both cases of the tangent point, distances are signed according to the following sign legend:



Where the arrow indicates the bearing from the first point A to the target point D.

3.2.4 Two Points and a Bearing Case



Given two points, A and C, and a bearing from the first point (A). Find the point D along the given bearing extended which is closest to C.

Run Inverse to find length and bearings between A and C.

Find difference in bearings to compute angle A.

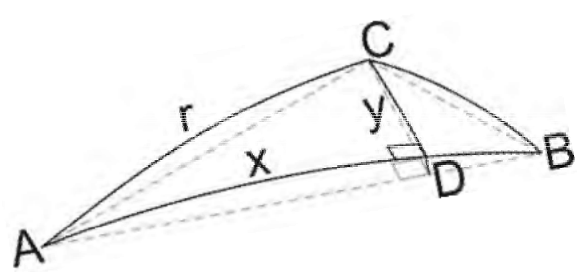
Use right spherical triangles to calculate y and x:

$$y = R \cdot sin^{-1}\left(sin\left(\frac{\mathrm{r}}{\mathrm{R}}\right) \cdot \sin(\mathrm{A})\right)$$

$$x = R \cdot cos^{-1}\left(\frac{cos\left(\frac{\mathrm{r}}{\mathrm{R}}\right)}{\cos\left(\frac{\mathrm{y}}{\mathrm{R}}\right)}\right)$$

Run Direct from A to find D using given bearing and computed length x.

3.2.5 Given Three Points Case



Given three points (A, B, C), find the point (D) on the geodesic line from the first two points which is the perpendicular foot from the third point.

Use Inverse to determine bearing from A to B.

Use Inverse to determine bearing and length from A to C.

Find the difference in bearings to determine angle A.

Use right spherical triangles to find the lengths x and y:

$$y = R \cdot sin^{-1}\left(sin\left(\frac{\mathrm{r}}{\mathrm{R}}\right) \cdot \sin(\mathrm{A})\right)$$

$$x = R \cdot cos^{-1}\left(\frac{cos\left(\frac{\mathrm{r}}{\mathrm{R}}\right)}{\cos\left(\frac{\mathrm{y}}{\mathrm{R}}\right)}\right)$$

Use Direct to calculate D from A using the computed bearing from A to B and computed distance x.

3.3 Tolerances

Two different convergence tolerances must be supplied so that the algorithms cease iterating once the error becomes sufficiently small. The first tolerance parameter is used in the forward and inverse routines; it is referred to as **eps** in the algorithm descriptions. The second parameter, labeled **tol**, is used in the intersection and projection routines to limit the overall error in the solution. Since the intersection and projection routines make multiple calls to the inverse and forward algorithms, the **eps** parameter should be several orders of magnitude smaller than the **tol** parameter to ensure that the iteration methods return correct results. Empirical studies have shown that
eps = 0.5e-13 and **tol = 1.0e-9** work well.

Finally, a maximum iteration count and convergence tolerances must be supplied to ensure that no algorithms can remain in an infinite loop if convergence is not reached. This parameter can be set by the programmer, but should be greater than five to ensure that all of the algorithms can reach convergence.

3.4 Direct and Inverse Algorithms

The Direct and Inverse cases utilize formulae from T. Vincenty's, Survey Review XXIII, No. 176, April 1975: Direct and Inverse Solutions of Geodesics on the Ellipsoid with Application of Nested Equations.

<u>Vincenty's notation is annotated below</u>:

a, b, major and minor semi axes of the ellipsoid.

f, flattening = $\frac{a-b}{a}$.

ϕ, geodetic latitude, positive north of the equator.

L, difference in longitude, positive east.

s, length of the geodesic.

α_1, α_2, bearings of the geodesic, clockwise from north; α_2 in the direction P_1P_2 produced.

α, bearing of the geodesic at the equator.

$u^2 = \frac{a^2-b^2}{b^2}\, cos^2\alpha.$

U, *reduced latitude, defined by* $\tan U = -(1-f)\tan \varnothing.$

λ, *difference in longitude on the auxiliary sphere.*

σ, angular distance P_1P_2, on the sphere.

σ_1, angular distance on the sphere from the equator to P_1.

σ_m, angular distance on the sphere from the equator to the midpoint of the line.

3.4.1 Vincenty's Direct Formula

$$tan\,\sigma_1 = \frac{\tan U_1}{\cos \alpha_1} \quad (1)$$

$$\sin\alpha = \cos U_1 \sin\alpha_1 \quad (2)$$

$$A = 1 + \frac{u^2}{16384}\{4096 + u^2[-768 + u^2(320 - 175u^2)]\} \quad (3)$$

$$B = \frac{u^2}{1024}\{256 + u^2[-128 + u^2(74 - 47u^2)]\} \quad (4)$$

$$2\sigma_m = 2\sigma_1 + \sigma \quad (5)$$

$$\Delta\,\sigma = B\sin\sigma\left\{\cos(2\sigma_m) + \frac{1}{4}B\left[cos(\sigma)(2cos^2(2\sigma_m) - 1) - \frac{1}{6}B\cos(2\sigma_m)(4sin^2\sigma - 3)(4cos^2(2\sigma_m) - 3)\right]\right\} \quad (6)$$

$$\sigma = \frac{s}{bA} + \Delta\,\sigma \quad (7)$$

Equations (5), (6), and (7) are iterated until there is a negligible change in σ. The first approximation of σ is the first term of (7).

Note 1: For 1 cm accuracy, σ can change no more than 1.57e-009.

$$\tan \varnothing_2 = \frac{\sin U_1 \cos\sigma + \cos U_1 \sin\sigma \cos\alpha_1}{(1-f)[sin^2\alpha + (\sin U_1 \sin\sigma - \cos U_1 \cos\sigma \cos\alpha_1)^2]^{\frac{1}{2}}} \tag{8}$$

$$\tan\lambda = \frac{\sin\sigma \sin\alpha_1}{\cos U_1 \cos\sigma - sin U_1 \sin\sigma \cos\alpha_1} \tag{9}$$

$$C = \frac{f}{16} cos^2\alpha[4 + f(4 - 3cos^2\alpha)] \tag{10}$$

$$L = \lambda - (1 - C)f \sin\alpha\{\sigma + C \sin\sigma[cos(2\sigma_m) + C \cos\sigma(2cos^2(2\sigma_m) - 1)]\} \tag{11}$$

$$\tan\alpha_2 = \frac{\sin\alpha}{-\sin U_1 \sin\sigma + \cos U_1 \cos\sigma \ \cos\alpha_1} \tag{12}$$

The latitude is found by computing the arctangent of (8) and α_2 is found by computing the arctangent of (12).

3.4.2 Vincenty's Inverse Formula

$\lambda = L$ (first approximation) (13)

$$sin^2\sigma = (\cos U_2 \sin\lambda)^2 + (\cos U_1 \sin U_2 - \sin U_1 \cos U_2 \cos\lambda)^2 \tag{14}$$

$$\cos\sigma = \sin \mathrm{U}_1 \sin \mathrm{U}_2 + \cos \mathrm{U}_1 \cos \mathrm{U}_2 \cos\lambda \tag{15}$$

$$\tan\sigma = \frac{\sin\sigma}{\cos\sigma} \tag{16}$$

$$\sin\alpha = \frac{\cos U_1 \cos U_2 \sin\lambda}{\sin\sigma} \tag{17}$$

$$cos(2\sigma_m) = \cos\sigma - \frac{2 \sin \mathrm{U}_1 \sin \mathrm{U}_2}{\cos^2\alpha} \tag{18}$$

λ is obtained by equations (10) and (11). This procedure is iterated starting with equation (14) until the change in λ is negligible. See Note 1.

$$s = bA(\sigma - \Delta\sigma) \tag{19}$$

Where $\Delta\sigma$ comes from equations (3), (4), and (6)

$$\tan\alpha_1 = \frac{\cos U_2 \sin\lambda}{\cos U_1 \sin U_2 - \sin U_1 \cos U_2 \cos\lambda} \tag{20}$$

$$\tan\alpha_2 = \frac{\cos U_1 \sin\lambda}{\cos U_1 \sin U_2 \cos\lambda - \sin U_1 \cos U_2} \tag{21}$$

The inverse formula may give no solution over a line between two nearly antipodal points. This will occur when λ, as computed by (11), is greater than π in absolute value. To find α_1, α_2, compute the arctangents of (20) and (21).

The remainder of this appendix will assume the direct and inverse use the following named functions:

Long **WGS84Dest (LLPoint, origin, double course, double distance, LLPoint* dest, double eps**) returns an **LLPoint** representing the destination point, where the inputs are:

`LLPoint origin`	=	Starting `LLPoint` with lat/lon in radian
`Double course`	=	Azimuth of geodesic at origin in radians
`Double distance`	=	Distance to desired point (in NM)
`LLPoint* dest`	=	Reference to `LLPoint` that will be updated with lat/lon of destination
`Double eps`	=	Maximum error allowed in computation

`Long` **`WGS84Inverse (LLPoint origin, LLPoint dest, double* crs, double* bcrs, double* dist, double eps`**`)` returns course and distance where the inputs are:

`LLPoint origin`	=	Coordinates of starting point
`LLPoint dest`	=	Coordinates of destination point
`Double* crs`	=	Reference to double that will be updated with course at origin in radians
`Double* bcrs`	=	Reference to double that will be updated with reciprocal course at destination in radians
`Double* dist`	=	Reference to return value that will contain the distance between `origin` and `dest`
`Double eps`	=	Maximum error allowed in computation

3.5 Geodesic Oriented at Specified Angle

In TERPS procedure design, it is often required to find a geodesic that lies at a prescribed angle to another geodesic. For instance, the end lines of an obstacle evaluation area (OEA) are typically projected from the flight path at a prescribed angle. Since the azimuth of a geodesic varies over the length of the curve, the angle between two geodesics must be measured by comparing the azimuth of each geodesic at the point where they intersect. The following pseudo-code represents an algorithm that will calculate the correct azimuth at any point on a geodesic described by its start and end points. This azimuth can easily be extended to find the azimuth of an intersecting geodesic at the point if the angle of intersection is known.

3.5.1 Input/Output

double WGS84GeodesicCrsAtPoint (LLPoint startPT, LLPoint endPT, LLPoint testPt, int length, int length, double* startCrs, double* revCrs, double* distToPt, long* err, double tol, double eps) returns a **double** representing the azimuth of the intersecting geodesic, where the inputs are:

LLPoint startPt	=	Coordinates of start point of given geodesic
LLPoint endPt	=	Coordinates of end point of geodesic
LLPoint testPt	=	Point at which course of geodesic is to be determined
double* startCrs	=	Azimuth of geodesic at **startPt** in radians
double* revCrs	=	Reciprocal azimuth of geodesic at **endPt** in radians
double* distToPt	=	Distance from **startPt** to **testPT** in NM
double tol	=	Accuracy tolerance for intersection calculation
double eps	=	Convergence parameter for forward/inverse algorithms

3.5.2 Algorithm Steps

<u>STEP 1</u>: Use the **WGS84PtIsOnLine** algorithm to check that **testPt** actually lies on geodesic defined by **startPt** and **endPt**.

<u>STEP 2</u>: Use Inverse algorithm to determine course and distance from **testPt** to **startPt**. Denote course as **crsToStart**.

STEP 3: Use Inverse algorithm to determine course and distance from **testPT** to **endPt**. Denote course as **crsToEnd**.

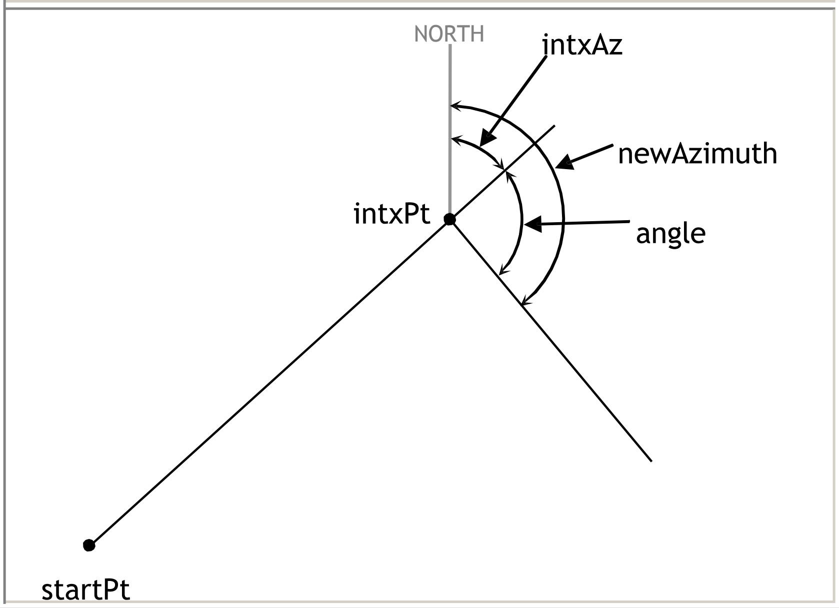
STEP 4: If **testPt** lies on geodesic between **startPt** and **endPt**, then the correct azimuth is **crsToEnd**.

STEP 5: If **testPt** lies on the geodesic beyond **endPt**, then the correct azimuth is **crsToStart** $+ \pi$

STEP 6: Return the calculated azimuth.

Note that if **angle** is positive, then the new geodesic will lie to the right of the given geodesic (from the perspective of standing at the start point and facing toward the end point); otherwise, the new geodesic will lie to the left.

Figure A-3. Projecting A Geodesic Through A Point Along The Specified Azimuth.



3.6 Determine If Point Lies on Geodesic

This algorithm returns a true value if a point lies on and within the bounds of a given geodesic. The bounds of the geodesic are specified by two pieces of information: the end point coordinates and an integer length code. If the length code is set to 0, then the geodesic is understood to exist only between its start and end points, so a value of true will be returned only if the test point also lies between the start and end points. If the length code is set to 1, then the geodesic is understood to extend beyond its end point to a distance of one half of earth's circumference from its end point. If the length code is set to 2, then the geodesic is understood to extend beyond both the start and end points.

Note that this algorithm relies on the concept of equality for two **LLPoint** structures. This will be defined to mean that the distance between the two **LLPoints** as calculated using the inverse algorithm, is less than **tol**.

3.6.1 Input/Output

int WGS84PtIsOnline (LLPoint startPt, LLPoint endPt, LLPoint testPt, LineType lenthCode, double tol, double eps) returns an integer value indicating whether **testPt** lies on geodesic, where the inputs are:

LLPoint startPt	=	Geodetic coordinate of line start point
LLPoint endPt	=	Geodetic coordinate of line end point
LLPoint testPt	=	Geodetic coordinate of point to test
LineType lenghCode	=	Integer that specifies extent of line. 0: geodesic exists only between **startPt** and **endPt**. 1: geodesic extends beyond **endPt**. 2: geodesic extends behind **startPt**.
double tol	=	Maximum difference allowed in distance
double eps	=	Convergence parameter for forward/inverse algorithms.

3.6.2 Algorithm Steps

See Figure A-4 for an illustration of the variables.

STEP 1: Use inverse algorithm to calculate the azimuth and distance from **startPt** to **endPt**. Denote these values by **crs12** and **dist12**, respectively.

STEP 2: Use **WGS84PtIsOnCrs** algorithm to determine if **testPt** lies on geodesic given by **startPT** and **endPt**.

1. Use inverse algorithm to calculate the distance from **startPt** to **testPt** Denote this value by **tmpDist1Test**.

2. Use direct algorithm to project a point from **startPT** along **crs12** a distance equal to distance equal to **tmpDist1Test**. Denote this point by **comparePt**.

3. Use **WGS84PointsAreSame** algorithm to determine if **testPt** is equal to equal to **comparePt**.

STEP 3: Examine error to determine whether **testPt** lies on the geodesic within **tol** as follows:

1. If (**error ≤ tol**) then,

    a. If (**lenghtCode** > 0) or (**dist13 - dist12 ≤ tol**) then ,

        (1) onLine = true.

    b. Else

        (1) onLine = false.

2. End if.

3. Else if (**lengthCode = 2**)

    a. Use the direct algorithm to project point from **startPT** along **crs12 + π** a distance **dist13.** Again, denote this point again by **testPt2**.

    b. Use the inverse algorithm to recalculate error which is the distance from **testPt** to **testPt2.**

    c. If (**error ≤ tol**) then **onLine = true.**

        (1) Else **onLine = false.**

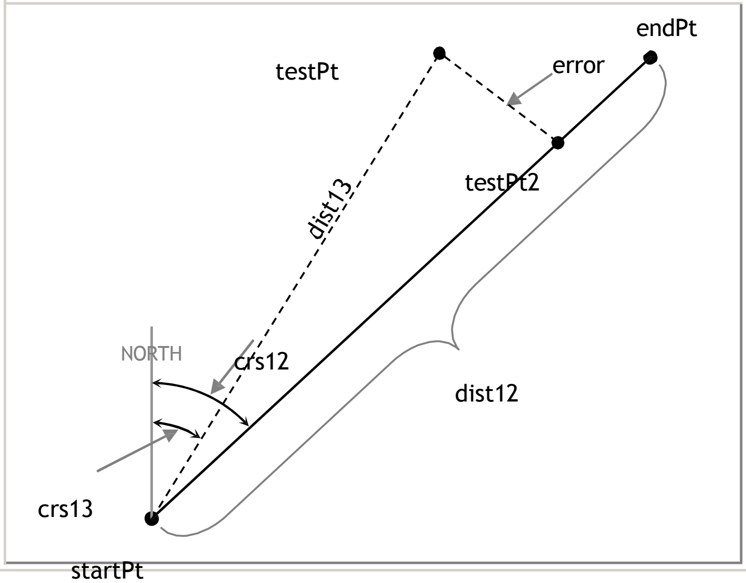
4. End if.

5. Else,

    a. onLine = false.

6. End if.

Figure A-4. Entities For Testing Whether a Point Lies on a Geodesic.



3.7 Determine If Point Lies on Arc

This algorithm returns a non-zero (true) value if the sample point lies on and between the bounds of the given arc. The arc is defined by its center point, radius, start azimuth, end azimuth, and orientation. A positive orientation parameter indicates that the arc is traversed in a counterclockwise sense, while a negative orientation parameter indicates that the arc is traversed clockwise. This algorithm is used in conjunction with the arc intersection functions (Algorithms 4.2, 4.3, and 4.6) to determine whether the computed intersections lie within the bounds of the desired arc.

3.7.1 Input/Output

int WGS84PtIsOnArc (LLPoint center, double radius, double startCrs, double endCrs, ArcDirection orientation, LLPoint testPt, double tol) returns an integer value indicating whether **testPt** lies on arc, where the inputs are:

LLPoint center	=	Geodetic coordinate of arc center
double radius	=	Arc radius
double startCrs	=	True azimuth from center to start of arc
double endCrs	=	True azimuth from center to end of arc
ArcDirection orientation	=	Maximum difference allowed in distance
double tol	=	Orientatiion of the arc. [+1 for counter-clockwise, -1 for clockwise]

LLPoint testPt	=	Geodetic coordinate of point to test
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms.

3.7.2 Algorithm Steps

See Figure A-5 for an illustration of the variables.

STEP 1: Use inverse algorithm to calculate distance and azimuth from center to **testPt**. Denote values as **dist** and **crs**, respectively.

STEP 2: If (**abs (dist-radius)** > **tol**) then **testPt** is not correct distance from **center**.

a. **onArc = false**

STEP 3: else.

a. Use Algorithm 6.0 - Calculate Angular Arc Extent to calculate the angle subtended by the full arc. Denote this value by **arcExtent**.

b. If (**arcExtent** = 360°) then,

(1) onArce = true.

c. Else.

(1) Use the inverse algorithm to calculate the azimuth from center to **testPt**. Denote this value by **testCrs**.

(2) Use Algorithm 6.0 - Calculate Angular Arc Extent to calculate the angle subtended by and arc starting at **startCrs** but ending at **testCrs**, with the same **orientation**. Denote this value by **subExtent**.

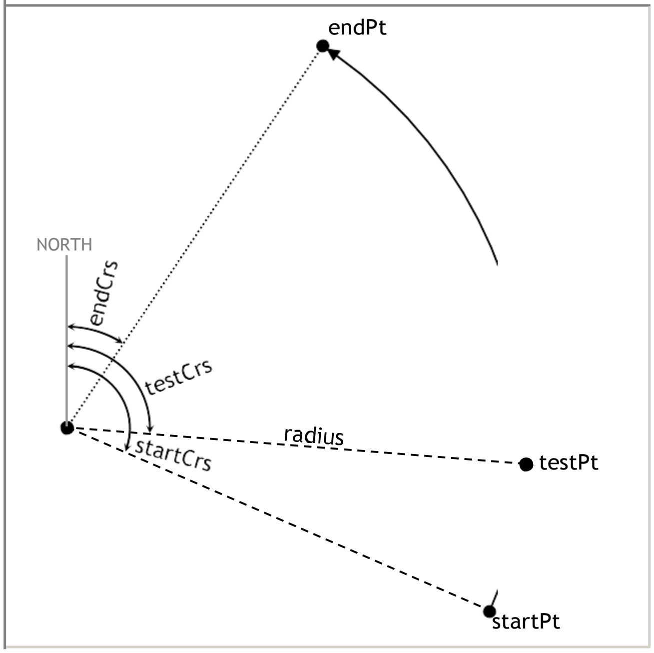
(3) If **(- .002 ≤ subExtent ≤ arcExtent + .002)** then traversing arc from **startCrs** to **endCrs**, one would encounter **testPt**, so it must lie on arc.

(a) onArc = true.

d. End if.

STEP 4: End if.

Figure A-5. Entities for Testing Whether a Point Lies on an Arc.



3.8 Calculate Length of Fixed Radius Arc

A fixed radius arc on an ellipsoid does not generally lie in a plane. Therefore, the length of the arc cannot be computed using the usual formula for the circumference of a circle. The following algorithm takes the approach of dividing the arc into many sub- arcs. Three points are then calculated on each sub-arc. Since any three points in space uniquely determine both a plane and an arc, the three points on each sub-arc are used to calculate the radius and subtended angle of the planar arc that contains all three points. The length of the approximating planar arc is then calculated for each sub-arc. The sum of the sub-arc lengths approaches the length of the original arc as the number of sub-arc increases (and each sub-arc's length decreases).

A simpler method that is sufficiently accurate for arcs with radius less than about 300 nautical miles (NM) is described in section 6.4.

3.8.1 Input/Output

double **WGS84DiscretizedArcLength** (**LLPoint center, double radius, double startCrs, double endCrs, int orient, int*n, double tol**) returns a double precision value representing the length of the arc, where the inputs are:

`LLPoint center`	=	Geodetic coordinates of arc center
`double radius`	=	Arc radius
`double startCrs`	=	True azimuth from center to start of arc
`double endCrs`	=	True azimuth from center to end of arc
`int orient`	=	Orientation of the arc [+1 for counter-clockwise; -1 for clockwise]
`int *n`	=	Reference to integer used to return number of steps in discretized arc
`double tol`	=	Maximum allowed error
`double eps`	=	Convergence parameter for forward/inverse algorithms

3.8.2 Algorithm Steps

See Figure A-6 for an illustration of the variables.

STEP 1: Set initial number of sub-arcs to use. The fixed value **n = 16** has been found through trial-and-error to be a good starting value. Alternatively, the initial value of n may be calculated based on the arc's subtended angle and its radius (i.e., its approximate arc length).

STEP 2: Convert **center** point to Earth-Centered, Earth-Fixed (ECEF) coordinates, **v0** according to Algorithm 6.1.

STEP 3: Compute subtended angle, **`subtAngle`**, using Algorithm 6.0.

STEP 4: Set iteration count, **`k` = 0.**

STEP 5: Do while **k= 0** or ((**error** > **tol**) and (k ≤ **maximumIterationCount**)).

a. Calculate subtended angle of each **sub-arc**, **dtheta = subAngle/n.**

b. Use direct algorithm from **center**, using **startCrs** and distance **radius** to project start point of arc. Denote this point by **p1**.

c. Convert **p1** to ECEF coordinates. Denote this vector by **v1.**

d. Initialize **arcLenght = 0**.

e. For **i = 0** to **n.**

(1) Compute azimuth from arc center to end point of sub-arc number **i: theta = startCrs + i*dtheta**.

(2) Use direct algorithm from azimuth **theta+0.5*dtheta** and distance **radius**, to project middle point of sub-arc. Denote this point by **p2.**

(3) Convert **p2** to ECEF coordinate **v2.**

(4) Use direct algorithm from **center** using azimuth **theta+dtheta** and distance **radius**, to project endpoint of sub-arc. Denote this point by **p3**.

(5) Convert **p3** to ECEF coordinate **v3.**

(6) Subtract **v2** from **v1** to find chord vector between **p1** and **p2**. Denote this vector by chord1 Compute **x1 = │chord1 │.**

(7) Subtract **v2** from **v3** to find chord vector between **p3** and **p2.** Denote this vector by **chord2**. Compute **x2 = │chord2 │.**

(8) Compute dot product of **chord1** and **chord2**. Denote this value as **d.**

(9) Use the following calculation to compute the length **L** of the **sub- arc**: (see Figure A-7)

(a) xi = d/ (x1*x2)

(b) sigma = sqrt (1-xi^ 2)

(c) R = (x2*sqrt ((x1/x2 – xi) ^2 + sigma^2))/(2*sigma)

(d) A = 2 (π – arccos (xi))

(e) L = R* A

$$\xi = \frac{d}{x_1 x_2}$$

$$\sigma = \sqrt{1 - \xi^2}$$

$$R = \frac{x_2 \sqrt{\left(\frac{x_1}{x_2} - \xi\right)^2 + \sigma^2}}{2\sigma}$$

$$A = 2(\pi - cos^{-1}\xi)$$

$$L = R \cdot A$$

Note that since the arc length is a planar (not geodetic) calculation, the subtended angle A is not equal to **dtheta**.

(10) Add **L** to cumulative length to get total length of sub-arcs through sub-arc number i**: length = length + L**.

f. end for loop.

g. Compute error, which is the change in length calculation between this iteration and the last: **error = abs(length – oldLength).**

h. Increment the iteration count: **k = k+1.**

i. Double the number of sub-arcs: **n = 2*n.**

j. Save the current length for comparison with the next iteration: **oldLength = length**.

STEP 6: End while loop.

STEP 7: Return **length**.

Figure A-6. Calculating Arc Length.

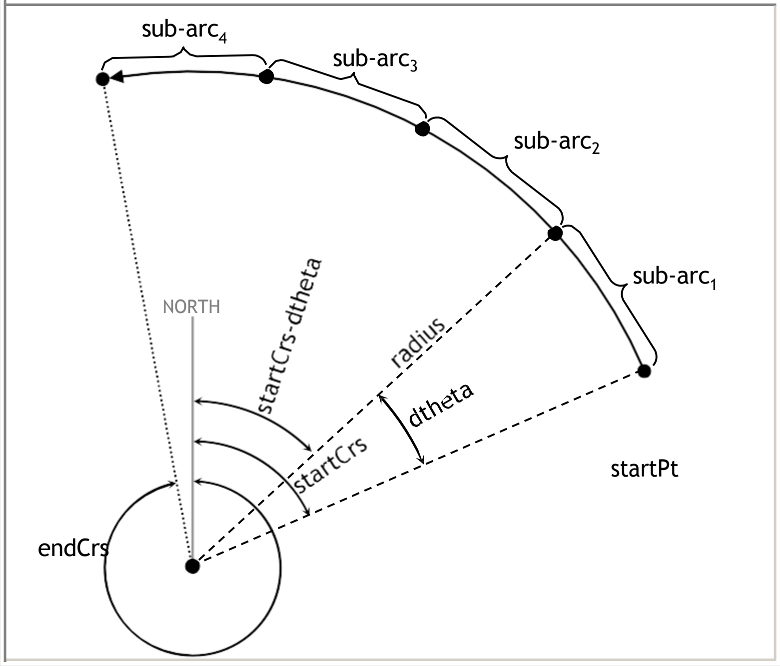
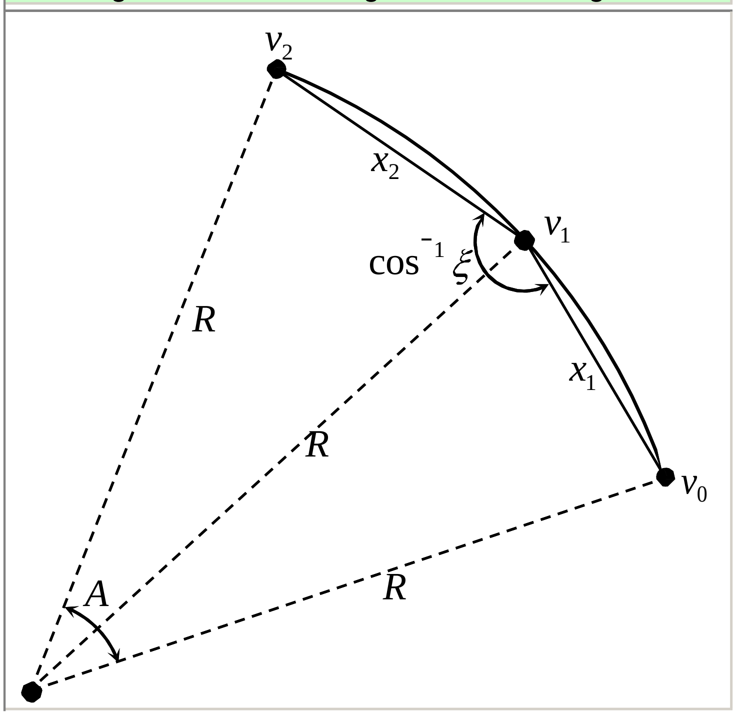


Figure A-7. Calculating the Sub-Arc Length.



3.9 Find Distance from Defining Geodesic to Locus

When computing a position on a locus of points, it is necessary to solve for the distance from the defining geodesic to the locus. This distance is constant if the locus is designed to be "parallel" to the defining geodesic. However, it is necessary to allow the locus distance to vary linearly with distance along the geodesic, since in some cases the locus will splay away from the defining geodesic. To account for this, we have included **`startDist`** and **`endDist`** attributes in the **`Locus`** structure defined above. For a given point on the geodesic (or given distance from the geodesic start point), the distance to the locus can then be calculated.

The two algorithms described below carry out the computation of locus distance for different input parameters. If the distance from the geodesic start point to the point of interest is known, then **`WGS84DistToLocusD`** may be used to calculate the locus distance. If instead a point on the defining geodesic is given, the **`WGS84DistToLocusP`** may be used. The latter algorithm simply computes the distance from the geodesic start point to the given point and then invokes the former algorithm. Therefore, steps are described for **`WGS84DistToLocusD`** only.

3.9.1 Input/Output

double WGS84DistToLocusD (Locus loc, double distance) returns the distance from the defining geodesic to the **locus** at the given distance from **loc.geoStart**, where the inputs are:

Locus loc	=	Locus of interest
double distance	=	Distance from locus start point to point where distance is to be computed

double **WGS84DistToLocusP (Locus loc, LLPoint geoPt, double *faz, double tol, double eps)** returns the distance from the defining geodesic to the **locus** at the given point, where the inputs are:

Locus loc	=	Locus of interest
LLPoint geoPt	=	Point on defining geodesic
double *faz	=	Pointer used to return forward azimuth of geodesic at **geopt**. This is needed if **geopt** is not between **geoStart** and **geoEnd**.
double tol	=	Maximum allowable error
double eps	=	Convergence parameter for forward/inverse algorithms

3.9.2 Algorithm Steps

The following steps are followed if the **distance** from **loc.geoStart** is given. If a point on the geodesic (**geoPt**) is given instead, then first use the inverse algorithm to compute the **distance** from **geoPt** to **loc.geoStart** and then follow the following steps (note that **distance** must be signed negative if the locus's line type is 2 and **geoPt** is farther from

geoEnd than it is from **geoStart**):

STEP 1: Use the inverse function to compute the length of the locus's defining geodesic. Denote this value as **geoLen**.

STEP 2: If (**geoLen = 0**) then **distToLoc** = **0.0**

STEP 3: Else:

$$\text{distToLoc} = \text{loc.startDist} + \frac{\text{distance}}{\text{geoLen}} * (\text{loc.endDist} - \text{loc.startDist})$$

STEP 4: End if.

STEP 5: Return distToLoc.

3.10 Project Point on Locus from Point on Defining Geodesic

Given a point on the defining geodesic, this algorithm computes the corresponding point on the locus.

3.10.1 Input/Output

LLPoint WGS84PtOnLocusP (Locus loc, LLPoint geoPt, LLPoint* ptonloc, double* perpCrs, double tol, double eps) returns the point on the locus that is abeam the given point, where the inputs are:

Locus loc	=	Locus of interest
LLPoint geoPt	=	Point on defining geodesic
LLPoint* ptonloc	=	Pointer to LLPoint, updated with coordinates of point on locus abeam given point.
Double* perpCrs	=	Pointer to double, updated with azimuth from point on geodesic to point on locus.
double tol	=	Maximum allowable error
double eps	=	Convergence parameter for forward/inverse algorithms

3.10.2 Algorithm Steps

STEP 1: Use Algorithm 3.9 (with point input) to determine the distance from **geoPt** to the locus. Denote this distance as **distp**.

STEP 2: If (**distp = 0**) return **geoPt**.

STEP 3: Use the inverse algorithm to compute the course from **geoPt** to the start point of the defining geodesic. Denote this value as **fcrs.**

STEP 4: If (**distp** > **0.0**) then the locus lies to the right of the geodesic. Let
***perpCrs = fcrs + π/2**

STEP 5: Else, the locus lies to the left of the geodesic. Let
***perpCrs = fcrs – π/2**

STEP 6: End if

STEP 7: Use the direct algorithm to project a point along ***perpCrs**, distance **abs(distp**) from **geoPt** Denote the point as **ptonLoc**.

STEP 8: Return **ptonLoc**.

3.11 Determine if Point Lies on Locus

This algorithm compares the position of a given point with the position of the corresponding point on the locus. The corresponding point on the locus is found by projecting the given point onto the locus's defining geodesic curve, computing the correct distance from there to the locus, and then projecting a point at that distance perpendicular to the geodesic. If distance from the corresponding point to the given point is less than the error tolerance, then a reference to the projected point on the geodesic is returned. Otherwise a null reference is returned.

An alternative implementation could simply return true or false, rather than references. However, it is more efficient to return the projected point as this is often needed in subsequent calculations.

3.11.1 Input/Output

int WGS84PtIsOnLocus (Locus loc, LLPoint testPt, LLPoint* ptOnGeo, double tol, double eps) returns a reference to the projection of **testPT** on the locus's defining geodesic if **testPt** lies on the locus and NULL otherwise, where the inputs are:

Locus loc	=	Locus of interest

LLPoint testPt	=	Point to test against locus
LLPoint* ptOnGeo	=	Pointer to **LLPoint**, updated with point on defining geodesic abeam the given point on the locus.
double tol	=	Maximum allowable error
double eps	=	Convergence parameter for forward/inverse algorithms

3.11.2 Algorithm Steps

See Figure A-8 for an illustration of the variables.

STEP 1: If **testPt** is the same as **loc.geoStart** or **loc.geoEnd** then return a reference to **ptOnGeo** containing the appropriate point.

STEP 2: Use Algorithm 5.1 to project **testPT** onto the locus's defining geodesic. Denote the projected point as **ptOnGeo**

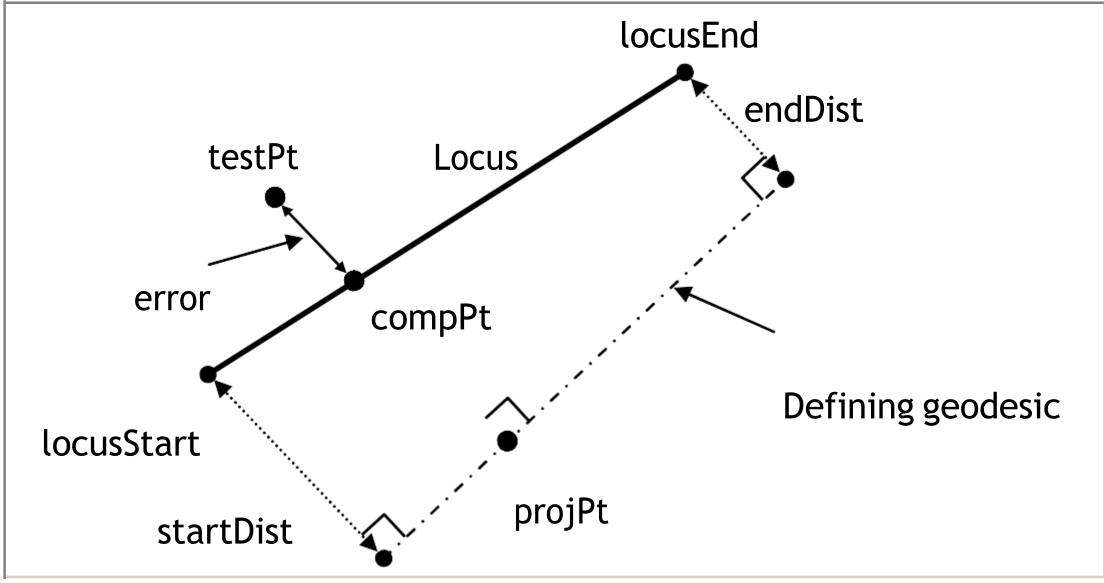
STEP 3: Use Algorithm 3.6 to determine whether **ptOnGeo** lies on the locus's defining geodesic. This will account for an infinite or semi-infinite locus. If it does not, then return 0 (false).

STEP 4: Use the Inverse Algorithm to find the course between **loc.geoStart** and **testPt** Use this course to determine which side of the locus **testPt**. falls. Apply the appropriate sign to this distance, **distFromPoint.**

STEP 5: Use Algorithm 3.9 to calculate the correct expected locus distance, **loc.Dist.**

STEP 6: If abs (**distFromPoint - locDist**) ≤ **tol**, then the point is on the locus. Return a reference to the projection on the defining geodesic.

Figure A-8. Locating a Point Relative to a Locus.



3.12 Compute Course of Locus

This algorithm is analogous to the inverse algorithm for a geodesic. It is used by other locus algorithms when the direction of the locus is needed.

3.12.1 Input/Output

double WGS84LocusCrsAtPoint (**Locus loc, LLPoint testPt, LLPoint* geoPt, double* perpCrs, double tol**) returns the course of the locus at the given point. Also sets values of calculation byproducts, including the corresponding point on the locus's geodesic and the course from the given point toward the geodesic point, where the inputs are:

`Locus loc`	=	Locus of Interest
`LLPoint testPt`	=	Point at which course will be calculated
`LLPoint* geoPt`	=	Projection of `testPt` on defining geodesic
`double* perpCrs`	=	Course for `testPt` to `geoPt`
`double tol`	=	Maximum allowable error
`double eps`	=	Convergence parameter for forward/inverse algorithms

3.12.2 Algorithm Steps

See Figure A-9 for an illustration of the variables.

STEP 1: Use Algorithm 3.11 to determine whether **testPt** lies on loc. This same step will return a reference to the projection of **testPt** onto the defining geodesic. Denote this reference as **geoPt**.

STEP 2: If (geoPt = NULL) then **testPt** is not a valid point at which to calculate the locus's course. Return -1.0. (Valid course values are in the range $[0, 2\pi]$.)

STEP 3: Use the inverse algorithm to calculate the course and distance from **testPt** to **geoPt**, denoted by **perpCrs** and **perpDist**, respectively.

STEP 4: Use Algorithm 3.9 to calculate **distToLoc**, the distance from the geodesic to the locus at **geoPt**. This step is required to determine which side of the geodesic the locus lies on because **perpDist** will always be positive.

STEP 5: Calculate the slope of the locus relative to the geodesic:

$$\boldsymbol{slope} = \frac{(\mathbf{loc.endDist} - \mathbf{loc.startDist})}{\mathbf{geoLen}}$$

STEP 6: Convert the slope to angular measure in radians:
$\mathbf{slope} = \mathbf{atan}(\mathbf{slope})$

STEP 7: Adjust the value of the perpendicular course by **slope**. This accounts for how the locus is approaching or receding from the geodesic:

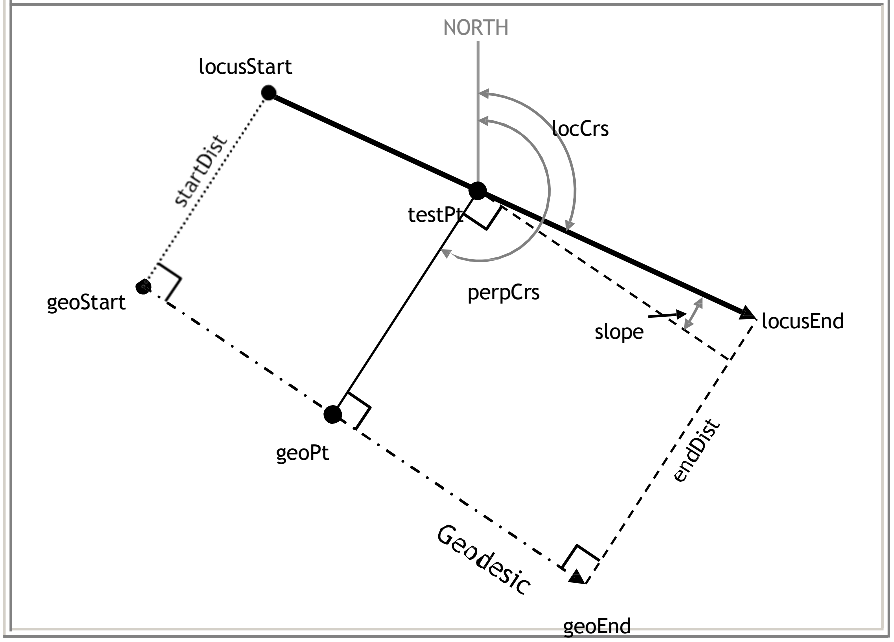
perpCrs = perpCrs+slope

STEP 8: If (`distToLoc < 0`), then `testPt` lies to the left of the geodesic, so `perpCrs` points to the right of the locus's course:
$\mathbf{locCrs} = \mathbf{perpCrs} - \pi/2$

STEP 9: Else, `testPt` lies to the right of the geodesic so `perpCrs` points to the left of the locus's course: $\mathbf{locCrs} = \mathbf{perpCrs} + \pi/2$

STEP 10: Return **locCrs**.

Figure A-9. Angle Used to Calculate the Course of a Locus.



4.0 Intersections

4.1 Intersection of Two Geodesics

The following algorithm computes the coordinates where two geodesic curves intersect. Each geodesic is defined by its starting coordinates and azimuth at that coordinate. The algorithm returns a single set of coordinates if the geodesics intersect and returns a null solution (no coordinates) if they do not.

4.1.1 Input/Output

long WGS84CrsIntersect (LLPoint pt1, double cres13, double* crs31, doubl* dist13. LLPoint pt2, double crs23, double*crs32, double* dist23, LLPoint* intx, double tol) returns a reference to an **LLPoint** structure that contains the intersection coordinates, where the inputs are:

LLPoint pt1	=	Start point of first geodesic
double crs13	=	Azimuth from **pt1** to intersection point
double* crs31	=	Reference to azimuth from intersection point to **pt1**
double* dist13	=	Reference to distance from **pt1** to intersection
LLPoint pt2	=	Start point of second geodesic

double crs23	=	Azimuth from **pt2** to intersection point
double* crs32	=	Reference to azimuth from intersection point to **pt2**
double* dist23	=	Reference to distance from **pt2** to intersection
LLPoint* intx	=	Reference to intersection point
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

.

4.1.2 Algorithm Steps

See Figure A-10 for an illustration of the variables.

STEP 1: Use inverse algorithm to calculate distance, azimuth and reverse azimuth from **pt1** to **pt2**. Denote these values by **dist12**, **crs21** and **crs12**, respectively. Run a check to see if **pt1** lies on the geodesic defined by **pt2** and **crs23** and if **pt2** lies on the geodesic defined by **pt1** and **crs13.**

a. If **pt1** falls on geodesic 2 and **pt2** falls on geodesic 1.

(1) Return an error. Courses are collinear. There are infinite intersections.

b. If pt1 falls on geodesic 2.

(1) Return intersection = **pt1**.

c. If pt2 falls on geodesic 1.

(1) Return intersection = **pt2**.

STEP 2: Calculate the signed azimuth difference in angle between **crs12** and **crs13** denoted by **angle1**

STEP 3: Calculate the signed azimuth difference in angle between **crs21** and **crs23** denoted by **angle2**.

STEP 4: If (**sin(angle1)*sin(angle2) < 0**) then the courses lay on opposite sides of the **pt1-pt2** line and cannot intersect in this hemisphere. Use reciprocal course so that the nearest intersection may be found.

a. If abs(angle1) > abs(angle2),

(1) angle1 = (crs13+π) - crs12.

b. Else,

(1) angle2 = crs21 - (crs23+π).

STEP 5: End if.

STEP 6: Locate the approximate intersection point, **intx**, using a spherical earth model. See the documents referenced in section 2.2 methods to accomplish this.

STEP 7: The following steps describe the function **iterateLineIntersection** which is called once the initial approximation, **intx**, of the line intersection is found. The purpose of the **iterateLineIntersection** function is to further refine the solution.

STEP 8: Use the inverse algorithm to calculate **dist13**, the distance from **pt1** to **intx**.

STEP 9: Use the inverse algorithm to calculate **dist23**, the distance from **pt2** to **intx**.

STEP 10: If **dist13** < **tol**, then the intersection point is very close to **pt1**. Calculation errors may lead to treating the point as if it were beyond the end of the geodesic. Therefore, it is helpful to move **pt1** a small distance along the geodesic.

1. Use the direct algorithm to move **pt1** from its original coordinates 1NM along azimuth **crs13** + π.

2. Use the inverse algorithm to calculate the azimuth **acrs13** for the geodesic from the new **pt1**.

STEP 11: Repeat steps 10, 10(1), and 10(1) for pt2 and crs23.

STEP 12: If (**dist23 < dist13**) then the intersection point is closer to **pt2** than **pt1**. In this case, the iterative scheme will be more accurate if we swap **pt1** and **pt2** This is because we iterate by projecting the approximate point onto the geodesic from **pt1** and then calculating the error in azimuth from **pt2**. If the distance from **pt2** to the intersection is small, then small errors in distance can correspond to large errors in azimuth, which will lead to slow convergence. Therefore, we swap the points so that we are always measuring azimuth errors farther from the geodesic starting point.

a. newPt = pt1

b. pt1 = pt2

c. pt2 = newPt

d. acrs13 = crs13

e. crs13 = crs23

f. crs23 = acrs13

g. dist13 = dist 23; We only need one distance so the other is not saved.

h. swapped = 1; This is a flag that is set so that the solutions can be swapped back after they are found.

STEP 13: End if.

STEP 14: Initialize the distance array: **distarray [0] = dist13**. Errors in azimuth from **pt2** will be measured as a function of distance from **pt1**. The two most recent distances from **pt1** are stored in a two element array. This array is initialized with the distance from **pt1 to intx.**

STEP 15: Use the direct algorithm to project **intx** onto the geodesic from **pt1**. Use **pt1** as the starting point, and a distance of **distarray** [0] and azimuth of **crs13**.

STEP 16: Use the inverse algorithm to measure the azimuth **acrs23** from **pt2** to **intx.**

STEP 17: Initialize the error array:
errarray [0] = signedAzimuthDifference (**acrs23, crs23**).

signedAzimuthDifference function; errarray [0] will be in the range ($-\pi$, π).

STEP 18: Initialize the second element of the distance array using a logical guess: distarray [1] =1.01***dist13**.

STEP 19: Use the direct algorithm to project the second approximation of **intx** onto the geodesic from **pt1**. Use **pt1** as the starting point, and a distance of **distarray [1]** and azimuth of **crs13**.

STEP 20: Use the inverse algorithm to measure the azimuth **acrs23** from **pt2** to **intx.**

STEP 21: Initialize the error array:
errarray [1] = signedAzimuthDifference (**acrs23, crs23**).

STEP 22: Initialize `k = 0`

STEP 23: Do while (k=0) or ((error > tol) and (k ≤ MAX_ITERATIONS)):

a. Use linear approximation to find root of errarray as a function of distarray This gives an improved approximation to **dist13.**

b. Use the direct algorithm to project the next approximation of the intersection point, newPt, onto the geodesic from **pt1** Use **pt1** as the starting point, and a distance of **dist13** (calculated in previous step) and azimuth of **crs13**.

c. Use inverse algorithm to calculate the azimuth **acrs23** from **pt2** to **intx**.

d. Use the inverse algorithm to compute the distance from **newPt** to **intx** (the previous estimate). Denote this value as the **error** for this iteration.

e. Update distarray and errarray with new values:
distarray [0] = distarray [1]
distarray [1] = dist13
errarray [0] = errarray [1]
errarray [1] = signedAzimuthDifference (**acrs23, crs23**)

f. Increment k: k = k + 1

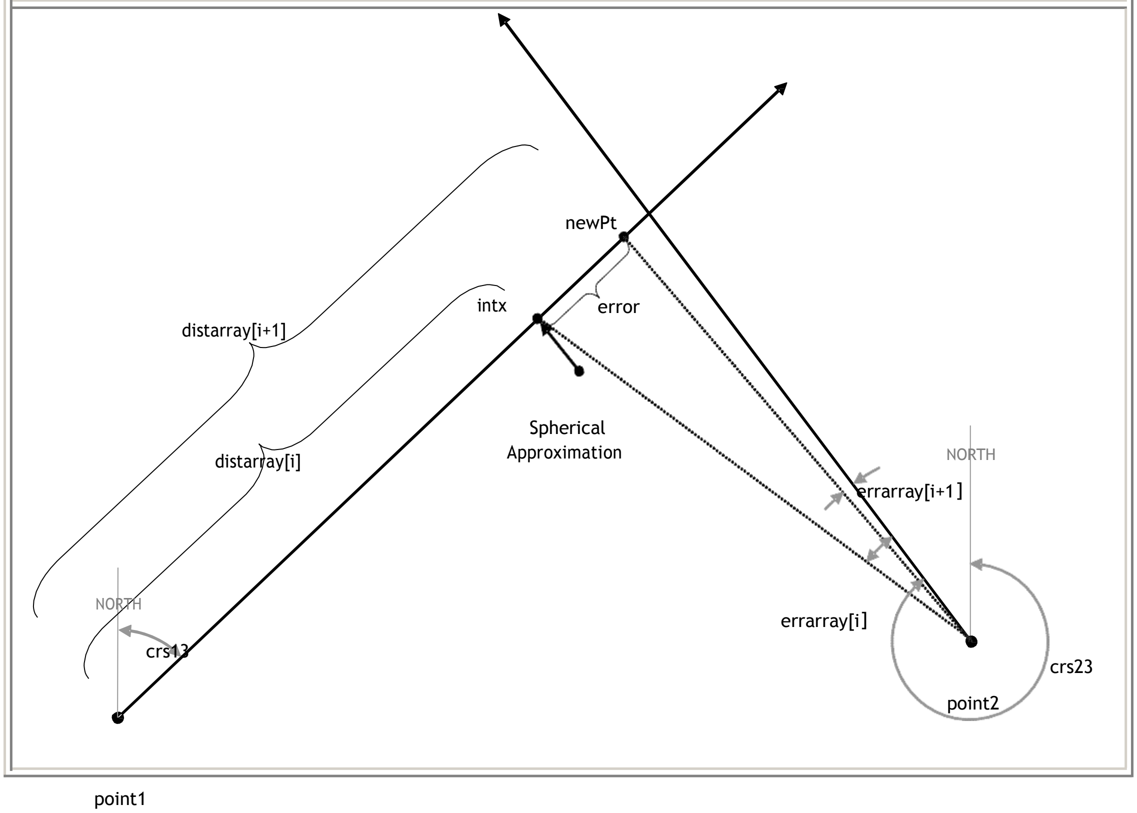
STEP 24: End while loop.

STEP 25: Check if k reached MAX_ITERATIONS. If so, then the algorithm may not have converged, so an error message should be displayed.

STEP 26: The distances and azimuths from **pt1** and **pt2** to **intx** are available at the end of this function, since they were calculated throughout the iteration. It may be beneficial to return them with the **intx** coordinates, since they may be needed by the calling function. If this is done, and if **swapped = 1,** then the original identities of **pt1** and **pt2** were exchanged and the azimuths and distances must be swapped again before they are returned.

STEP 27: Return **intx**.

Figure A-10. Finding the Intersection of Two Geodesics.



4.2 Intersection of Two Arcs

The following algorithm computes the intersection points of two arcs. Each arc is defined by its center point coordinates and radius. The algorithm will return a null solution (no points) if the arcs do not intersect; it will return a single set of coordinates if the arcs intersect tangentially; and it will return two sets of coordinates if the arcs overlap.

4.2.1 Input/Output

long WGS84ArcIntersect(LLPoint center1, double radius1, LLPoint center2, double radius2, LLPointPair intx, int* n, double tol) returns a reference to an **LLPoint** structure array that contains the coordinates of the intersection(s), where the inputs are:

LLPoint center1	=	Geodetic coordinates of first arc center
double radius1	=	Radius of first arc in nautical miles
LLPoint center2	=	Geodetic coordinates of second arc center
double radius2	=	Radius of second arc in nautical miles

LLPointPair intx	=	Two-element array of **LLPoint** objects that will be updated with intersections' coordinates
int* n	=	Reference to integer number of intersection points returned
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

4.2.2 Algorithm Steps

See Figure A-11 for an illustration of the variables.

This algorithm treats the arcs as full circles. Once the intersections of the circles are found, then each intersection point may be tested and discarded if it does not lie within the bounds of the arc.

STEP 1: Use inverse algorithm to calculate the distance and azimuth between **center1** and **center2**. Denote these values as **dist12** and **crs12**, respectively.

STEP 2: If (**radius1 + radius2 –dist12 + tol < 0**) or (**abs(radius1-radius2) > dist12**) then the circles are spaced such that they do not intersect. If the first conditional is true, then the arcs are too far apart. If the second conditional is true, then one arc is contained within the other.

a. Return no intersections.

STEP 3: Else if (abs**(radius1+radius2-dist12) ≤ tol**) then the circles are tangent to each other and intersect in exactly one point.

a. Use direct algorithm to project point from **center1**, along **crs12**, distance **radius1**.

b. Return projected point.

STEP 4: End if

STEP 5: Calculate approximate intersection points, intx[0] and intx[1] according to section 3.2.

STEP 6: Iterate to improve approximation to **pt**:

a. `k` = 0

b. Use inverse algorithm to find azimuth from **center2** to **pt**, denote this value as **crs2x**.

c. Use direct algorithm to move **pt** along **crs2x** to circumference of circle 2. Use **center2** as starting point, **crs2x** as azimuth, **radius2** as distance.

d. Use inverse algorithm to compute distance and azimuth from **center1** to **pt**. Denote these values as **dist1x** and **crs1x**, respectively.

e. Compute error at this iteration step: **error** = **radius1** - **dist1x**.

f. Initialize arrays to store error as function of course from **center1**:
errarray[1] = error
crsarray[1] = crs1x

g. While (k $\leq$ maximumIterationCount) and (**abs(errarray[1]) > tol**), improve approximation

(1) Use direct function to move **pt** along **crs1x** to circumference of **circle1**. Use **center1** as starting point, **crs1x** as azimuth, and **radius1** as distance. Note that **crs1x** was calculated as last step in previous iteration.

(2) Use inverse function to find azimuth from **center2** to **pt**, **crs2x**.

(3) Use direct function to move **pt** along **crs2x** to circumference of **circle2**. Use **center2** as starting point, **crs2x** as azimuth, and **radius2** as distance.

(4) Use inverse algorithm to compute distance and azimuth from **center1** to **pt**. Denote these values as **dist1x** and **crs1x**, respectively.

(5) Update function arrays:
crsarray[0] = crsarray[1]
crsarray[1] = **crs1x**
errarray[0] = errarray[1]
errarray[1] = error

(6) Use linear root finder to find the azimuth value that corresponds to zero error. Update the variable **crs1x** with this root value.

(7) Increment k: k = k + 1

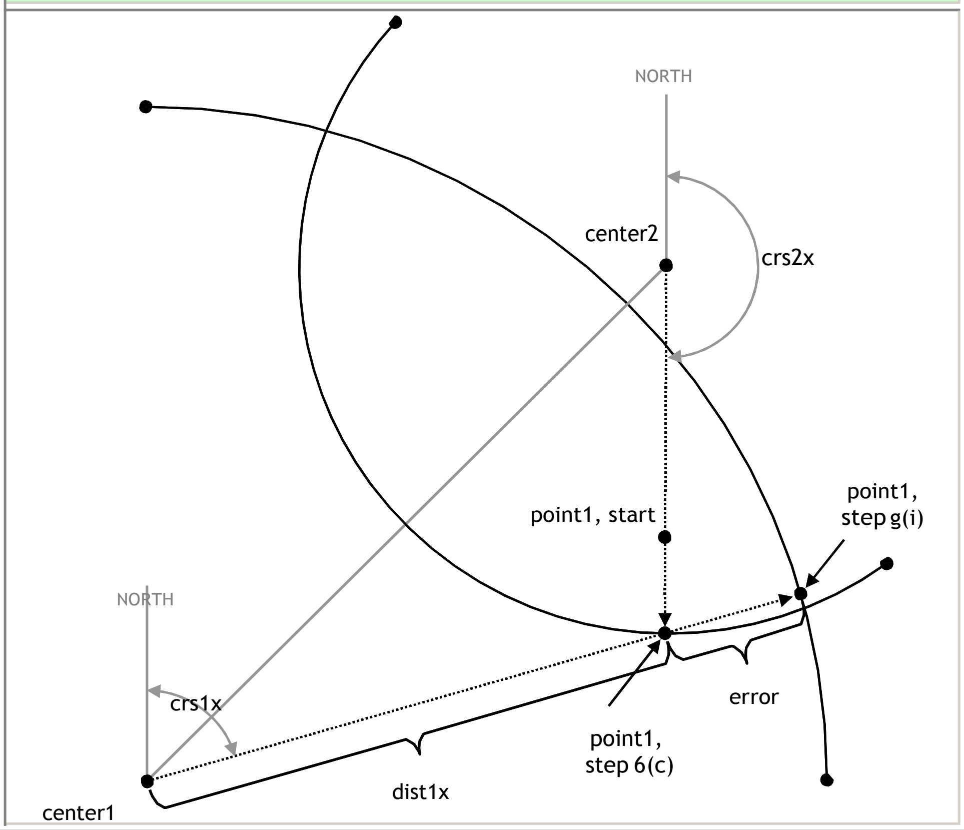
h. End while loop.

STEP 7: Store **point** in array to be returned: **intx[0]** = point.

STEP 8: Repeat step 6 for approximation **intx[1].**

STEP 9: Return array **intx.**

Figure A-11. Intersection of Two Arcs.



4.3 Intersections of Arc and Geodesic

The following algorithm computes the point where a geodesic intersects an arc. The geodesic is defined by its starting coordinates and azimuth. The arc is defined by its center point coordinates and radius. The algorithm will return a null solution (no points) if the arc and geodesic do not intersect; it will return a single set of coordinates if the arc and geodesic intersect tangentially; and it will return two sets of coordinates if the arc and geodesic overlap.

4.3.1 Input/Output

long WGS84LineArcIntersect (LLPoint pt1, double crs1, LLPoint center, double radius, LLPointPair intx, int* n, double tol) returns a reference to an **LLPoint** structure array that contains the coordinates of the intersection(s), where the inputs are:

LLPoint pt1	=	Geodetic coordinates of start point of geodesic
double crs1	=	Initial azimuth of geodesic at start point
LLPoint center	=	Geodetic coordinates of arc center point
double radius	=	Arc radius in nautical miles
LLPointPair intx	=	Two-element array of LLPoint objects that will be updated with intersections' coordinates.
int* n	=	Reference to number of intersection points returned
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

4.3.2 Algorithm Steps

This algorithm treats the arc and geodesic as unbounded. Once intersection points are found, they must be tested using Algorithms 3.6 and 3.7 to determine which, if any, lie within the curves' bounds. This algorithm fails if the arc and geodesic describe the same great circle. A test for this case is embedded in step 7. See Figure A-12 for an illustration of the variable names.

STEP 1: Use Algorithm 5 .1 to find the perpendicular projection point from arc center point (**center**) to the geodesic defined by starting point **pt1** and azimuth **crs1** Denote this point by **perpPt.** Denote the distance as **perpDist.**

STEP 2: Use inverse Algorithm to calculate the azimuth of the geodesic at **perpPt.** Denote the azimuth from **perpPt** to **pt1** as **crs.**

STEP 3: If (**abs(perpDist – radius) < tol**), then the geodesic is tangent to the arc and intersection point is at **perpPt**.

a. Return **intx[0] = perpPt**

STEP 4: Else if (**perpDist > radius**) then geodesic passes too far from center of circle; there is no intersection.

a. Return empty array.

STEP 5: End if.

STEP 6: Use spherical triangle approximation to find distance from **perpPt** to one intersection points. Since the spherical triangle formed from **center** **perpPt,** and either intersection point has a right angle at the **perpPt** vertex, the distance from **perpPt** to either intersection is:

dist = SPHERE_RADIUS*acos (cos(radius/SPHERE_RADIUS) / cos(perpDist/SPHERE_RADIUS))

where SPHERE_RADIUS is the radius of the spherical earth approximation.

Note that a test must be performed so that if cos(perpDist/SPHERE_RADIUS) = 0, then no solution is returned

STEP 7: Find ellipsoidal approximation **intx[0]** to first intersection by starting at **perpPt** and using direct algorithm with distance **dist** and azimuth **Crs.** This will place **intx[0]** on the geodesic.

STEP 8: Initialize iteration count k = 0.

STEP 9: Use inverse algorithm to calculate the distance from center to **intx[0]**. Denote this value by **radDist** In the same calculation, calculate azimuth from **intx[0]** to **center** Denote this value by **rcrs** it will be used to improve the solution.

STEP 10: Calculate error for this iteration: **error = radius - radDist.**

STEP 11: Initialize arrays that will hold distance and error function values so that linear interpolation may be used to improve approximation:
distarray[0] = dist
errarray[0] = error

STEP 12: Do one iterative step using spherical approximation near intersection point (see Figure A-13):

a. Use the inverse algorithm to calculate the azimuth from **intx[0]** to **perpPt** Denote this value by **bcrs.**

b. Compute the angle between the arc's radial line and the geodesic at **intx[0]**. This is depicted by **B** in Figure A-13:

B = abs (signedAzimuthDifference (bcrs, rcrs)

c. Calculate the angle opposite the radial error:

A = acos [sin(B)*cos(abs(error)/sphereRad)]

d. If (**abs(sin(A) < eps**) then the triangle is nearly isosceles, so use simple formula for correction term c: **c = error**

e. Else, if (**abs(A) < eps**) then the error is very small, so use flat approximation: **c = error / cos (B).**

f. Else, use a spherical triangle approximation for c: **c=sphereRad*asin[sin(error/sphereRad)/sin(A)]**

g. End if.

h. h. If (**error > 0**), then **intx[0]** is inside the circle, so approximation must be moved away from **perpPt**: **dist = dist + c**

i. Else **dist = dist – c.**

j. End if.

k. Use the direct algorithm to move **intx[0]** closer to solution. Use **perpPt** as the starting point with distance **dist** and azimuth **crs**.

l. Use the inverse algorithm to calculate the distance from **center** to **intx[0]**Denote this value again as **radDist**.

m. Initialize second value of **distarray and errarray**:
distarray[1] = dist
errarray[1] = radius-radDist

STEP 13: Do while (**abs(error) > tol**) and (**k < maximumIterationCount**)

a. Use a linear root finder to find the distance value that corresponds to zero error. Update the variable **dist** with this root value.

b. Use the direct algorithm again to move **intx[0]** closer to solution. Use **perpPt** as the starting point with distance **dist** and azimuth **crs.**

c. Use the inverse algorithm to calculate the distance from **center** to **intx[0]** Denote this value **radDist**.

d. Update **distarray** and **errarray** with the new values:
distarray[0] = distarray[1]
errarray[0] = errarray[1]
distarray[1] = dist
errarray[1] = error

e. Increment the iteration count: k = k + 1

STEP 14: End while loop.

STEP 15: Prepare variables to solve for second solution, **intx[1].**

a. Second solution lies on other side of **perpPt** so set **crs = crs + π.**

b. Use direct algorithm to find **intx[1]** Start at **perpPt** using **crs** for the azimuth and **dist** for the distance, since the distance from **perpPt** to **intx[0]** is a very good approximation to the distance from **perpPt** to **intx[1].**

c. Use inverse algorithm to calculate **radDist** the distance from **center** to **intx[1].**

d. Initialize the error function array:
errarray[0] = radius - radDist.

STEP 16: Repeat steps 13 - 14 to improve solution for **intx[1].**

STEP 17: Return **intx[0]** and **intx[1].**

Figure A-12. Locating First Intersection of Geodesic and Arc.

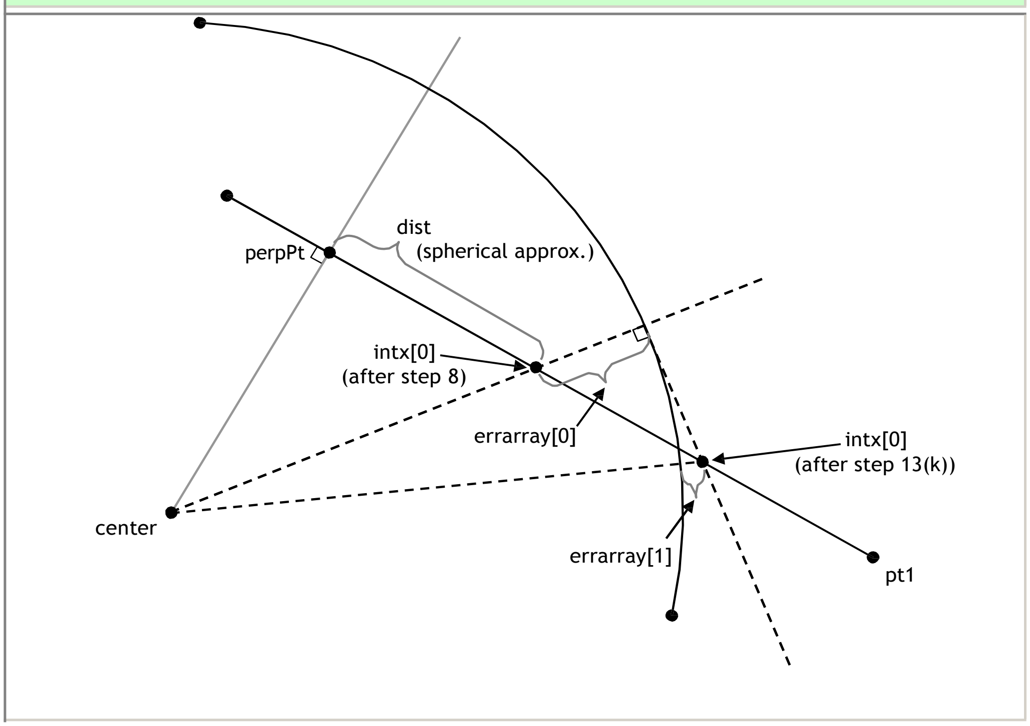
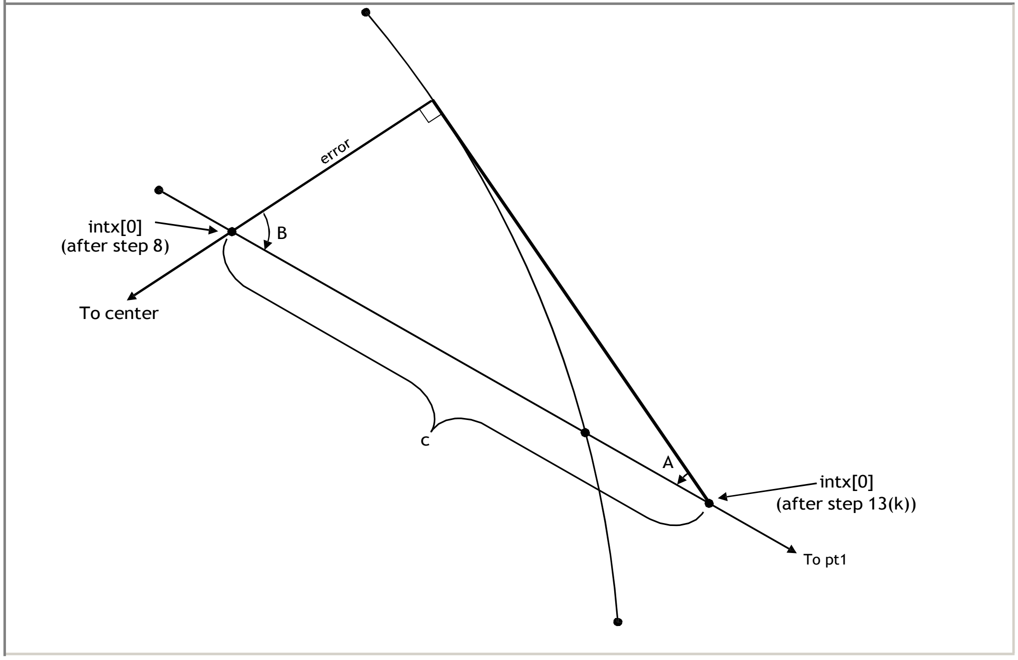


Figure A-13. Area Near the Appropriate Geodesic-Arc Intersection Point With Spherical Triangle Components That Are Used to Improve the Solution.



4.4 Arc Tangent to Two Geodesics

This algorithm is useful for finding flight path arcs, such as fitting a fly-by turn or radius-to-fix (RF) leg between two track-to-fix (TF) legs. Note that for the arc to be tangent to both the incoming and outgoing geodesics, the two tangent points must be different distances from the geodesics' intersection point.

4.4.1 Input/Output

long WGS84TangentFixedRadiusArc (LLPoint pt1, double crs12, LLPoint pt3, double crs3, double radius, ArcDirection* dir, double tol) returns a reference to an **LLPoint** structure array that contains the coordinates of the center point and both tangent points of the arc that is tangent to both given geodesic, where the inputs are:

LLPoint pt1	=	Geodetic coordinates of start point of first geodesic
double crs12	=	Azimuth of first geodesic at **pt1**
LLPoint pt3	=	Geodetic coordinates of end point of second geodesic
double crs3	=	Azimuth of second geodesic at **pt3**
double radius	=	Radius of desired arc

ArcDirection*dir	=	Reference to an integer that represents direction of turn. dir = 1 for left hand turn dir = - 1 for right hand turn
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

4.4.2 Algorithm Steps

See Figure A-14 for an illustration of the variable names.

STEP 1: Use Algorithm 4.1 to locate the intersection point of the given geodesics. The first geodesic has azimuth **crs12** at **pt1**, while the second geodesic has azimuth crs3 at **pt3** Denote their intersection point by **pt2**.

STEP 2: If intersection point **pt2** is not found, then no tangent arc can be found.

a. Return empty array.

STEP 3: End if.

STEP 4: Use the inverse algorithm to calculate the distance from **pt1** to **pt2** (denoted by **dist12**) Also calculate the azimuth at **pt2** to go from **pt2** to **pt1**. Denote this value by **crs21.**

STEP 5: Use the inverse algorithm to compute the azimuth at **pt2** to go from **pt2** to **pt3** Denote this value by **crs23**.

STEP 6: Calculate angle between courses at **pt2** (see Algorithm 6.2). Denote this value by **vertexAngle**:
vertexAngle =signedAzimuthDifference (crs21,crs23)

STEP 7: If **abs (sin (vertexAngle)) < tol**, then either there is no turn or the turn is 180 degrees. In either case, no tangent arc can be found.

a. Return empty array.

STEP 8: Else if **vertexAngle > 0** then course changes direction to the right: dir = -1.

STEP 9: Else, the course changes direction to the left: dir = 1.

STEP 10: End if.

STEP 11: Use spherical triangle calculations to compute the approximate distance from **pt2** to the points where the arc is tangent to either geodesic. Denote this distance by **distToStart**:

a. B = vertexAngle/2.

b. If (**radius** > **sphereRad*B**) then no arc of the required radius will fit between the given geodesics

(1) Return empty array.

c. End if.

d. Calculate **distToStart** using the approximate formula from Napier's Rule of Circular Parts.

distToStart = phereRad*asin (tan(radius/sphereRad)/ tan(B))

STEP 12: Initialize the iteration count: **k = 0**

STEP 13: Initialize the error measure: **error = 0.0**

STEP 14: Do while (**k = 0**) or ((**abs(error)** > **tol**) and (**k ≤ maximumIterationCount**))

a. Adjust the distance to tangent point based on current error value (this has no effect on first pass through, because **error = 0**) :

distToStart = distToSTart + (error/sin(vertexAngle))

b. Use the direct algorithm to project **startPt** distance **distToStart** from **pt1** Use **pt1** as the starting point with azimuth of **crs12** and distance of **distToStart**.

c. Use the inverse algorithm to compute azimuth of geodesic at **startPt**. Denote this value by **perpCrs**.

d. If (**dir** < **0**), then the tangent arc must curve to the right. Add **π/2** to **perpCrs** to get the azimuth from **startPt** to center of arc:

perpCrs = perpCrs + π/2

e. Else, the tangent arc must curve to the left. Subtract π/2 from perpCrs to get the azimuth from startPt to center of arc:

perpCrs = perpCrs - π/2

f. End if.

g. Use the direct algorithm to locate the arc center point, **centerPoint**. Use **startPt** as the starting point, **perpCrs** for the azimuth, and radius for the distance.

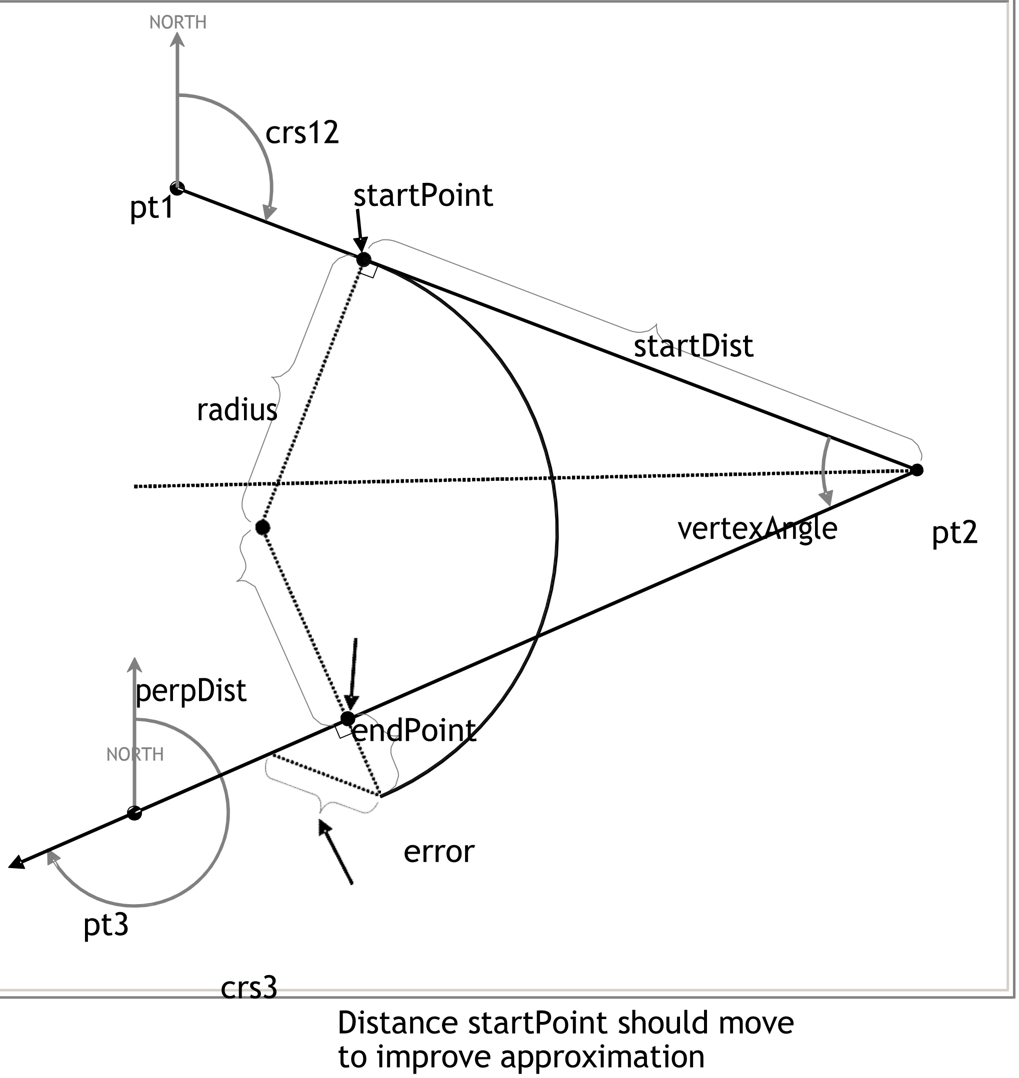
h. Use Algorithm 5.1 to project **centerPoint** to the second geodesic. Denote the projected point by **endPt.** This is approximately where the arc will be tangent to the second geodesic. Denote the distance from **centerPoint** to **endPoint** as **perpDist**.

i. Calculate the tangency error: **error = radius – perpDist**. This error value will be compared against the required tolerance parameter. If its magnitude is greater than **tol**, then it will be used to adjust the position of **startPoint** until both **startPoint** and **endPoint** are the correct distance from **centerPoint.**

STEP 15: End while.

STEP16: Return the values for **centerPoint**, the center of the arc, **startPoint**, the tangent point on the first geodesic, and **endPoint** the tangent point of second geodesic.

Figure A-14. Finding Arc Center and Points at Which Arc is Tangent to Two Geodesics.



4.5 Intersections of Geodesic and Locus

This algorithm is useful for finding the corner points of TF sub-segment's OEA, where a parallel (represented as a locus of points) intersects the geodesic end line.

4.5.1 Input/Output

long WGS84GeoLocusIntersect (LLPoint geoSt, LLPoint geoEnd, LLPoint* pint, Locus Loc, double tol) returns a reference to an **LLPoint** structure array that contains the coordinates of the intersection point, where the inputs are:

LLPoint geoSt	=	Geodetic coordinates of start point of geodesic
LLPoint geoEnd	=	Geodetic coordinates of end point of geodesic

Locus Loc	=	Structure defining locus of points
LLPoint* pint	=	Reference to **LLPoint** that will be updated with intersection coordinates
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

4.5.2 Algorithm Steps

See Figure A-15 for an illustration of the variable names.

STEP 1: Use the geodesic intersection algorithm (Algorithm 4.1) to find a first approximation to the point where the given geodesic and locus intersect. Use the start and end coordinates of the locus along with the start and end coordinates of given geodesic as inputs to the geodesic intersection algorithm. This will erroneously treat the locus as a geodesic; however, the calculated intersection will be close to the desired intersection. The geodesic intersection algorithm will return the approximate intersection point, pt1, along with the courses and distances from the **pt1** to the start points of the locus and given geodesic. Denote these courses and distances as **crs31, dist13, crs32**, **dist23**, respectively.

STEP 2: If **pt1** is not found, then the locus and geodesic to not intersect.

a. Return empty point.

STEP 3: End if.

STEP 4: Use the inverse algorithm to calculate the course from **geoSt** to **geoEnd** Denote this value as **fcrs.** This value is needed by the direct algorithm to locate new points on the given geodesic.

STEP 5: Use the inverse algorithm to calculate the distance and course from **pt1** to **geoSt**. Denote these values as **distBase** and **crsBase** respectively.

STEP 6: Obtain the forward course of the locus's defining geodesic. This course is stored **loc.geoAz**. Denote this course as **tcrs.** This value is needed to project the approximate point onto the defining geodesic in order to calculate the appropriate **locus** distance.

STEP 7: Use Algorithm 5.1 to project **pt1** onto the locus’s defining geodesic. Use **pt1, loc.geoStart**, and **tcrs** as inputs. Denote the returned point as

pInt, the returned course as **crsFromPt** and the returned distance as **distFromPt.**

STEP 8: Use Algorithm 3.9 to calculate the distance from the defining geodesic to the locus at **pInt**. Denote this value as **distLoc**. Note that **distLoc** may be positive or negative, depending on which side of defining geodesic the locus lays.

STEP 9: Calculate the distance from **pt1** to the locus. This is the initial error: **errarray[1] = distFromPt - abs(distLoc).**

STEP 10: Save the initial distance from **geoSt** to the approximate point: **geodarray[1] = distBase.**. We will iterate to improve the approximation by finding a new value for **distBase** that makes **errarray** zero.

STEP 11: Calculate a new value of **distBase** that will move **pt1** closer to the locus. This is done by approximating the region where the given geodesic and locus intersect as a right Euclidean triangle and estimating the distance from the current **pt1** position to the locus (see Figure A-16).

a. Calculate the angle between the geodesic from **pt1** to **pInt** and the geodesic from **pt1** to **geoSt:**

thera=abs(signedAzimuthDifference (crsFrompt, crsBase))

b. Calculate a new value for **distBase**:

newdistbase = distbase - errarray[1] / cos (theta)

STEP 12: Initialize the iteration count: **k = 0**.

STEP 13: Do while (**abs(errarray[1] > tol)** and **(k < maxIterationCount)):**

a. Use **geoSt**, **fcrs** and **newDistBase** in the direct algorithm to update the value of **pt1**.

b. Save the current values of **errarray** and geodarray:
errarray[0] = errarray[1]
geodarray[0] = geodarray[1]

c. Set **geodarray[1] = newDistBase.**

d. Repeat steps 7, 8, and 9 to calculate the distance from **pt1** to the **locus**, **distloc**, and the corresponding update to **errarray[1].**

e. Use a linear root finder with **geodarray** and **errarray** to find the distance value that makes the error zero. Update **newDistBase** with this root value.

STEP 14: End while

STEP 15: Return **pint = pt1**.

Figure A-15. Intersection of Geodesic with Locus of Points.

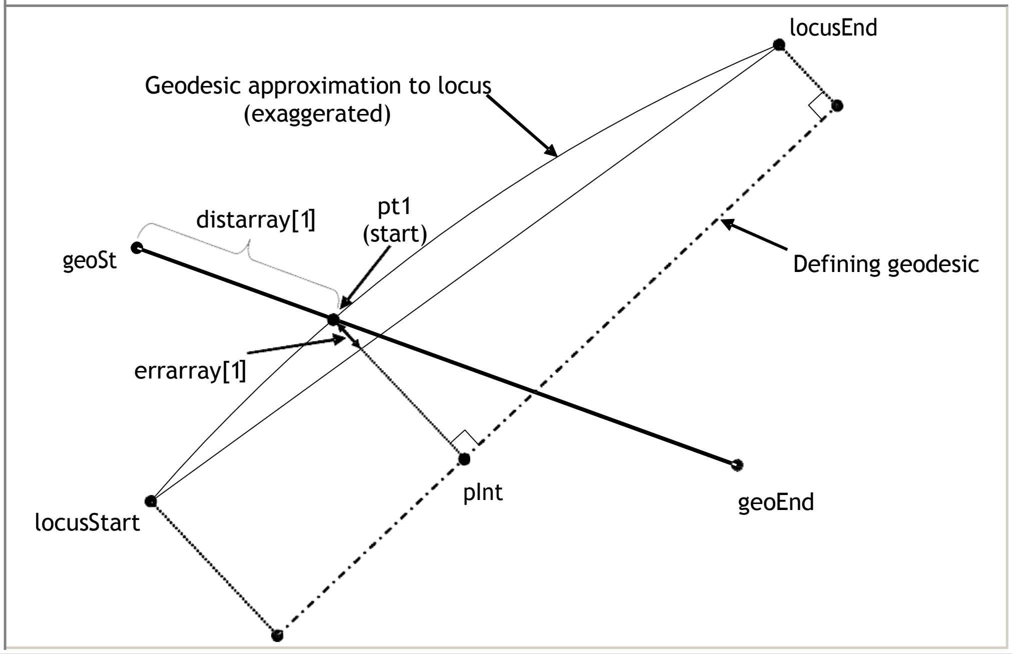
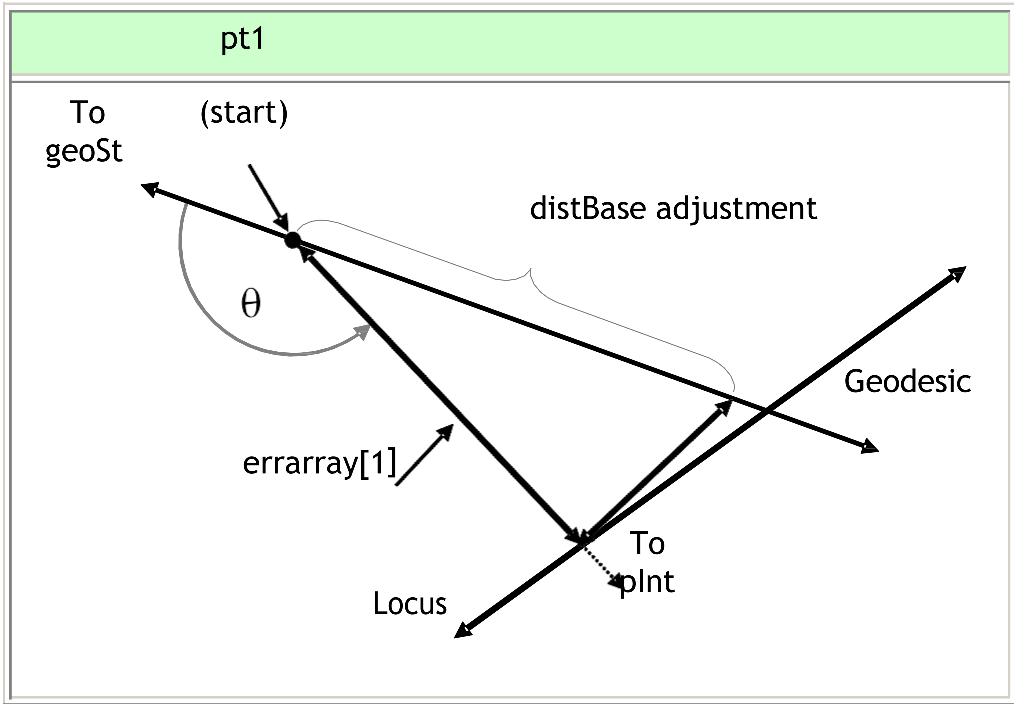


Figure A-16. Computing First Update to Locus-Geodesic Intersection.



4.6 Intersections of Arc and Locus

This algorithm solves for the intersection of a fixed radius arc and a locus. It is very similar to Algorithm 4.3, which computes the intersections of an arc and a geodesic. It begins by treating the locus as a geodesic and applying Algorithm 4.3 to find approximate intersection points. The approximation is improved by traveling along the locus, measuring the distance to the arc center at each point. The difference between this distance and the given arc radius is the error. The error is modeled as a series of linear functions of position on the locus. The root of each function gives the next approximation to the intersection. Iteration stops when the error is less than the specified tolerance.

4.6.1 Input/Output

long WGS84LocusArcIntersect (Locus loc, LLPoint center, double radius, LLPoinPair intx, int* n, double tol) returns a reference to an **LLPoint** structure array that contains the coordinates of the intersection(s), where the inputs are:

Locus loc	=	Locus of interest
LLPoint center	=	Geodetic coordinates of arc
double radius	=	Arc radius

LLPoint intx	=	Two-element array of **LLPoint** that will be updated with intersection coordinate
int* n	=	Number of intersections found
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithm

4.6.2 Algorithm Steps

See Figure A-17 for an illustration of the variables.

STEP 1: Initialize number of intersections: **n = 0.**

STEP 2: Use the inverse algorithm to compute the course from **`loc.locusStart`** to **`loc.locusEnd`**. Denote this value as **`fcrs`**.

STEP 3: Use Algorithm 5.2 to project the center of the arc to the locus. Denote the projected point as **locpt**. Denote the distance and course from **center** to **locpt** as **distFromPoint** and **crsFromPoint**, respectively. If **locpt** is on or within the radius of the arc, then it will be used to find the intersection(s) of the locus and the arc, **intx**.

STEP 4: If (**distFromPoint** > **radius**), then no approximate intersections were found. Return **NULL**.

STEP 5: End if.

STEP 6: Else if **distFromPoint** is equal to **radius** within tolerance level, then:

a. Locus is tangent to arc. One intersection exists.

b. intx[0] = locpt

STEP 7: End if.

STEP 8: Otherwise, **distFromPoint** must be less than **radius**, meaning there are two possible intersections. These two approximate intersections are found using spherical trigonometry and the direct algorithm. Denote the approximate intersections as **intx[0]** and **intx[1].**

STEP 9: Use the inverse algorithm to compute the forward and reverse course from **loc.geoStart** to **loc.geoEnd** Store these values as **fcrs1** and **bcrs**, respectively.

STEP 10: For **i = 0, i < n1** :

a. Use Algorithm 5.1 to project **intx[0]** to the locus's defining geodesic. Denote the projected point as **perpPt**.

b. Use the inverse algorithm to calculate **distBase**, the distance from **perpPint** to **loc.geoStart**.

c. Use Algorithm 3.10 to project **locPt** onto the locus from **perpPint**.

d. Use the inverse algorithm to calculate **distCent**, the distance from **locPt** to **center**.

e. Calculate the error and store it in an array:
errarray[1] = distCent - radius

f. If (**abs (errarray[1]) < tol**), then **locPt** is close enough to the circle. Set **intx[n] = locPt, n = n+1**, and continue to the end of the for loop, skipping steps **g** through **m** below.

g. Save the current value of **distbase** to an array: **geodarray[1] = distbase**

h. Initialize the iteration count: **k = 0**

i. Perturb **distbase** by a small amount to generate a second point at which to measure the error: **newDistabase = 1.001*distbase**.

j. Do while (**k < maxIterationCount**) and **(abs(errarray[1]) > tol).**

k. Project **Pt1**on the defining geodesic a distance **newDistbase** along course **fcrs1** from **loc.geoStart**.

(1) Use Algorithm 3.10 to project **locPt** onto the locus from **Pt1.**

(2) Use the inverse algorithm to calculate **dist1** the distance from **locPt** to **center**.

(3) Calculate the error: **error = dist1 - radius**

(4) Update the distance and error arrays:
geodarray[0] = geodarray[1]
geodarray[1] =newDistbase
errarray[0] = errarray[1]
errarray[1]= error

(5) Use a linear root finder with geodarray and errarray to find the distance value that makes the error zero. Update newDistbase with this root value.

l. End while.

m. If locPt is on the locus according to Algorithm 3.11, then

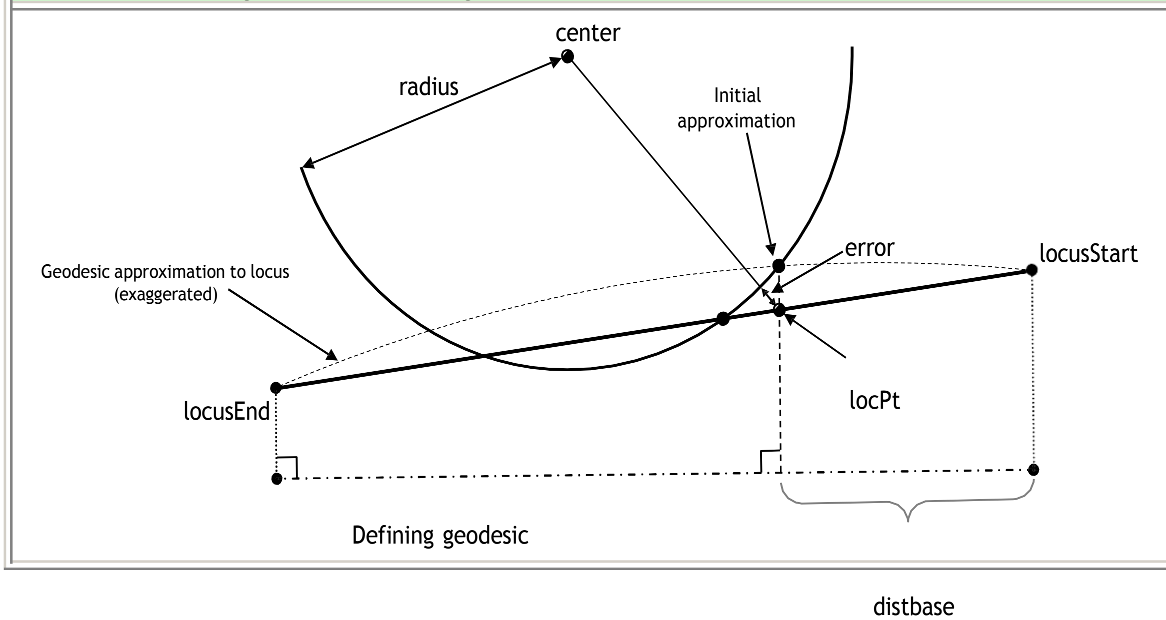
(1) Copy locPt to the output array: **intx[n] = locPt.**

(2) Update the count of intersection points found: n = n + 1.

STEP 11: End for loop.

STEP 12: Return intx.

Figure A-17. Finding the Intersection of an Arc and a Locus.



4.7 Intersections of Two Loci

4.7.1 Input/Output

long WGS84LocusIntersect (Locus loc1, Locus loc2, LLPoint* intx, double tol) returns a reference to an **LLPoint** structure array that contains the coordinates of the intersection coordinates, where the inputs are:

Locus loc1	=	First locus of interest
Locus loc2	=	Second locus of interest

LLPoint* intx	=	Reference to **LLPoint** that will be updated with intersection coordinates.
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

4.7.2 Algorithm Steps

See Figure A-18 for an illustration of the variables and calculation steps.

STEP 1: Use the inverse algorithm to calculate the course of the geodesic approximation to **loc1**. Use **loc.locusStart** and **loc1.locusEnd** as start and end points. Denote this course as **crs1**.

STEP 2: Use the inverse algorithm to calculate the course of the geodesic approximation to **loc2**. Use **loc2.locusStart** and **loc2.locusEnd** as start and end points. Denote this course as **crs2**.

STEP 3: Use **loc1.locusStart, crs1, loc2.locusStart** and **crs2** as input to Algorithm 4.1 to calculate an approximate solution to the locus intersection. Denote the approximate intersection point at **p1**.

STEP 4: If (**p1 = NULL**) then the loci do not intersect, so return **NULL**.

STEP 5: Use the inverse algorithm to calculate the course of **loc1's** defining geodesic. Use **loc1.geoStart** and **loc1.geoEnd** as the start and end points, and denote the course as **tcrs1**.

STEP 6: Project **p1** to the geodesic of **loc1** using Algorithm 5.1 with **loc1.geoStart** and **tcrs1** as input parameters. Store the projected point as **pint1**.

STEP 7: If (**pint1 = NULL**), then no projected point was found so return NULL.

STEP 8: Use the inverse algorithm to calculate **distbase**, the distance from **loc1.geoStart** to **pint1**.

STEP 9: Initialize iteration counter: **k = 0**

STEP 10: Do while (**`k = 0`**) or ((**`k < maxIterationCount`**) and (**abs`(error)> tol)`**)

a. If (**`k > 0`**) then apply direct algorithm to project new **`pint1`** on **`loc1`**. Use starting point **`loc1.geoStart`**, course **`tcrs1`**, and distance **`distbase`**.

b. Use Algorithm 3.10 to project a point on **loc1** from the current **pint1**. Denote the projected point as **ploc1**.

c. Project **ploc1** to the geodesic of **loc2** using Algorithm 5.1 with **loc2.geoStart** and **tcrs2** as input parameters. Store the projected point as **pint2**.

d. Use Algorithm 3.10 to project a point on **loc2** from **pint2**. Denote the projected point as **ploc2**. If **ploc1** were truly at the intersection of the **loci**, then **ploc2** and **ploc1** would be the same point. The distance between them measures the error at this calculation step.

e. Compute the error by using the inverse algorithm to calculate the distance between **ploc1** and **ploc2.**

f. Update the error and distance arrays and store the current values:

```
errarray[0]  = errarray[1]
errarray[1]  = error
distarray[0] = distarray[1]
distarray[1] = distbase
```

g. If (**k = 0**), then project **ploc2** onto **loc1** to get a new estimate of **distbase**:

   (1) Project **ploc2** to the geodesic of **loc1** using Algorithm 5.1 with **loc1.geoStart** and **tcrs1** as input parameters. Store the projected point as **pint1**.

   (2) Use the inverse algorithm to calculate **distbase**, the distance from **loc1.geoStart** to **pint1**.

h. Else,

   (1) Use a linear root finder with **distarray** and **errarray** to find the distance value that makes the error zero. Update **distbase** with this root value. This is possible only after the first update step because two values are required in each array.

i. End if.

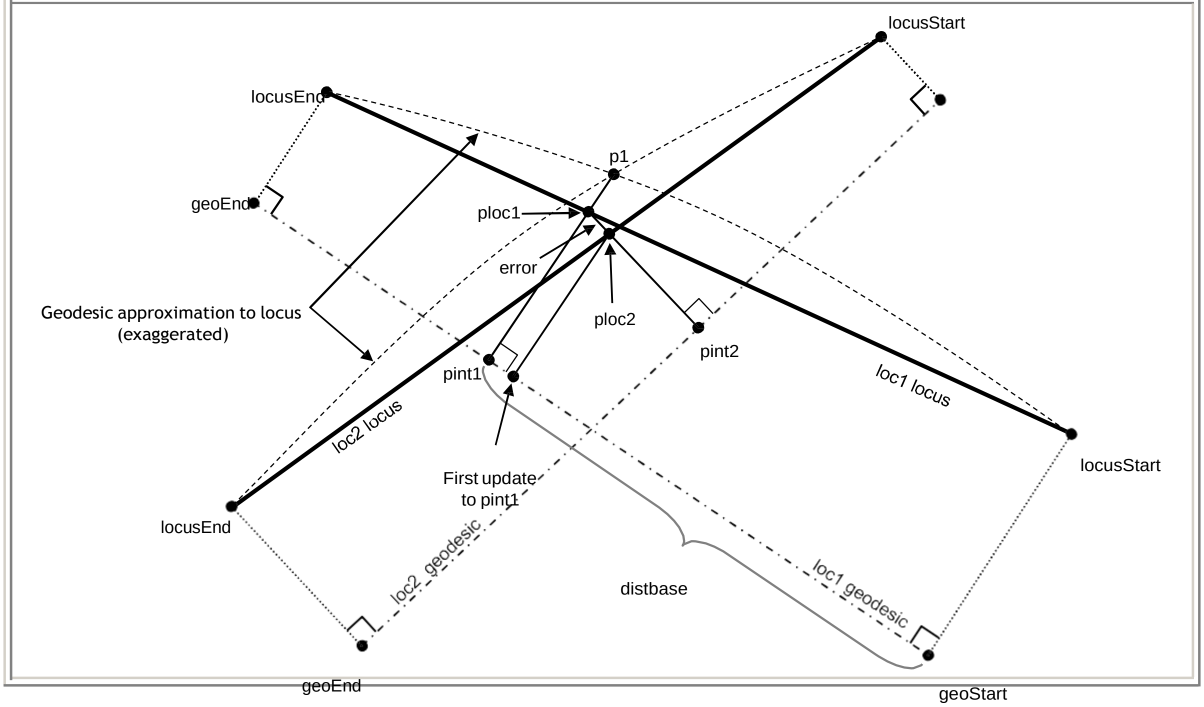
j. Increment iteration count: `k = k +` **1.**

STEP 11: End while.

STEP 12: Use Algorithm 3.11 with inputs of **loc1** and **ploc1** to determine if **ploc1** lies on the **loc1**. Then use Algorithm 3.11 with inputs of **loc2** and **ploc1** to determine if **ploc1** lies on the **loc2**. If **ploc1** does not lie on both **loci**, return **NULL**.

STEP 13: Return **ploc1**.

Figure A-18. Computing the Intersection of Two Loci.



4.8 Arc Tangent to Two Loci

Computing a tangent arc of a given radius to two **loci** is very similar to fitting an arc to two geodesics. The following algorithm uses the same basic logic as Algorithm 4.4.

4.8.1 Input/Output

long WGS84LocusTanFixedRadiusArc (Locus loc1, Locus loc2, double radius, LLPoint* centerPoint, LLPoint* startPoint, LLPoint* endpoint, ArcDirection* dir, double tol) returns a reference to an **LLPoint** structure array that contains the coordinates of the center point and both tangent points of the arc that is tangent to both given **loci**, where the inputs are:

Locus loc1	=	Structure defining first locus
Locus loc2	=	Structure defining second locus
double radius	=	Radius of desired arc

LLPoint* centerPoint	=	Reference to LLPoint that will contain arc's center coordinates.
LLPoint* startPoint	=	Reference to LLPoint that will containarc's start point coordinates.
LLPoint* endPoint	=	Reference to LLPoint that will containarc's endpoint coordinates.
ArcDirction* dir	=	Reference to an integer that represents direction of turn. dir = 1 for left hand turn dir = -1 for right hand turn
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

4.8.2 Algorithm Steps

See Figure A-19.

STEP 1: Use inverse algorithm to calculate `crs12`, the course from `loc1.locusStart` to `loc1.locusEnd`.

STEP 2: Use inverse algorithm to calculate `gcrs1` and `geoLen1`, the course and distance from `loc1.geoStart` to `loc1.geoEnd`.

STEP 3: Use inverse algorithm to calculate `crs32`, the course from `loc2.locusEnd` to `loc2.locusStart`. Convert `crs32` to its reciprocal: $crs32 = crs32 + \pi$.

STEP 4: Apply Algorithm 4.4 to find the arc tangent to the geodesic approximations to `loc1` and `loc2`. Use `loc1.locusStart`, `crs12`, `loc2.locusEnd`, `crs32`, and `radius` as input parameter. Denote the array of points returned as `intx`. `intx[0]` will be the approximate arc center point, `intx[1]` will be the tangent point near `loc1`, and `intx[2]` will be the tangent point near `loc2`. Also returned will be the direction of the arc, `dir`.

STEP 5: If (`intx = NULL`) then there is no tangent arc. Return `NULL`.

STEP 6: Calculate the approximate angle at the vertex where loc1 and loc2 intersect. This will be used only to estimate the first improvement to the tangent point intx[1]. Thus we use an efficient spherical triangles approximation (see Figure A-20):

a. Use the spherical inverse function to calculate the rcrs1, the course from intx[0] (the approximate arc center) to intx[1] (the approximate tangent point on loc1).

b. Use the spherical inverse function to calculate the rcrs2, the course from intx[0] to intx[2] (the other approximate tangent point).

c. Calculate the angle difference between rcrs1 and rcrs2:
$\texttt{angle} = \text{abs}\left(\text{signedAzimuthDifference}\left(\texttt{rcrs1},\texttt{rcrs2}\right)\right)$

d. $\texttt{vertexAngle} = 2 * \texttt{acos}\left(\sin\left(\frac{\texttt{angle}}{2}\right)\cos\left(\frac{\texttt{radius}}{\texttt{SPHERE\_RADIUS}}\right)\right)$

STEP 7: Calculate the inclination angle of loc1 relative to its geodesic:
$\texttt{locAngle} = \texttt{atan}\left[\left(\texttt{loc1.endDist} - \texttt{loc1.startDist}\right) / \texttt{geoLen1}\right]$

STEP 8: Initialize **distbase = 0.1**

STEP 9: Initialize the iteration count: **k = 0**

STEP 10: Do while (k = 0) or ((k < maxIterationCount) and abs(error) > tol)):

a. Use direct algorithm with starting point loc1.geoStart, course gcrs1 and distance distbase to project point geoPt

b. Use Algorithm 3.10 to project a point on loc1 from the current geoPt1 Denote the projected point as **intx[1].**

d. Use Algorithm 3.12 to calculate lcrs1, the course of loc1 at intx[1].

e. Convert lcrs1 into the correct perpendicular course toward the arc center (note that dir>0 indicates a left-hand turn):

$$\text{lcrs1} = \text{lcrs1} - \text{dir} * \frac{\pi}{2}$$

f. Use the direct algorithm with starting point `intx[1]`, course `lcrs1`, and distance `radius` to project the arc center point, `intx[0]`.

g. Use Algorithm 5.2 to project `intx[0]` onto `loc2`. Reassign `intx[2]` as the projected point.

h. Use the inverse algorithm to calculate `r2`, the distance from `intx[0]` to `intx[2]`.

i. Calculate the error: `error = r2 – radius`

j. Update the distance and error function arrays:
```
distarray[0] = distarray[1]
distarray[1] = distbase
errarray[0] = errarray[1]
errarray[1] = error
```

k. If (`k = 0`), then estimate better `distbase` value using spherical approximation and calculated error:

$$\texttt{distbase} = \texttt{distbase} + \texttt{error} * \frac{\cos(\texttt{locAngle})}{\sin(\texttt{vertexAngle})}$$

l. Else, use a linear root finder with `distarray` and `errarray` to find the distance value that makes the error zero. Update `distbase` with this root value.

m. End if

STEP 12: End while.

STEP 13: Return `intx`.

Figure A-19. Arc Tangent to Two Loci.

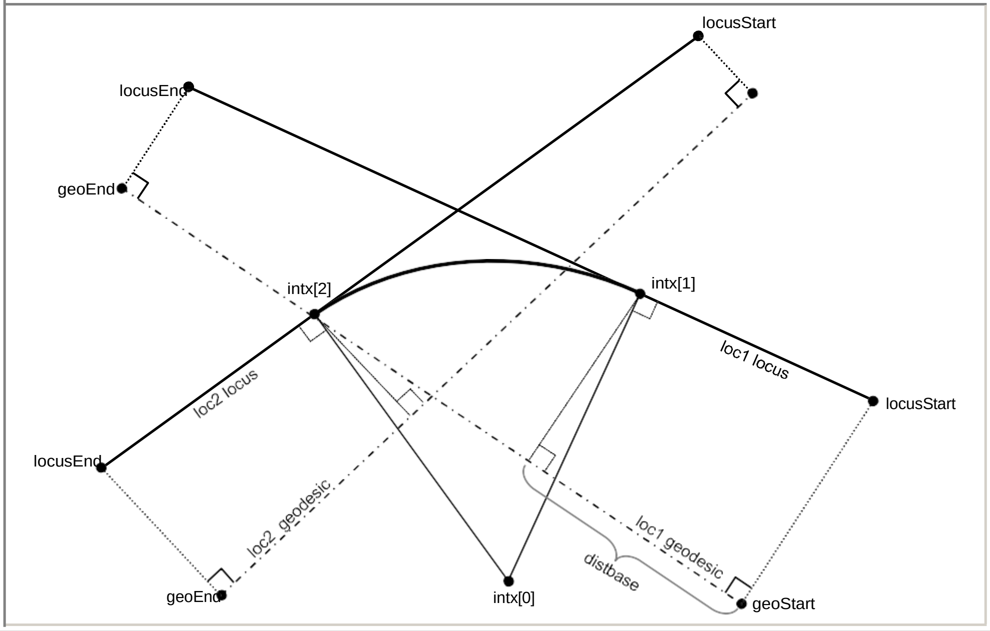
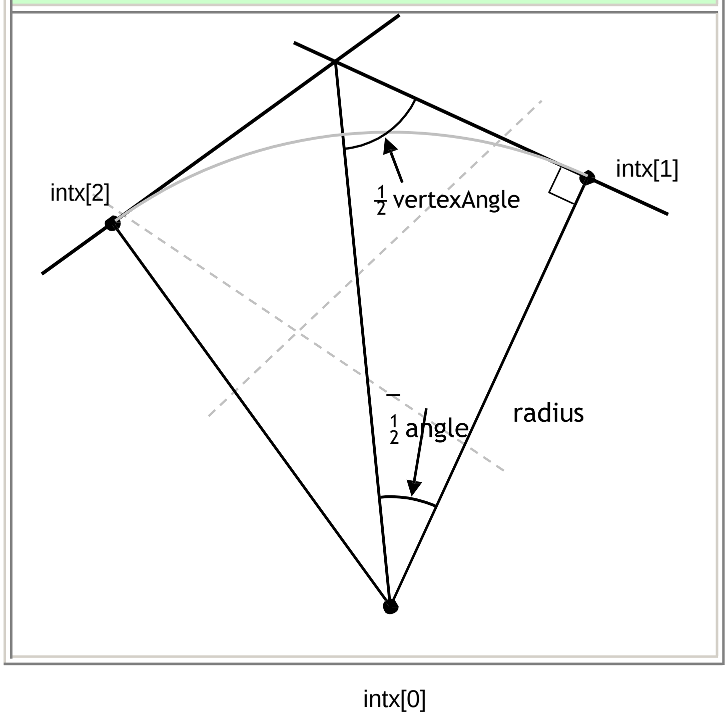


Figure A-20. Spherical Triangle Construction Used for Calculating the Approximate Vertex Angle at the Intersection of Two Loci.



5.0 Projections

5.1 Project Point to Geodesic

This algorithm is used to determine the shortest distance from a point to a geodesic. It also locates the point on the geodesic that is nearest the given point.

5.1.1 Input/Output

long WGS84PerpIntercept (Locus pt1, double crs12, LLPoint* pt2, LLPoint pt3, double*crsFromPoint, double* distFromPoint, double tol) returns a reference to an **LLPoint** structure that contains the coordinates of the projected point, where the inputs are:

LLPoint pt1	=	Coordinates of geodesic start point
double crs13	=	Initial azimuth of geodesic at start point
LLPoint pt3	=	Coordinates of point to be projected to geodesic
LLPoint* pt2	=	Reference to LLPoint that will be updated with coordinates of projected point
double* crsFromPoint	=	Reference to azimuth of geodesic from pt3to projected point, in radians
double* distFromPoint	=	Reference to distance from pt3 to projected point, in radians
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

5.1.2 Algorithm Steps

This algorithm treats the geodesic as unbounded, so that projected points that lie “behind” the geodesic starting point **pt1** will be returned. If it is desired to limit solutions to those that lie along the forward direction of the given geodesic, then step 4g may be modified to return a **NULL** solution (see Figure A-21).

<u>STEP 1</u>: Use the inverse algorithm to calculate the distance, azimuth, and reverse azimuth from **pt1** to **pt3** Denote these values as **crs13, crs31** and **dist13**, respectively.

STEP 2: Calculate the angle between the given geodesic and the geodesic between **pt1** and **pt3**. This is accomplished using **signedAzimuthDifference** function (see Algorithm 6.2).

angle = abs (signedAzimuthDifference (crs13, crs12))

STEP 3: If (**dist13** $\leq$ **tol**), then **pt2** is the same point as **pt1**.

STEP 4: If **π/2 - angle < tol**, then the projected point **pt2** is very close to or behind **pt1** (the start of the geodesic), so extend the geodesic backward far enough to catch the projection. Use a spherical triangle approximation to calculate the needed extension distance:

a. B=angle

b. A=dist13/sphereRad

c. B=asin(sin(B)sin(a))

d. dist12=2*sphereRad*atan(tan(0.5*(a-b))*sin(0.5*(A-B)))

e. If **abs(dist12) < tol**, , then the projected point is identical to **pt1** to within the required accuracy.

   (1) crsFRomPoint = crs31;

   (2) distFromPoint = dist13;

   (3) Return pt2 = pt1

f. End if.

g. Use the direct algorithm to move **pt1** along reverse geodesic course. Use **1.1*dist12** for the distance, **crs12+π** for the azimuth, and then store the new location in the temporary variable **newPt1**. A distance greater than **dist12** is used to compensate for possible errors in the spherical approximation.

h. Use the inverse algorithm to calculate the azimuth from **newPt** to **pt1** This value replaces the original azimuth value **crs12**.

   (1) Rename **newPT1** as **pt1: pt1 = newPt1**.

STEP 5: Calculate the approximate distance from **pt1** to the projected point using the spherical triangle formula from steps 4(a) through 4(d). Denote the approximate distance found as **dist13**.

STEP 6: Use the direct algorithm to project a point on the given geodesic distance **dist13** from **pt1**. Use **pt1** for the starting point, **dist12** for distance, and **crs12** for azimuth. Denote the computed point by **pt2.**

STEP 7: Use the inverse algorithm to calculate the azimuth **crs21** from **pt2** to **pt1**.

STEP 8: Use the inverse algorithm to calculate the azimuth **crs23** and distance **dist23** from **pt3** to **pt2**.

STEP 9: Calculate the angle between the geodesics that intersect at **pt3** and cast that angle into the range **[0 , π]** using the following formula (see Algorithm 5.1):

angle = abs (signedAzimuthDifference (crs21, crs23))

STEP 10: Calculate the error and store it as the first element in the error function array:
errarray[0] = angle – π/2

STEP 11 Store the current distance from **pt1** to **pt2** in the distance function array:
distarray[0] = dist12

STEP 12: A second distance/error value must be calculated before linear interpolation may be used to improve the solution. The following formula may be used:

distarray[1] = distarray[0] + errarray[0] *dist23

STEP 13: Use the direct algorithm to project point on the given geodesic distance **distarray[1]** from **pt1** Use **pt1** for the starting point, **distarray[1]** for distance, and **crs12** for azimuth. Denote the computed point by **pt2**.

STEP 14: Use the inverse algorithm to calculate the azimuth **crs21** from **pt2** to **pt1**.

STEP 15: Use the inverse algorithm to calculate the azimuth **crs23** from **pt2** to **pt3**.

STEP 16: Calculate the error in angle (see Algorithm 5.1):

errarray[1] = abs (signedAzimuthDifference(crs21, crs23)) - π/2

STEP 17: Initialize the iteration count: k = 0.

STEP 18: Do while (**k = 0**) or ((**error > tol) and (k < maxIterationCount**))

a. Use linear approximation to find root of **errarray** as a function of **distarray**. This gives an improved approximation to **dist12**.

b. Use the direct algorithm to project point on the given geodesic distance **dist12** from **pt1**. Use **pt1** for the starting point, **dist12** for distance, and **crs12** for azimuth. Denote the computed point by **pt2**.

c. Use the inverse algorithm to calculate the azimuth **crs21** from **pt2** to **pt1**.

d. Use the inverse algorithm to calculate the distance **dist23**, azimuth **crs32**, and reverse azimuth crs23 from **pt3** to **pt2**.

e. Update **distarray** and **errarray** with the new values:
distarray[0] = distarray[1]
errarray[0] = errarray[1]
distarray[1] = dist13
errarray[1] = abs (signedAzimuthDifference(crs21, crs23)) - π/2

f. Calculate the difference between the two latest distance values. This serves as the error function for measuring convergence:

error = abs (distarray[1] - distarray[0])

STEP 19: End while.

STEP 20: Set **crsToPoint = crs32**.

STEP 21: Set **distToPoint = dist23**.

STEP 22: Return **pt2.**

Figure A-21. Projecting a Point to a Geodesic.

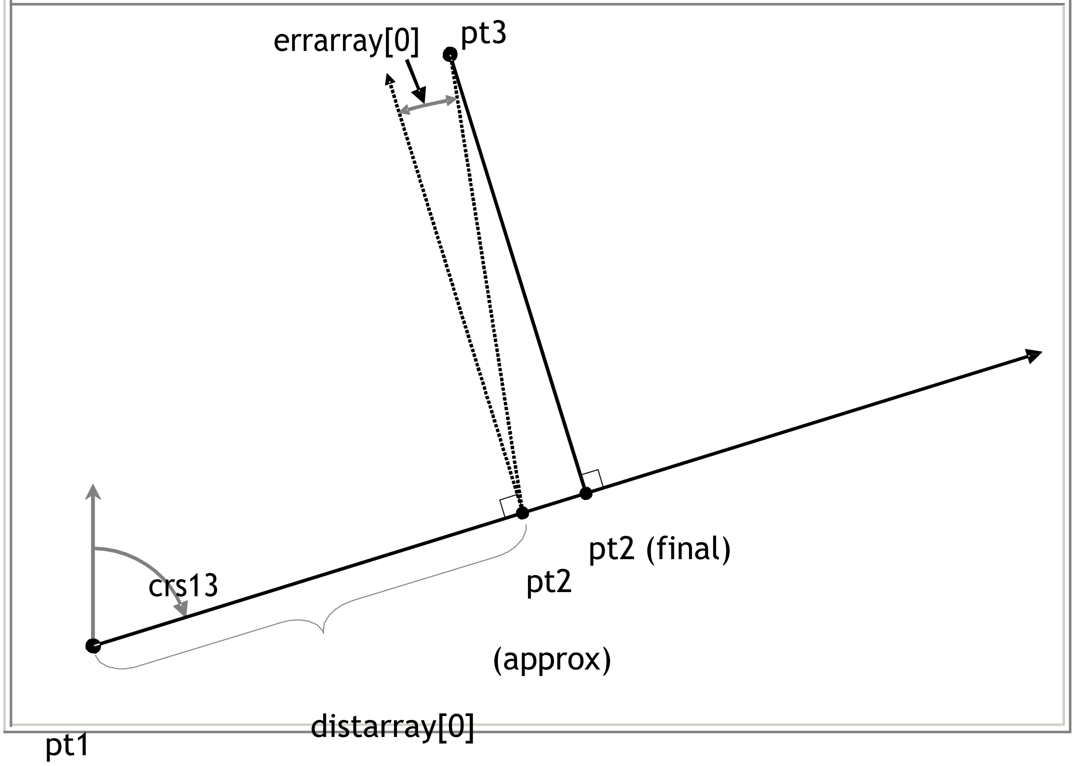
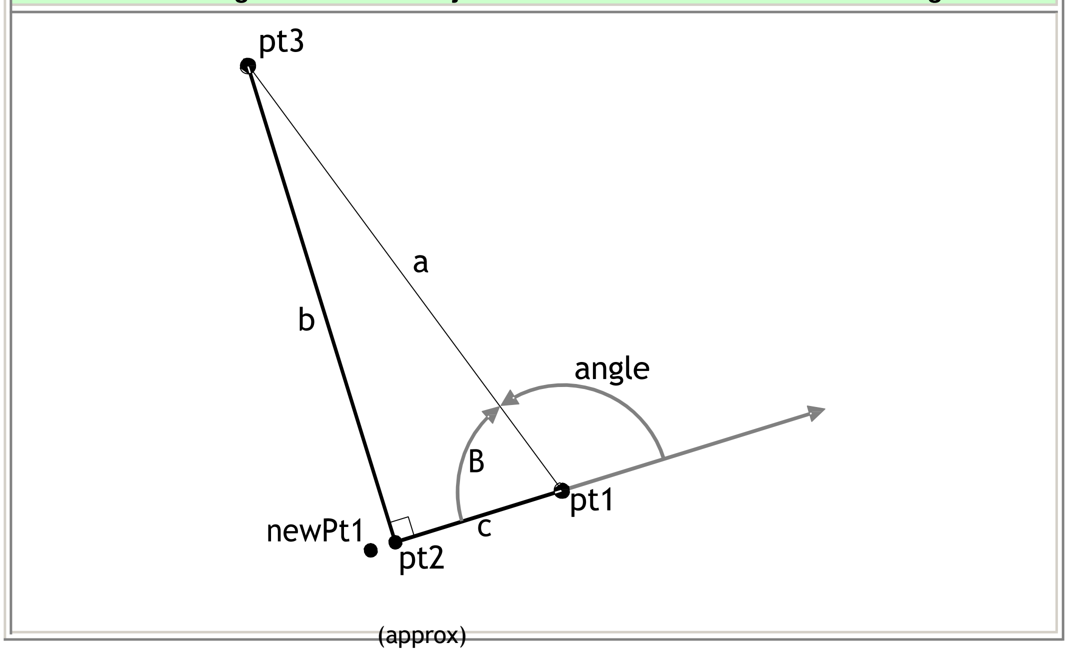


Figure A-22. Elements of Spherical Triangle Used to Determine New Geodesic Starting Point When Projected Point Lies Behind Given Starting Point.



5.2 Project Point to Locus.

This algorithm returns the point on a locus nearest the given sample point. It is used in Algorithm 4.8 to calculate an arc tangent to two **loci**.

5.2.1 Input/Output

LLPoint* WGS84LocusPerpIntercept (Locus loc, LLPoint pt2, double* crsFromPoint, double* distFromPoint, double tol) returns a reference to an **LLPoint** structure that contains the coordinates of the projected point, where the inputs are:

Locus loc	=	Locus structure to which point will be projected
LLPoint pt2	=	Coordinates of point to be projected to locus
double* crsFromPoint	=	Reference to value that will store the course from **pt2** to projected point
double* distFromPoint	=	Reference to value that will store the distance from **pt2** to projected point
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/ inverse algorithms

5.2.2 Algorithm Steps

See Figure A-23 for an illustration of the variables.

STEP 1: Define the course and distance from **loc.geoStart** to **loc.geoEnd** as **gcrs** and **gdist** respectively. This course and distance is a part of the locus structure.

a. gcrs = loc.geoAz

b. gdist = loc.geoLenght

STEP 2: If (**abs(loc.startDist-loc.endDist) < tol**), then the locus is "parallel" to its defining geodesic. In this case, the projected point on the locus will lie on the geodesic joining **pt2** with its projection on the defining geodesic, and the calculation is simplified:

a. Apply Algorithm 5.1 to project **pt2** onto the defining geodesic of **loc**. Use **loc.geoStart**, **gcrs** and **pt2** as input parameters. The intersection point, **perpPt,** will be returned along with the course and distance from **pt2** to **perpPt**. Denote the course and distance values as **crsFromPoint** and **distFromPoint,** respectively.

b. Use Algorithm 3.10 to project a point **locPt** on the locus from **perpPt** on the geodesic.

c. Use the inverse algorithm to recalculate **distFromPoint** as the distance between **pt2** and **locPt.**

d. Return **locPt**.

STEP 3: End If.

STEP 4: Use the inverse algorithm to compute **lcrs**, the course from **loc.locusStart** to **loc.locusEnd**.

STEP 5: Use Algorithm 5.1 to project **pt2** onto the geodesic approximation of the locus. Pass **loc.locusStart, lcrs,** and **pt2** as parameters. Denote the computed point as **locPt** (In general, this point will not exactly lie on the locus. We will adjust its position so that it is on the locus in a subsequent step.)

STEP 6: Calculate the locus inclination angle, relative to its geodesic:

locAngle = atan ((loc.startDist – loc.endDist)/gdist)

STEP 7: Use Algorithm 5.1 to project **locPt** onto the locus's defining geodesic. Pass **loc.geoStart**, **gcrs,** and **locPt** as parameters. Denote the computed point as **geoPt**.

STEP 8: Use the inverse function to calculate the distance from **loc.geoStart** to **geoPt**. Store this value as **distrarray[1].**

STEP 9: Initialize the iteration count: k = 0

STEP 10: Do while (**k = 0**) or (**abs(errarray[1] > tol**) and (k < maxIterationCount))

a. Use Algorithm 3.10 with distrarray[1] to project a point onto the locus. Reassign **locPt** as this point.

b. Use Algorithm 3.12 to recompute lcrs the course of the locus at locPt.

c. Use the inverse algorithm to compute **crsToPoint** and **distToPoint**, the course and distance from locPt to pt2.

d. Compute the signed angle between the locus and the geodesic from locPt to pt2:

angle = signedAzimuthDifference (lcrs, crsToPoint)

e. Store the approximate error as:
errarray [1] = -distToPoint*cos(angle)

This converts the error in angle into an error in distance which can be compared to **tol**.

f. If (**k = 0**) then a direct calculation is used to improve the approximation:

newDist = distarray[1] + essarray[1]*cos(locAngle)

g. Else, use a linear root finder with **distrarray** and **essarray** to solve for the distance value that makes the error zero. Denote this value as **newDist**.

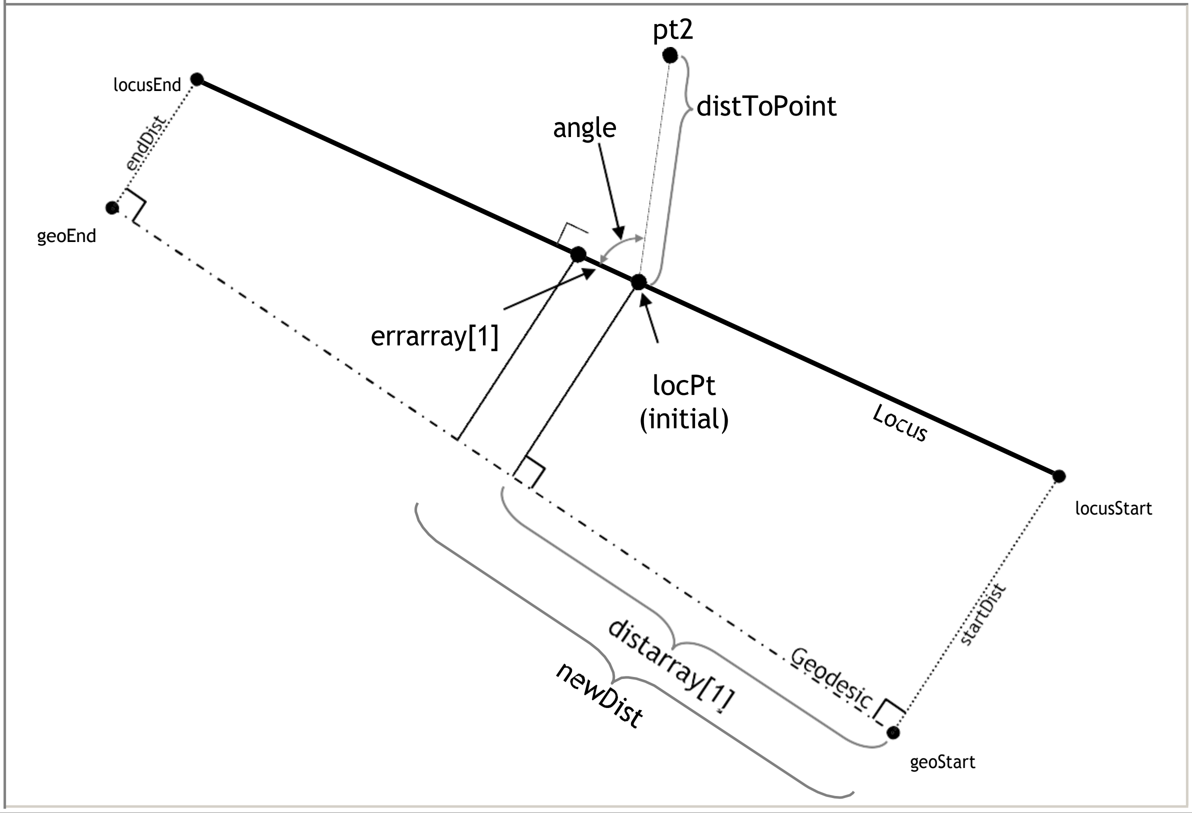
h. End if.

i. Update the distance and error arrays:
distrarray[0] = distrarray[1]
essarray[0] = essarray[1] =
distrarray[1] = newDist

STEP 11: End while.

STEP 12: Return locPt.

Figure A-23. Projecting a Point to a Locus.



5.3 Tangent Projection from Point to Arc

This projection is used in obstacle evaluation when finding the point on an RF leg or fly-by turn path where the distance to an obstacle must be measured.

5.3.1 Input/Output

long WGS84PointToArcTangents (LLPoint point, LLPoint center, double radius, LLPointPair tanPt, int* n, double tol) returns a reference to an **LLPoint** structure that contains the coordinates of the point are tangent to arc, where the inputs are:

LLPoint point	=	Point from which lines will be tangent to arc
LLPoint center	=	Geodetic centerpoint coordinates of arc
double radius	=	Radius of arc
LLPoint point tanPt	=	Two-element array of **LLPoint** objects that will be updated with tangent points' coordinates.

Int* n	=	Reference to number of tangent points found (0, 1, or 2).
double tol	=	Maximum error allowed in solution.
double eps	=	Convergence parameter for forward/inverse algorithms.

5.3.2 Algorithm Steps

This algorithm treats the arc as a complete circle, so either zero or two tangent points will be returned. If the arc is bounded and two tangent points are found, then each point must be tested using Algorithm 3.7 to determine whether they lie within the arc's bounds. (See Figure A-24).

STEP 1: Use the inverse algorithm to calculate the distance, azimuth, and reverse azimuth from point to **center**. Denote these values by **crsToCenter**, **crsFromCenter**, and **distToCenter**, respectively.

STEP 2: If **abs(distToCenter - radius) < tol**, then point lies on the arc and is a tangent point.

a. Set **n = 1.**

b. Return **tanPt = point.**

STEP 3: Else, if **distToCenter < radius**, then point lies inside of the arc and no tangent points exist.

a. Return no solution.

STEP 4: End if.

STEP 5: There must be two tangent points on the circle, so set **n = 2.**

STEP 6: Use spherical trigonometry to compute approximate tangent points:

a. **a = distToCenter/ SPHERE_RADIUS**

b. **b = radius/SPHERE_RADIUS**

c. **c = acos(tan(b)/tan(a))**

This is the approximate angle between the geodesic that joins **point** with **center** and the geodesic that joins **center** with either tangent point.

STEP 7: Initialize iteration count: **k = 0**

STEP 8: Do while (**k = 0**) or (**abs(error) < tol** and **k < maxIterationCount**):

a. Use the direct algorithm to locate **tanPt[0]** on arc. Use **center** as the starting point, **radius** as the distance, and **courseFromCenter + C** as the azimuth.

b. Use the inverse algorithm to calculate the azimuth from **tanPt[0]** to **center**. Denote this value as **radCrs**.

c. Use the inverse algorithm to calculate the azimuth from **tanPt[0]** to point. Denote this value as **tanCrs**.

d. Use the function in Algorithm 6.2 to calculate the angle between the two courses and cast it into the range ,(-π,π):

diff = signedAzimuthDifference(radCrs, tanCrs)

e. Compute the error: **error = abs(diff) - (π/2).**

f. Adjust the value of **C** to improve the approximation: **C = C + error**

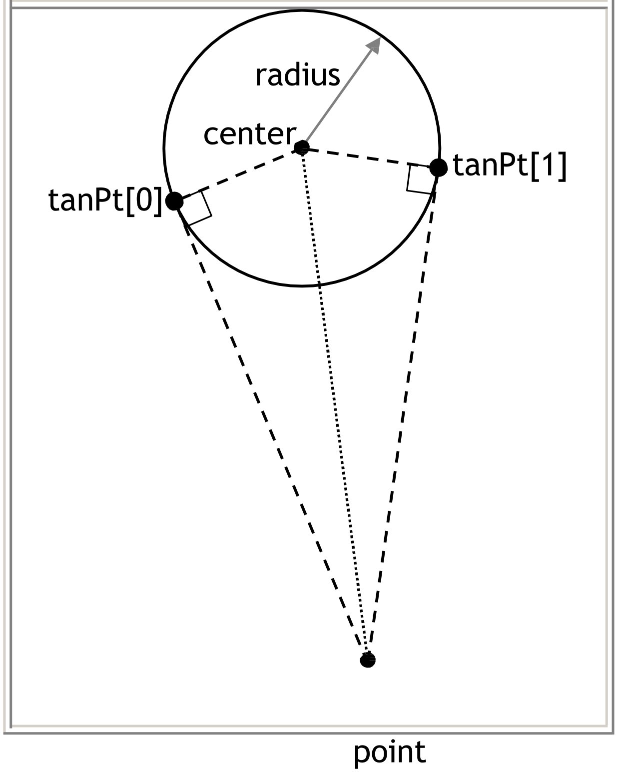
g. Increment the iteration count: **k = k + 1.**

STEP 9: End while loop.

STEP 10: Repeat steps 7-9 to solve for **tanPt[1]** In each iteration; however, use **crsFromPoint-C** for azimuth in step 8(a).

STEP 11: Return **tanPt[0]** and **tanPt[1].**

Figure A-24. Projecting Point to Tangent Points on an Arc.



5.4 Project Arc to Geodesic

This algorithm is used for obstacle evaluation when finding a point on the straight portion of TF leg where distance to an obstacle must be measured.

5.4.1 Input/Output

long WGS84PerpTangentPoints(LLPoint lineStart, double crs, LLPoint center, double radius, LLPointPair linePts, LLPointPair tanPTs, double tol) updates geodesic intercepts, but returns no output, where the inputs are:

LLPoint lineStart	=	Start point of geodesic to which arc tangent points will be projected
double crs	=	Initial course of geodesic
LLPoint center	=	Geodetic coordinates of arc center
double radius	=	Arc radius
LLPoitnPair linePts	=	Two-element array of projected points on Geodesic

LLPoint point tanPts	=	Two-element array of tangent points on arc
double tol	=	Maximum error allowed in solution
double eps	=	Convergence parameter for forward/inverse algorithms

5.4.2 Algorithm Steps

See Figure A-25 for an illustration of the variable names.

STEP 1: Use the inverse algorithm to calculate the distance, azimuth, and reverse azimuth from **lineStart** to **center** Denote these values as **distStartToCenter, crsStartToCenter**, and **crsCenterToStart**, respectively.

STEP 2: Compute the angle between the given geodesic and the geodesic that joins **lineStart** to **center** (see Algorithm 6.2):

angle1 = signedAzimuthDifference(crs, crsStartToCenter)

STEP 3: If **abs (distStartToCenter* (crsStartToCenter-crs)) < tol,** then center lies on the given geodesic, which is a diameter of the circle. In this case, the tangent points and project points are the same:

a. Use the direct algorithm to compute **tanPts[0].** Use **lineStart** as the starting point, **crs** as the azimuth, and **distStartToCenter** – **radius** as the distance.

b. Use the direct algorithm to compute **tanPts[0]**Use **lineStart** as the starting point, **crs** as the azimuth, and **distStartToCenter** + **radius** as the distance.

c. Set **linePts[0] = tanPts[0].**

d. Set **linePts[1] = tanPts[1].**

e. Return all four points.

STEP 4: End if.

STEP 5: Use Algorithm 5.1 to project **center** to the geodesic defined by **lineStart** and **crs** Denote the projected point by **perpPt**.

STEP 6: Use the inverse algorithm to calculate the distance, azimuth, and reverse azimuth from **prepPt** to **lineStart**. Denote these values by **dist12** and **crs21** respectively.

STEP 7: Set **delta = radius.**

STEP 8: Initialize iteration count: **k = 0.**

STEP 9: Do while (**k = 0**) or **(abs(error) > tol** and **k < maxIterationCount):**

a. Use the direct algorithm to compute **linePts[0]** Use **perpPt** as the starting point, **delta** as the distance, and **crs21 +** $\boldsymbol{\pi}$ as the azimuth.

b. Use the inverse algorithm to calculate the course from **linePts[0]** to **perpPt** Denote this value by **strCrs**.

c. Calculate the azimuth, **perpCrs** from **linePts[0]** to the desired position of **tanPts[0].** The azimuth depends upon which side of the line the circle lies, which is given by the sign of **angle1**:

(1) If the circle lies to the right of the line:
perpCrs = **strCrs** + $\pi/2$.

(2) If the circle lies to he left of the line:
perpCrs = **strCrs** - $\pi/2$.

d. Use Algorithm 5.1 to project **center** onto the geodesic passing through **linePts[0]** at azimuth **perpCrs** Algorithm 5.1 will return the projected point, **tanPts[0]**along with the distance from **center** to **tanPts[0]**Denote this distance by **radDist**.

e. Calculate the error, the amount that **radDist** differs from **radius:**
error = radDist – radius

f. Adjust the distance from **lineStart to linePts[0]:**
delta = delta - errror

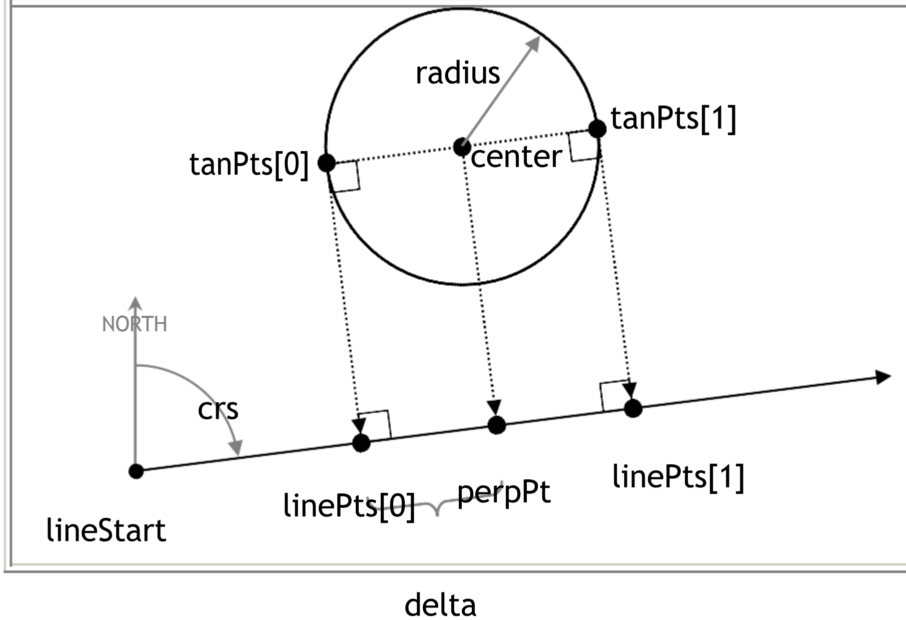
g. Increment the iteration count: k = k + 1

STEP 10: End while loop.

STEP 11: Repeat steps 7-10 to solve for **linePts[1]** and **tanPts[1]**In each iteration; however, use **crs21** for azimuth in step a). Note that using the final **delta** value for the first iteration in the search for **linePts[1]** will make the code more efficient (i.e., don't repeat step 7).

STEP 12: Return **linePts[0]** , **linePts[1]** , **tanPts[0]** and **tanPts[1].**

Figure A-25. Projecting an Arc to a Geodesic.



Useful Functions.

6.0 Calculate Angular Arc Extent

When calculating the angle subtended by an arc, one must take into account the possibility that the arc crosses the northern branch cut, where 0° = 360°. The following algorithm accounts for this case.

Input/Output

double WGS84GetArcExtent (double startCrs, double endCrs, int orientation, double tol) returns a double precision value containing the arc's subtended angle, where the inputs are:

double startCrs	=	Azimuth from center to start point of arc
double endCrs	=	Azimuth from center to end point of arc
int orientation	=	Integer that indicates the direction in which the arc is traversed to go from **startCrs** to **endCrs**.
orientation	=	1 if the arc is traversed counter-clockwise,
orientation	=	-1 if the arc is traversed clockwise.
double tol	=	Maximum error allowed in calculations.

6.01 Algorithm Steps

STEP 1: If **(abs(startCrs - endCrs) < tol)** return **2*π**

STEP 2: If **orientation < 0**, then orientation is clockwise. Cast the arc into a positive orientation (counter-clockwise) so only one set of calculations is required

a. **temp = startCrs**

b. **startCrs = endCrs**

c. **endCrs = temp**

STEP 3: End if.

STEP 4: If **startCrs > endCrs**, then **angle = startCrs - endCrs**.

STEP 5: Else **angle = 2*π + startCrs - endCrs.**

STEP 6: End if.

STEP 7: If **orientation < 0,** then **angle = -angle.**

STEP 8: Return **angle.**

6.1 Converting Geodetic Latitude/Longitude to ECEF Coordinates

Geodetic coordinates may be converted to rectilinear ECEF coordinates using the following formulae[1]. Given geodetic latitude φ, geodetic longitude θ, semi-major axis a and flattening parameter f, calculate the square of the eccentricity

$e^2 = f(2 - f)$ and the curvature in the prime vertical: $N = \frac{a}{\sqrt{1 - e^2 \sin^2 \varphi}}$.

The ECEF coordinates are then

$$x = N \cos\varphi \cos\theta$$
$$y = N \cos\varphi \sin\theta$$
$$z = N(1 - e^2)\sin\varphi$$

6.2 Signed Azimuth Difference

It is often necessary to calculate the signed angular difference in azimuth between two geodesics at the point where they intersect. The following functions casts the difference between two geodesics into the range $[-\pi, \pi)$:

$$\texttt{signedAzimuthDifference}(a_1, a_2) = \bmod(a_1 - a_2 + \pi, 2\pi) - \pi$$

This function returns the angle between the two geodesics as if the geodesic that is oriented along azimuth a_1 were on the positive x-axis and the geodesic oriented along azimuth a_2 passed through the origin. In other words, if $\text{signedAzimuthDifference}(a_1, a_2) > 0$ azimuth a_2 is to the left when standing at the geodesics' intersection point and facing in the direction of azimuth a_1.

The mod function in the definition of **signedAzimuthDifference** must always return a non-negative value. Note that the C language's built in **fmod** function does not have this behavior, so a replacement must be supplied. The following code suffices:

```
double mod(double a, double b) {
a = fmod(a,b) ;
   If (a < 0.0) a = a + b ;
return a;       }
```

[1] Dana, Peter H., "Coordinate Conversion Geodetic Latitude, Longitude, and Height to ECEF, X, Y, Z", http://www.colorado.edu/geography/gcraft/notes/datum/gif/llhxyz.gif>, 11 February, 2003

6.3 Approximate Fixed Radius Arc Length

Algorithm 3.8 describes a method for computing the length of an arc to high precision. The following algorithm provides a solution accurate to 1 centimeter for an arc whose radius is less than about 300 nautical miles (NM). This algorithm approximates the ellipsoid at the center of the arc in question with a “best fit” sphere, whose radius is computed as the geometric mean of the meridional and prime-vertical curvatures at the arc’s center.

Given the arc center’s latitude θ, the ellipsoidal semi-major axis a and flattening f, compute the local radius of curvature R as follows:

$$e^2 = f\left(2 - f\right)$$

$$M = \frac{a\left(1-e^2\right)}{\left(1-e^2\sin^2\theta\right)^{\frac{3}{2}}}$$

$$N = \frac{a}{\sqrt{1-e^2\sin^2\theta}}$$

$$R = \sqrt{MN}$$

If the radius and subtended angle of the of the constant radius arc are r and A, respectively, then the length of the arc is given by:

$$L = AR\sin\left(\frac{r}{R}\right)$$

7.0 Sample Function Test Results

The following pages provide test inputs with expected outputs. This data is included here to make it easy to verify that an independent implementation of these algorithms produces the same results. All of these results were obtained using the tolerance parameter $\texttt{tol} = 1.0\text{e}-9$ and forward/inverse convergence parameter $\texttt{eps} = 0.5\text{e}-13$.

Test results are not included for those algorithms that are fairly straightforward applications of other algorithms, such as 3.9, 3.10, and 3.11.

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Test Identifier	Starting Latitude	Starting Longitude	Distance (NM)	Initial Azimuth (degrees)	Computed Destination Latitude	Computed Destination Longitude
test1	40:10:24.50000N	70:12:45.60000W	200.0	90.0	40:05:30.77099N	65:52:03.22158W
test2	40:10:24.50000N	70:12:45.60000W	200.0	0.0	43:30:29.87690N	70:12:45.60000W
test3	40:10:24.50000N	70:12:45.60000W	200.0	180.0	36:50:12.19034N	70:12:45.60000W
test4	40:10:24.50000N	70:12:45.60000W	200.0	270.0	40:05:30.77099N	74:33:27.97842W
test5	40:10:24.50000N	70:12:45.60000W	200.0	46.0	42:26:44.93817N	66:58:26.80185W
test6	40:10:24.50000N	70:12:45.60000W	200.0	127.0	38:06:56.47029N	66:50:21.71131W
test7	40:10:24.50000N	70:12:45.60000W	200.0	199.0	37:00:37.63806N	71:34:01.15378W
test8	40:10:24.50000N	70:12:45.60000W	200.0	277.0	40:29:56.05779N	74:33:04.77416W
test9	40:10:24.50000N	70:12:45.60000W	2.0	90.0	40:10:24.47060N	70:10:09.05140W
test10	40:10:24.50000N	70:12:45.60000W	2.0	0.0	40:12:24.58831N	70:12:45.60000W
test11	40:10:24.50000N	70:12:45.60000W	2.0	180.0	40:08:24.41100N	70:12:45.60000W
test12	40:10:24.50000N	70:12:45.60000W	2.0	270.0	40:10:24.47060N	70:15:22.14860W
test13	40:10:24.50000N	70:12:45.60000W	2.0	46.0	40:11:47.90520N	70:10:52.95004W
test14	40:10:24.50000N	70:12:45.60000W	2.0	127.0	40:09:12.20998N	70:10:40.61155W
test15	40:10:24.50000N	70:12:45.60000W	2.0	199.0	40:08:30.95052N	70:13:36.54366W
test16	40:10:24.50000N	70:12:45.60000W	2.0	277.0	40:10:39.10616N	70:15:20.99098W
test17	40:10:24.50000N	70:12:45.60000W	3000.0	90.0	24:30:24.17902N	13:01:17.08239W
test18	40:10:24.50000N	70:12:45.60000W	3000.0	0.0	89:58:28.94717N	109:47:14.40000E
test19	40:10:24.50000N	70:12:45.60000W	3000.0	180.0	10:00:44.08298S	70:12:45.60000W
test20	40:10:24.50000N	70:12:45.60000W	3000.0	270.0	24:30:24.17902N	127:24:14.11761W
test21	40:10:24.50000N	70:12:45.60000W	3000.0	46.0	55:17:03.30750N	4:30:00.21623E
test22	40:10:24.50000N	70:12:45.60000W	3000.0	127.0	3:28:31.38990N	32:28:57.95936W
test23	40:10:24.50000N	70:12:45.60000W	3000.0	199.0	8:09:04.17050S	84:46:29.97795W
test24	40:10:24.50000N	70:12:45.60000W	3000.0	277.0	29:06:16.65778N	130:30:47.88401W
test25	50:10:52.50000N	123:06:57.10000W	200.0	90.0	50:03:56.42973N	117:56:18.19536W
test26	50:10:52.50000N	123:06:57.10000W	200.0	0.0	53:30:36.93183N	123:06:57.10000W
test27	50:10:52.50000N	123:06:57.10000W	200.0	180.0	46:51:01.16657N	123:06:57.10000W
test28	50:10:52.50000N	123:06:57.10000W	200.0	270.0	50:03:56.42973N	128:17:36.00464W
test29	50:10:52.50000N	123:06:57.10000W	200.0	46.0	52:25:49.36941N	119:11:51.80053W
test30	50:10:52.50000N	123:06:57.10000W	200.0	127.0	48:06:24.18375N	119:08:33.75213W
test31	50:10:52.50000N	123:06:57.10000W	200.0	199.0	47:01:13.78683N	124:42:04.78016W
test32	50:10:52.50000N	123:06:57.10000W	200.0	277.0	50:28:19.21956N	128:17:55.21964W
test33	50:10:52.50000N	123:06:57.10000W	2.0	90.0	50:10:52.45833N	123:03:50.41132W
test34	50:10:52.50000N	123:06:57.10000W	2.0	0.0	50:12:52.37823N	123:06:57.10000W
test35	50:10:52.50000N	123:06:57.10000W	2.0	180.0	50:08:52.62108N	123:06:57.10000W
test36	50:10:52.50000N	123:06:57.10000W	2.0	270.0	50:10:52.45833N	123:10:03.78868W
test37	50:10:52.50000N	123:06:57.10000W	2.0	46.0	50:12:15.75291N	123:04:42.74250W
test38	50:10:52.50000N	123:06:57.10000W	2.0	127.0	50:09:40.32859N	123:04:28.06612W
test39	50:10:52.50000N	123:06:57.10000W	2.0	199.0	50:08:59.14786N	123:07:57.83998W
test40	50:10:52.50000N	123:06:57.10000W	2.0	277.0	50:11:07.06846N	123:10:02.41284W
test41	50:10:52.50000N	123:06:57.10000W	3000.0	90.0	29:37:18.55208N	61:31:12.91277W
test42	50:10:52.50000N	123:06:57.10000W	3000.0	0.0	80:00:57.51620N	56:53:02.90000E
test43	50:10:52.50000N	123:06:57.10000W	3000.0	180.0	0:02:43.03479N	123:06:57.10000W
test44	50:10:52.50000N	123:06:57.10000W	3000.0	270.0	29:37:18.55208N	175:17:18.71277E

test45	50:10:52.50000N	123:06:57.10000W	3000.0	46.0	56:40:22.79938N	33:42:20.71403W
test46	50:10:52.50000N	123:06:57.10000W	3000.0	127.0	11:23:14.37898N	84:34:26.55554W
test47	50:10:52.50000N	123:06:57.10000W	3000.0	199.0	1:35:14.22889N	137:32:13.52544W
test48	50:10:52.50000N	123:06:57.10000W	3000.0	277.0	33:39:39.03338N	171:08:27.87014E
test49	42:44:32.10000N	66:27:19.60000E	200.0	90.0	42:39:10.81410N	70:58:29.15259E
test50	42:44:32.10000N	66:27:19.60000E	200.0	0.0	46:04:32.07438N	66:27:19.60000E
test51	42:44:32.10000N	66:27:19.60000E	200.0	180.0	39:24:25.11928N	66:27:19.60000E
test52	42:44:32.10000N	66:27:19.60000E	200.0	270.0	42:39:10.81410N	61:56:10.04741E
test53	42:44:32.10000N	66:27:19.60000E	200.0	46.0	45:00:33.43147N	69:50:07.10761E
test54	42:44:32.10000N	66:27:19.60000E	200.0	127.0	40:40:50.71563N	69:57:17.17656E
test55	42:44:32.10000N	66:27:19.60000E	200.0	199.0	39:34:47.61048N	65:03:08.96220E
test56	42:44:32.10000N	66:27:19.60000E	200.0	277.0	43:03:35.51327N	61:56:24.98803E
test57	42:44:32.10000N	66:27:19.60000E	2.0	90.0	42:44:32.06784N	66:30:02.45101E
test58	42:44:32.10000N	66:27:19.60000E	2.0	0.0	42:46:32.13452N	66:27:19.60000E
test59	42:44:32.10000N	66:27:19.60000E	2.0	180.0	42:42:32.06478N	66:27:19.60000E
test60	42:44:32.10000N	66:27:19.60000E	2.0	270.0	42:44:32.06784N	66:24:36.74899E
test61	42:44:32.10000N	66:27:19.60000E	2.0	46.0	42:45:55.46641N	66:29:16.78884E
test62	42:44:32.10000N	66:27:19.60000E	2.0	127.0	42:43:19.84058N	66:29:29.61668E
test63	42:44:32.10000N	66:27:19.60000E	2.0	199.0	42:42:38.60108N	66:26:26.60774E
test64	42:44:32.10000N	66:27:19.60000E	2.0	277.0	42:44:46.69688N	66:24:37.95230E
test65	42:44:32.10000N	66:27:19.60000E	3000.0	90.0	25:52:49.48262N	124:39:55.85184E
test66	42:44:32.10000N	66:27:19.60000E	3000.0	0.0	87:25:13.54228N	113:32:40.40000W
test67	42:44:32.10000N	66:27:19.60000E	3000.0	180.0	7:25:57.78702S	66:27:19.60000E
test68	42:44:32.10000N	66:27:19.60000E	3000.0	270.0	25:52:49.48262N	8:14:43.34816E
test69	42:44:32.10000N	66:27:19.60000E	3000.0	46.0	55:52:47.54426N	144:47:50.12500E
test70	42:44:32.10000N	66:27:19.60000E	3000.0	127.0	5:30:44.95719N	104:18:35.77997E
test71	42:44:32.10000N	66:27:19.60000E	3000.0	199.0	5:39:14.93608S	51:58:13.27568E
test72	42:44:32.10000N	66:27:19.60000E	3000.0	277.0	30:21:08.45258N	4:52:35.40656E
test73	31:12:52.30000N	125:28:47.50000E	200.0	90.0	31:09:21.00038N	129:21:55.26637E
test74	31:12:52.30000N	125:28:47.50000E	200.0	0.0	34:33:15.83037N	125:28:47.50000E
test75	31:12:52.30000N	125:28:47.50000E	200.0	180.0	27:52:22.52362N	125:28:47.50000E
test76	31:12:52.30000N	125:28:47.50000E	200.0	270.0	31:09:21.00038N	121:35:39.73363E
test77	31:12:52.30000N	125:28:47.50000E	200.0	46.0	33:30:10.60726N	128:20:48.89100E
test78	31:12:52.30000N	125:28:47.50000E	200.0	127.0	29:10:03.77133N	128:31:13.43437E
test79	31:12:52.30000N	125:28:47.50000E	200.0	199.0	28:02:57.01708N	124:15:14.09016E
test80	31:12:52.30000N	125:28:47.50000E	200.0	277.0	31:33:48.07660N	121:36:24.04854E
test81	31:12:52.30000N	125:28:47.50000E	2.0	90.0	31:12:52.27886N	125:31:07.43524E
test82	31:12:52.30000N	125:28:47.50000E	2.0	0.0	31:14:52.56685N	125:28:47.50000E
test83	31:12:52.30000N	125:28:47.50000E	2.0	180.0	31:10:52.03253N	125:28:47.50000E
test84	31:12:52.30000N	125:28:47.50000E	2.0	270.0	31:12:52.27886N	125:26:27.56476E
test85	31:12:52.30000N	125:28:47.50000E	2.0	46.0	31:14:15.83349N	125:30:28.18558E
test86	31:12:52.30000N	125:28:47.50000E	2.0	127.0	31:11:39.90782N	125:30:39.23361E
test87	31:12:52.30000N	125:28:47.50000E	2.0	199.0	31:10:58.58265N	125:28:01.95668E
test88	31:12:52.30000N	125:28:47.50000E	2.0	277.0	31:13:06.93605N	125:26:28.60187E
test89	31:12:52.30000N	125:28:47.50000E	3000.0	90.0	19:27:03.05786N	179:41:20.83695E
test90	31:12:52.30000N	125:28:47.50000E	3000.0	0.0	81:07:29.93181N	125:28:47.50000E
test91	31:12:52.30000N	125:28:47.50000E	3000.0	180.0	18:59:46.09922S	125:28:47.50000E
test92	31:12:52.30000N	125:28:47.50000E	3000.0	270.0	19:27:03.05786N	71:16:14.16305E

test93	31:12:52.30000N	125:28:47.50000E	3000.0	46.0	52:04:30.90569N	171:09:46.53647W
test94	31:12:52.30000N	125:28:47.50000E	3000.0	127.0	3:37:54.96189S	163:12:50.99996E
test95	31:12:52.30000N	125:28:47.50000E	3000.0	199.0	16:50:15.39672S	110:24:43.33889E
test96	31:12:52.30000N	125:28:47.50000E	3000.0	277.0	24:24:11.81091N	69:01:02.24210E
test97	49:10:24.50000S	75:12:45.60000W	200.0	90.0	49:03:42.87631S	70:08:25.93407W
test98	49:10:24.50000S	75:12:45.60000W	200.0	0.0	45:50:31.05302S	75:12:45.60000W
test99	49:10:24.50000S	75:12:45.60000W	200.0	180.0	52:30:11.00366S	75:12:45.60000W
test100	49:10:24.50000S	75:12:45.60000W	200.0	270.0	49:03:42.87631S	80:17:05.26593W
test101	49:10:24.50000S	75:12:45.60000W	200.0	46.0	46:48:17.31010S	71:43:18.85029W
test102	49:10:24.50000S	75:12:45.60000W	200.0	127.0	51:06:09.21946S	70:59:16.31551W
test103	49:10:24.50000S	75:12:45.60000W	200.0	199.0	52:18:31.88478S	76:58:48.10816W
test104	49:10:24.50000S	75:12:45.60000W	200.0	277.0	48:39:31.53843S	80:12:23.46911W
test105	49:10:24.50000S	75:12:45.60000W	2.0	90.0	49:10:24.45978S	75:09:42.72995W
test106	49:10:24.50000S	75:12:45.60000W	2.0	0.0	49:08:24.60011S	75:12:45.60000W
test107	49:10:24.50000S	75:12:45.60000W	2.0	180.0	49:12:24.39920S	75:12:45.60000W
test108	49:10:24.50000S	75:12:45.60000W	2.0	270.0	49:10:24.45978S	75:15:48.47005W
test109	49:10:24.50000S	75:12:45.60000W	2.0	46.0	49:09:01.18981S	75:10:34.11555W
test110	49:10:24.50000S	75:12:45.60000W	2.0	127.0	49:11:36.63156S	75:10:19.49448W
test111	49:10:24.50000S	75:12:45.60000W	2.0	199.0	49:12:17.86267S	75:13:45.17447W
test112	49:10:24.50000S	75:12:45.60000W	2.0	277.0	49:10:09.84830S	75:15:47.09213W
test113	49:10:24.50000S	75:12:45.60000W	3000.0	90.0	29:08:15.41939S	14:06:51.81153W
test114	49:10:24.50000S	75:12:45.60000W	3000.0	0.0	0:58:06.24146N	75:12:45.60000W
test115	49:10:24.50000S	75:12:45.60000W	3000.0	180.0	81:01:11.20478S	104:47:14.40000E
test116	49:10:24.50000S	75:12:45.60000W	3000.0	270.0	29:08:15.41939S	136:18:39.38847W
test117	49:10:24.50000S	75:12:45.60000W	3000.0	46.0	7:52:38.83544S	41:28:29.05694W
test118	49:10:24.50000S	75:12:45.60000W	3000.0	127.0	52:04:51.42106S	7:52:24.35518E
test119	49:10:24.50000S	75:12:45.60000W	3000.0	199.0	73:51:36.66725S	168:08:53.56896E
test120	49:10:24.50000S	75:12:45.60000W	3000.0	277.0	25:11:20.18815S	132:13:38.05215W
test121	43:10:45.70000S	123:42:43.40000W	200.0	90.0	43:05:19.50216S	119:09:38.75232W
test122	43:10:45.70000S	123:42:43.40000W	200.0	0.0	39:50:39.63379S	123:42:43.40000W
test123	43:10:45.70000S	123:42:43.40000W	200.0	180.0	46:30:44.75296S	123:42:43.40000W
test124	43:10:45.70000S	123:42:43.40000W	200.0	270.0	43:05:19.50216S	128:15:48.04768W
test125	43:10:45.70000S	123:42:43.40000W	200.0	46.0	40:49:05.78329S	120:33:14.53881W
test126	43:10:45.70000S	123:42:43.40000W	200.0	127.0	45:07:29.89631S	119:57:05.47191W
test127	43:10:45.70000S	123:42:43.40000W	200.0	199.0	46:19:13.99376S	125:16:37.84869W
test128	43:10:45.70000S	123:42:43.40000W	200.0	277.0	42:41:04.43281S	128:11:59.62018W
test129	43:10:45.70000S	123:42:43.40000W	2.0	90.0	43:10:45.66735S	123:39:59.39209W
test130	43:10:45.70000S	123:42:43.40000W	2.0	0.0	43:08:45.67398S	123:42:43.40000W
test131	43:10:45.70000S	123:42:43.40000W	2.0	180.0	43:12:45.72532S	123:42:43.40000W
test132	43:10:45.70000S	123:42:43.40000W	2.0	270.0	43:10:45.66735S	123:45:27.40791W
test133	43:10:45.70000S	123:42:43.40000W	2.0	46.0	43:09:22.30610S	123:40:45.46715W
test134	43:10:45.70000S	123:42:43.40000W	2.0	127.0	43:11:57.91229S	123:40:32.37455W
test135	43:10:45.70000S	123:42:43.40000W	2.0	199.0	43:12:39.18273S	123:43:36.82325W
test136	43:10:45.70000S	123:42:43.40000W	2.0	277.0	43:10:31.04038S	123:45:26.17463W
test137	43:10:45.70000S	123:42:43.40000W	3000.0	90.0	26:06:37.08296S	65:19:15.88930W
test138	43:10:45.70000S	123:42:43.40000W	3000.0	0.0	6:59:37.06995N	123:42:43.40000W
test139	43:10:45.70000S	123:42:43.40000W	3000.0	180.0	86:59:08.38590S	56:17:16.60000E
test140	43:10:45.70000S	123:42:43.40000W	3000.0	270.0	26:06:37.08296S	177:53:49.08930E

test141	43:10:45.70000S	123:42:43.40000W	3000.0	46.0	2:51:33.84923S	90:17:19.02340W
test142	43:10:45.70000S	123:42:43.40000W	3000.0	127.0	50:58:42.47481S	48:01:25.22327W
test143	43:10:45.70000S	123:42:43.40000W	3000.0	199.0	75:32:45.23169S	140:44:35.89858E
test144	43:10:45.70000S	123:42:43.40000W	3000.0	277.0	21:49:17.43560S	178:34:03.34260W
test145	30:13:55.50000S	54:53:17.40000E	200.0	90.0	30:10:32.24599S	58:44:04.46955E
test146	30:13:55.50000S	54:53:17.40000E	200.0	0.0	26:53:23.96278S	54:53:17.40000E
test147	30:13:55.50000S	54:53:17.40000E	200.0	180.0	33:34:20.90547S	54:53:17.40000E
test148	30:13:55.50000S	54:53:17.40000E	200.0	270.0	30:10:32.24599S	51:02:30.33045E
test149	30:13:55.50000S	54:53:17.40000E	200.0	46.0	27:52:57.82170S	57:35:36.72392E
test150	30:13:55.50000S	54:53:17.40000E	200.0	127.0	32:12:18.30198S	58:01:31.85506E
test151	30:13:55.50000S	54:53:17.40000E	200.0	199.0	33:23:02.92727S	53:35:33.92865E
test152	30:13:55.50000S	54:53:17.40000E	200.0	277.0	29:46:10.92312S	51:05:09.54001E
test153	30:13:55.50000S	54:53:17.40000E	2.0	90.0	30:13:55.47966S	54:55:35.92341E
test154	30:13:55.50000S	54:53:17.40000E	2.0	0.0	30:11:55.21431S	54:53:17.40000E
test155	30:13:55.50000S	54:53:17.40000E	2.0	180.0	30:15:55.78508S	54:53:17.40000E
test156	30:13:55.50000S	54:53:17.40000E	2.0	270.0	30:13:55.47966S	54:50:58.87659E
test157	30:13:55.50000S	54:53:17.40000E	2.0	46.0	30:12:31.93209S	54:54:57.02201E
test158	30:13:55.50000S	54:53:17.40000E	2.0	127.0	30:15:07.87646S	54:55:08.05224E
test159	30:13:55.50000S	54:53:17.40000E	2.0	199.0	30:15:49.22963S	54:52:32.28676E
test160	30:13:55.50000S	54:53:17.40000E	2.0	277.0	30:13:40.82086S	54:50:59.91478E
test161	30:13:55.50000S	54:53:17.40000E	3000.0	90.0	18:52:29.86498S	108:49:20.15190E
test162	30:13:55.50000S	54:53:17.40000E	3000.0	0.0	19:58:48.22673N	54:53:17.40000E
test163	30:13:55.50000S	54:53:17.40000E	3000.0	180.0	80:08:58.44983S	54:53:17.40000E
test164	30:13:55.50000S	54:53:17.40000E	3000.0	270.0	18:52:29.86498S	0:57:14.64810E
test165	30:13:55.50000S	54:53:17.40000E	3000.0	46.0	7:58:13.96628N	88:37:37.35172E
test166	30:13:55.50000S	54:53:17.40000E	3000.0	127.0	46:16:23.75384S	116:51:12.92431E
test167	30:13:55.50000S	54:53:17.40000E	3000.0	199.0	71:41:54.15847S	2:36:27.57861E
test168	30:13:55.50000S	54:53:17.40000E	3000.0	277.0	14:01:56.87883S	3:23:24.56420E
test169	71:03:45.50000S	155:13:37.40000E	200.0	90.0	70:47:04.46404S	165:21:13.27121E
test170	71:03:45.50000S	155:13:37.40000E	200.0	0.0	67:44:32.20108S	155:13:37.40000E
test171	71:03:45.50000S	155:13:37.40000E	200.0	180.0	74:22:54.50904S	155:13:37.40000E
test172	71:03:45.50000S	155:13:37.40000E	200.0	270.0	70:47:04.46404S	145:06:01.52879E
test173	71:03:45.50000S	155:13:37.40000E	200.0	46.0	68:37:38.70618S	161:47:11.03268E
test174	71:03:45.50000S	155:13:37.40000E	200.0	127.0	72:51:42.35787S	164:14:58.08728E
test175	71:03:45.50000S	155:13:37.40000E	200.0	199.0	74:09:55.67082S	151:16:06.01068E
test176	71:03:45.50000S	155:13:37.40000E	200.0	277.0	70:23:23.03906S	145:22:23.31016E
test177	71:03:45.50000S	155:13:37.40000E	2.0	90.0	71:03:45.39916S	155:19:45.39068E
test178	71:03:45.50000S	155:13:37.40000E	2.0	0.0	71:01:45.98931S	155:13:37.40000E
test179	71:03:45.50000S	155:13:37.40000E	2.0	180.0	71:05:45.01026S	155:13:37.40000E
test180	71:03:45.50000S	155:13:37.40000E	2.0	270.0	71:03:45.39916S	155:07:29.40932E
test181	71:03:45.50000S	155:13:37.40000E	2.0	46.0	71:02:22.42883S	155:18:01.80054E
test182	71:03:45.50000S	155:13:37.40000E	2.0	127.0	71:04:57.35874S	155:18:31.58931E
test183	71:03:45.50000S	155:13:37.40000E	2.0	199.0	71:05:38.48847S	155:11:37.40237E
test184	71:03:45.50000S	155:13:37.40000E	2.0	277.0	71:03:30.83602S	155:07:32.22736E
test185	71:03:45.50000S	155:13:37.40000E	3000.0	90.0	37:33:28.76348S	130:07:28.60879W
test186	71:03:45.50000S	155:13:37.40000E	3000.0	0.0	21:04:35.11214S	155:13:37.40000E
test187	71:03:45.50000S	155:13:37.40000E	3000.0	180.0	59:09:32.80147S	24:46:22.60000W
test188	71:03:45.50000S	155:13:37.40000E	3000.0	270.0	37:33:28.76348S	80:34:43.40879E

test189	71:03:45.50000S	155:13:37.40000E	3000.0	46.0	25:50:57.88581S	167:05:40.45264W
test190	71:03:45.50000S	155:13:37.40000E	3000.0	127.0	49:25:34.58238S	94:31:25.79851W
test191	71:03:45.50000S	155:13:37.40000E	3000.0	199.0	57:40:40.95961S	2:56:35.65351E
test192	71:03:45.50000S	155:13:37.40000E	3000.0	277.0	35:23:25.31483S	86:40:04.05968E

WGS84 Inverse Test Results

Test Identifier	Starting Latitude	Starting Longitude	Destination Latitude	Destination Longitude	Computed Azimuth (degrees)	Computed Reverse Azimuth (degrees)	Computed Distance NM)
test1	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	65:52:03.22158W	90.00000	272.80147	200.00000
test2	40:10:24.50000N	70:12:45.60000W	43:30:29.87690N	70:12:45.60000W	0.00000	180.00000	200.00000
test3	40:10:24.50000N	70:12:45.60000W	36:50:12.19034N	70:12:45.60000W	180.00000	0.00000	200.00000
test4	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	74:33:27.97842W	270.00000	87.19853	200.00000
test5	40:10:24.50000N	70:12:45.60000W	42:26:44.93817N	66:58:26.80185W	46.00000	228.13861	200.00000
test6	40:10:24.50000N	70:12:45.60000W	38:06:56.47029N	66:50:21.71131W	127.00000	309.13021	200.00000
test7	40:10:24.50000N	70:12:45.60000W	37:00:37.63806N	71:34:01.15378W	199.00000	18.15487	200.00000
test8	40:10:24.50000N	70:12:45.60000W	40:29:56.05779N	74:33:04.77416W	277.00000	94.19092	200.00000
test9	40:10:24.50000N	70:12:45.60000W	40:10:24.47060N	70:10:09.05140W	90.00000	270.02805	2.00000
test10	40:10:24.50000N	70:12:45.60000W	40:12:24.58831N	70:12:45.60000W	0.00000	180.00000	2.00000
test11	40:10:24.50000N	70:12:45.60000W	40:08:24.41100N	70:12:45.60000W	180.00000	0.00000	2.00000
test12	40:10:24.50000N	70:12:45.60000W	40:10:24.47060N	70:15:22.14860W	270.00000	89.97195	2.00000
test13	40:10:24.50000N	70:12:45.60000W	40:11:47.90520N	70:10:52.95004W	46.00000	226.02019	2.00000
test14	40:10:24.50000N	70:12:45.60000W	40:09:12.20998N	70:10:40.61155W	127.00000	307.02239	2.00000
test15	40:10:24.50000N	70:12:45.60000W	40:08:30.95052N	70:13:36.54366W	199.00000	18.99087	2.00000
test16	40:10:24.50000N	70:12:45.60000W	40:10:39.10616N	70:15:20.99098W	277.00000	96.97215	2.00000
test17	40:10:24.50000N	70:12:45.60000W	24:30:24.17902N	13:01:17.08239W	90.00000	302.81413	3000.00000
test18	40:10:24.50000N	70:12:45.60000W	89:58:28.94717N	109:47:14.40000E	0.00000	0.00000	3000.00000
test19	40:10:24.50000N	70:12:45.60000W	10:00:44.08298S	70:12:45.60000W	180.00000	0.00000	3000.00000
test20	40:10:24.50000N	70:12:45.60000W	24:30:24.17902N	127:24:14.11761W	270.00000	57.18587	3000.00000
test21	40:10:24.50000N	70:12:45.60000W	55:17:03.30750N	4:30:00.21623E	46.00000	285.35933	3000.00000
test22	40:10:24.50000N	70:12:45.60000W	3:28:31.38990N	32:28:57.95936W	127.00000	322.25100	3000.00000
test23	40:10:24.50000N	70:12:45.60000W	8:09:04.17050S	84:46:29.97795W	199.00000	14.57444	3000.00000
test24	40:10:24.50000N	70:12:45.60000W	29:06:16.65778N	130:30:47.88401W	277.00000	60.28734	3000.00000
test25	50:10:52.50000N	123:06:57.10000W	50:03:56.42973N	117:56:18.19536W	90.00000	273.97445	200.00000
test26	50:10:52.50000N	123:06:57.10000W	53:30:36.93183N	123:06:57.10000W	0.00000	180.00000	200.00000
test27	50:10:52.50000N	123:06:57.10000W	46:51:01.16657N	123:06:57.10000W	180.00000	0.00000	200.00000
test28	50:10:52.50000N	123:06:57.10000W	50:03:56.42973N	128:17:36.00464W	270.00000	86.02555	200.00000
test29	50:10:52.50000N	123:06:57.10000W	52:25:49.36941N	119:11:51.80053W	46.00000	229.05914	200.00000
test30	50:10:52.50000N	123:06:57.10000W	48:06:24.18375N	119:08:33.75213W	127.00000	310.00613	200.00000
test31	50:10:52.50000N	123:06:57.10000W	47:01:13.78683N	124:42:04.78016W	199.00000	17.81022	200.00000
test32	50:10:52.50000N	123:06:57.10000W	50:28:19.21956N	128:17:55.21964W	277.00000	93.00968	200.00000
test33	50:10:52.50000N	123:06:57.10000W	50:10:52.45833N	123:03:50.41132W	90.00000	270.03983	2.00000
test34	50:10:52.50000N	123:06:57.10000W	50:12:52.37823N	123:06:57.10000W	0.00000	180.00000	2.00000
test35	50:10:52.50000N	123:06:57.10000W	50:08:52.62108N	123:06:57.10000W	180.00000	0.00000	2.00000
test36	50:10:52.50000N	123:06:57.10000W	50:10:52.45833N	123:10:03.78868W	270.00000	89.96017	2.00000
test37	50:10:52.50000N	123:06:57.10000W	50:12:15.75291N	123:04:42.74250W	46.00000	226.02867	2.00000
test38	50:10:52.50000N	123:06:57.10000W	50:09:40.32859N	123:04:28.06612W	127.00000	307.03179	2.00000
test39	50:10:52.50000N	123:06:57.10000W	50:08:59.14786N	123:07:57.83998W	199.00000	18.98704	2.00000
test40	50:10:52.50000N	123:06:57.10000W	50:11:07.06846N	123:10:02.41284W	277.00000	96.96046	2.00000
test41	50:10:52.50000N	123:06:57.10000W	29:37:18.55208N	61:31:12.91277W	90.00000	312.48202	3000.00000
test42	50:10:52.50000N	123:06:57.10000W	80:00:57.51620N	56:53:02.90000E	0.00000	360.00000	3000.00000
test43	50:10:52.50000N	123:06:57.10000W	0:02:43.03479N	123:06:57.10000W	180.00000	0.00000	3000.00000
test44	50:10:52.50000N	123:06:57.10000W	29:37:18.55208N	175:17:18.71277E	270.00000	47.51798	3000.00000

test45	50:10:52.50000N	123:06:57.10000W	56:40:22.79938N	33:42:20.71403W	46.00000	303.05928	3000.00000
test46	50:10:52.50000N	123:06:57.10000W	11:23:14.37898N	84:34:26.55554W	127.00000	328.48986	3000.00000
test47	50:10:52.50000N	123:06:57.10000W	1:35:14.22889N	137:32:13.52544W	199.00000	12.06222	3000.00000
test48	50:10:52.50000N	123:06:57.10000W	33:39:39.03338N	171:08:27.87014E	277.00000	49.84895	3000.00000
test49	42:44:32.10000N	66:27:19.60000E	42:39:10.81410N	70:58:29.15259E	90.00000	273.06555	200.00000
test50	42:44:32.10000N	66:27:19.60000E	46:04:32.07438N	66:27:19.60000E	360.00000	180.00000	200.00000
test51	42:44:32.10000N	66:27:19.60000E	39:24:25.11928N	66:27:19.60000E	180.00000	0.00000	200.00000
test52	42:44:32.10000N	66:27:19.60000E	42:39:10.81410N	61:56:10.04741E	270.00000	86.93445	200.00000
test53	42:44:32.10000N	66:27:19.60000E	45:00:33.43147N	69:50:07.10761E	46.00000	228.34339	200.00000
test54	42:44:32.10000N	66:27:19.60000E	40:40:50.71563N	69:57:17.17656E	127.00000	309.32917	200.00000
test55	42:44:32.10000N	66:27:19.60000E	39:34:47.61048N	65:03:08.96220E	199.00000	18.07623	200.00000
test56	42:44:32.10000N	66:27:19.60000E	43:03:35.51327N	61:56:24.98803E	277.00000	93.92550	200.00000
test57	42:44:32.10000N	66:27:19.60000E	42:44:32.06784N	66:30:02.45101E	90.00000	270.03070	2.00000
test58	42:44:32.10000N	66:27:19.60000E	42:46:32.13452N	66:27:19.60000E	360.00000	180.00000	2.00000
test59	42:44:32.10000N	66:27:19.60000E	42:42:32.06478N	66:27:19.60000E	180.00000	0.00000	2.00000
test60	42:44:32.10000N	66:27:19.60000E	42:44:32.06784N	66:24:36.74899E	270.00000	89.96930	2.00000
test61	42:44:32.10000N	66:27:19.60000E	42:45:55.46641N	66:29:16.78884E	46.00000	226.02210	2.00000
test62	42:44:32.10000N	66:27:19.60000E	42:43:19.84058N	66:29:29.61668E	127.00000	307.02451	2.00000
test63	42:44:32.10000N	66:27:19.60000E	42:42:38.60108N	66:26:26.60774E	199.00000	18.99001	2.00000
test64	42:44:32.10000N	66:27:19.60000E	42:44:46.69688N	66:24:37.95230E	277.00000	96.96952	2.00000
test65	42:44:32.10000N	66:27:19.60000E	25:52:49.48262N	124:39:55.85184E	90.00000	305.21226	3000.00000
test66	42:44:32.10000N	66:27:19.60000E	87:25:13.54228N	113:32:40.40000W	360.00000	0.00000	3000.00000
test67	42:44:32.10000N	66:27:19.60000E	7:25:57.78702S	66:27:19.60000E	180.00000	0.00000	3000.00000
test68	42:44:32.10000N	66:27:19.60000E	25:52:49.48262N	8:14:43.34816E	270.00000	54.78774	3000.00000
test69	42:44:32.10000N	66:27:19.60000E	55:52:47.54426N	144:47:50.12500E	46.00000	289.76179	3000.00000
test70	42:44:32.10000N	66:27:19.60000E	5:30:44.95719N	104:18:35.77997E	127.00000	323.83257	3000.00000
test71	42:44:32.10000N	66:27:19.60000E	5:39:14.93608S	51:58:13.27568E	199.00000	13.92399	3000.00000
test72	42:44:32.10000N	66:27:19.60000E	30:21:08.45258N	4:52:35.40656E	277.00000	57.70460	3000.00000
test73	31:12:52.30000N	125:28:47.50000E	31:09:21.00038N	129:21:55.26637E	90.00000	272.01250	200.00000
test74	31:12:52.30000N	125:28:47.50000E	34:33:15.83037N	125:28:47.50000E	0.00000	180.00000	200.00000
test75	31:12:52.30000N	125:28:47.50000E	27:52:22.52362N	125:28:47.50000E	180.00000	360.00000	200.00000
test76	31:12:52.30000N	125:28:47.50000E	31:09:21.00038N	121:35:39.73363E	270.00000	87.98750	200.00000
test77	31:12:52.30000N	125:28:47.50000E	33:30:10.60726N	128:20:48.89100E	46.00000	227.53504	200.00000
test78	31:12:52.30000N	125:28:47.50000E	29:10:03.77133N	128:31:13.43437E	127.00000	308.52956	200.00000
test79	31:12:52.30000N	125:28:47.50000E	28:02:57.01708N	124:15:14.09016E	199.00000	18.39361	200.00000
test80	31:12:52.30000N	125:28:47.50000E	31:33:48.07660N	121:36:24.04854E	277.00000	94.98210	200.00000
test81	31:12:52.30000N	125:28:47.50000E	31:12:52.27886N	125:31:07.43524E	90.00000	270.02014	2.00000
test82	31:12:52.30000N	125:28:47.50000E	31:14:52.56685N	125:28:47.50000E	0.00000	180.00000	2.00000
test83	31:12:52.30000N	125:28:47.50000E	31:10:52.03253N	125:28:47.50000E	180.00000	360.00000	2.00000
test84	31:12:52.30000N	125:28:47.50000E	31:12:52.27886N	125:26:27.56476E	270.00000	89.97986	2.00000
test85	31:12:52.30000N	125:28:47.50000E	31:14:15.83349N	125:30:28.18558E	46.00000	226.01450	2.00000
test86	31:12:52.30000N	125:28:47.50000E	31:11:39.90782N	125:30:39.23361E	127.00000	307.01608	2.00000
test87	31:12:52.30000N	125:28:47.50000E	31:10:58.58265N	125:28:01.95668E	199.00000	18.99345	2.00000
test88	31:12:52.30000N	125:28:47.50000E	31:13:06.93605N	125:26:28.60187E	277.00000	96.98000	2.00000
test89	31:12:52.30000N	125:28:47.50000E	19:27:03.05786N	179:41:20.83695E	90.00000	294.84102	3000.00000
test90	31:12:52.30000N	125:28:47.50000E	81:07:29.93181N	125:28:47.50000E	0.00000	180.00000	3000.00000
test91	31:12:52.30000N	125:28:47.50000E	18:59:46.09922S	125:28:47.50000E	180.00000	360.00000	3000.00000
test92	31:12:52.30000N	125:28:47.50000E	19:27:03.05786N	71:16:14.16305E	270.00000	65.15898	3000.00000

test93	31:12:52.30000N	125:28:47.50000E	52:04:30.90569N	171:09:46.53647W	46.00000	271.27816	3000.00000
test94	31:12:52.30000N	125:28:47.50000E	3:37:54.96189S	163:12:50.99996E	127.00000	316.76433	3000.00000
test95	31:12:52.30000N	125:28:47.50000E	16:50:15.39672S	110:24:43.33889E	199.00000	16.92311	3000.00000
test96	31:12:52.30000N	125:28:47.50000E	24:24:11.81091N	69:01:02.24210E	277.00000	68.81857	3000.00000
test97	49:10:24.50000S	75:12:45.60000W	49:03:42.87631S	70:08:25.93407W	90.00000	266.16411	200.00000
test98	49:10:24.50000S	75:12:45.60000W	45:50:31.05302S	75:12:45.60000W	0.00000	180.00000	200.00000
test99	49:10:24.50000S	75:12:45.60000W	52:30:11.00366S	75:12:45.60000W	180.00000	0.00000	200.00000
test100	49:10:24.50000S	75:12:45.60000W	49:03:42.87631S	80:17:05.26593W	270.00000	93.83589	200.00000
test101	49:10:24.50000S	75:12:45.60000W	46:48:17.31010S	71:43:18.85029W	46.00000	223.40538	200.00000
test102	49:10:24.50000S	75:12:45.60000W	51:06:09.21946S	70:59:16.31551W	127.00000	303.75602	200.00000
test103	49:10:24.50000S	75:12:45.60000W	52:18:31.88478S	76:58:48.10816W	199.00000	20.36902	200.00000
test104	49:10:24.50000S	75:12:45.60000W	48:39:31.53843S	80:12:23.46911W	277.00000	100.76518	200.00000
test105	49:10:24.50000S	75:12:45.60000W	49:10:24.45978S	75:09:42.72995W	90.00000	269.96156	2.00000
test106	49:10:24.50000S	75:12:45.60000W	49:08:24.60011S	75:12:45.60000W	0.00000	180.00000	2.00000
test107	49:10:24.50000S	75:12:45.60000W	49:12:24.39920S	75:12:45.60000W	180.00000	0.00000	2.00000
test108	49:10:24.50000S	75:12:45.60000W	49:10:24.45978S	75:15:48.47005W	270.00000	90.03844	2.00000
test109	49:10:24.50000S	75:12:45.60000W	49:09:01.18981S	75:10:34.11555W	46.00000	225.97237	2.00000
test110	49:10:24.50000S	75:12:45.60000W	49:11:36.63156S	75:10:19.49448W	127.00000	306.96929	2.00000
test111	49:10:24.50000S	75:12:45.60000W	49:12:17.86267S	75:13:45.17447W	199.00000	19.01253	2.00000
test112	49:10:24.50000S	75:12:45.60000W	49:10:09.84830S	75:15:47.09213W	277.00000	97.03815	2.00000
test113	49:10:24.50000S	75:12:45.60000W	29:08:15.41939S	14:06:51.81153W	90.00000	228.53270	3000.00000
test114	49:10:24.50000S	75:12:45.60000W	0:58:06.24146N	75:12:45.60000W	0.00000	180.00000	3000.00000
test115	49:10:24.50000S	75:12:45.60000W	81:01:11.20478S	104:47:14.40000E	180.00000	180.00000	3000.00000
test116	49:10:24.50000S	75:12:45.60000W	29:08:15.41939S	136:18:39.38847W	270.00000	131.46730	3000.00000
test117	49:10:24.50000S	75:12:45.60000W	7:52:38.83544S	41:28:29.05694W	46.00000	208.40144	3000.00000
test118	49:10:24.50000S	75:12:45.60000W	52:04:51.42106S	7:52:24.35518E	127.00000	238.15368	3000.00000
test119	49:10:24.50000S	75:12:45.60000W	73:51:36.66725S	168:08:53.56896E	199.00000	130.11219	3000.00000
test120	49:10:24.50000S	75:12:45.60000W	25:11:20.18815S	132:13:38.05215W	277.00000	134.10803	3000.00000
test121	43:10:45.70000S	123:42:43.40000W	43:05:19.50216S	119:09:38.75232W	90.00000	266.88737	200.00000
test122	43:10:45.70000S	123:42:43.40000W	39:50:39.63379S	123:42:43.40000W	0.00000	180.00000	200.00000
test123	43:10:45.70000S	123:42:43.40000W	46:30:44.75296S	123:42:43.40000W	180.00000	0.00000	200.00000
test124	43:10:45.70000S	123:42:43.40000W	43:05:19.50216S	128:15:48.04768W	270.00000	93.11263	200.00000
test125	43:10:45.70000S	123:42:43.40000W	40:49:05.78329S	120:33:14.53881W	46.00000	223.88618	200.00000
test126	43:10:45.70000S	123:42:43.40000W	45:07:29.89631S	119:57:05.47191W	127.00000	304.37967	200.00000
test127	43:10:45.70000S	123:42:43.40000W	46:19:13.99376S	125:16:37.84869W	199.00000	20.10232	200.00000
test128	43:10:45.70000S	123:42:43.40000W	42:41:04.43281S	128:11:59.62018W	277.00000	100.05767	200.00000
test129	43:10:45.70000S	123:42:43.40000W	43:10:45.66735S	123:39:59.39209W	90.00000	269.96883	2.00000
test130	43:10:45.70000S	123:42:43.40000W	43:08:45.67398S	123:42:43.40000W	0.00000	180.00000	2.00000
test131	43:10:45.70000S	123:42:43.40000W	43:12:45.72532S	123:42:43.40000W	180.00000	0.00000	2.00000
test132	43:10:45.70000S	123:42:43.40000W	43:10:45.66735S	123:45:27.40791W	270.00000	90.03117	2.00000
test133	43:10:45.70000S	123:42:43.40000W	43:09:22.30610S	123:40:45.46715W	46.00000	225.97759	2.00000
test134	43:10:45.70000S	123:42:43.40000W	43:11:57.91229S	123:40:32.37455W	127.00000	306.97509	2.00000
test135	43:10:45.70000S	123:42:43.40000W	43:12:39.18273S	123:43:36.82325W	199.00000	19.01016	2.00000
test136	43:10:45.70000S	123:42:43.40000W	43:10:31.04038S	123:45:26.17463W	277.00000	97.03094	2.00000
test137	43:10:45.70000S	123:42:43.40000W	26:06:37.08296S	65:19:15.88930W	90.00000	234.37420	3000.00000
test138	43:10:45.70000S	123:42:43.40000W	6:59:37.06995N	123:42:43.40000W	0.00000	180.00000	3000.00000
test139	43:10:45.70000S	123:42:43.40000W	86:59:08.38590S	56:17:16.60000E	180.00000	180.00000	3000.00000
test140	43:10:45.70000S	123:42:43.40000W	26:06:37.08296S	177:53:49.08930E	270.00000	125.62580	3000.00000

test141	43:10:45.70000S	123:42:43.40000W	2:51:33.84923S	90:17:19.02340W	46.00000	211.73748	3000.00000
test142	43:10:45.70000S	123:42:43.40000W	50:58:42.47481S	48:01:25.22327W	127.00000	247.60161	3000.00000
test143	43:10:45.70000S	123:42:43.40000W	75:32:45.23169S	140:44:35.89858E	199.00000	108.26051	3000.00000
test144	43:10:45.70000S	123:42:43.40000W	21:49:17.43560S	178:34:03.34260W	277.00000	128.69292	3000.00000
test145	30:13:55.50000S	54:53:17.40000E	30:10:32.24599S	58:44:04.46955E	90.00000	268.06441	200.00000
test146	30:13:55.50000S	54:53:17.40000E	26:53:23.96278S	54:53:17.40000E	0.00000	180.00000	200.00000
test147	30:13:55.50000S	54:53:17.40000E	33:34:20.90547S	54:53:17.40000E	180.00000	360.00000	200.00000
test148	30:13:55.50000S	54:53:17.40000E	30:10:32.24599S	51:02:30.33045E	270.00000	91.93559	200.00000
test149	30:13:55.50000S	54:53:17.40000E	27:52:57.82170S	57:35:36.72392E	46.00000	224.68558	200.00000
test150	30:13:55.50000S	54:53:17.40000E	32:12:18.30198S	58:01:31.85506E	127.00000	305.37336	200.00000
test151	30:13:55.50000S	54:53:17.40000E	33:23:02.92727S	53:35:33.92865E	199.00000	19.68306	200.00000
test152	30:13:55.50000S	54:53:17.40000E	29:46:10.92312S	51:05:09.54001E	277.00000	98.90168	200.00000
test153	30:13:55.50000S	54:53:17.40000E	30:13:55.47966S	54:55:35.92341E	90.00000	269.98063	2.00000
test154	30:13:55.50000S	54:53:17.40000E	30:11:55.21431S	54:53:17.40000E	0.00000	180.00000	2.00000
test155	30:13:55.50000S	54:53:17.40000E	30:15:55.78508S	54:53:17.40000E	180.00000	360.00000	2.00000
test156	30:13:55.50000S	54:53:17.40000E	30:13:55.47966S	54:50:58.87659E	270.00000	90.01937	2.00000
test157	30:13:55.50000S	54:53:17.40000E	30:12:31.93209S	54:54:57.02201E	46.00000	225.98607	2.00000
test158	30:13:55.50000S	54:53:17.40000E	30:15:07.87646S	54:55:08.05224E	127.00000	306.98452	2.00000
test159	30:13:55.50000S	54:53:17.40000E	30:15:49.22963S	54:52:32.28676E	199.00000	19.00631	2.00000
test160	30:13:55.50000S	54:53:17.40000E	30:13:40.82086S	54:50:59.91478E	277.00000	97.01923	2.00000
test161	30:13:55.50000S	54:53:17.40000E	18:52:29.86498S	108:49:20.15190E	90.00000	246.00043	3000.00000
test162	30:13:55.50000S	54:53:17.40000E	19:58:48.22673N	54:53:17.40000E	0.00000	180.00000	3000.00000
test163	30:13:55.50000S	54:53:17.40000E	80:08:58.44983S	54:53:17.40000E	180.00000	0.00000	3000.00000
test164	30:13:55.50000S	54:53:17.40000E	18:52:29.86498S	0:57:14.64810E	270.00000	113.99957	3000.00000
test165	30:13:55.50000S	54:53:17.40000E	7:58:13.96628N	88:37:37.35172E	46.00000	218.90713	3000.00000
test166	30:13:55.50000S	54:53:17.40000E	46:16:23.75384S	116:51:12.92431E	127.00000	265.83428	3000.00000
test167	30:13:55.50000S	54:53:17.40000E	71:41:54.15847S	2:36:27.57861E	199.00000	63.35732	3000.00000
test168	30:13:55.50000S	54:53:17.40000E	14:01:56.87883S	3:23:24.56420E	277.00000	117.80900	3000.00000
test169	71:03:45.50000S	155:13:37.40000E	70:47:04.46404S	165:21:13.27121E	90.00000	260.42680	200.00000
test170	71:03:45.50000S	155:13:37.40000E	67:44:32.20108S	155:13:37.40000E	360.00000	180.00000	200.00000
test171	71:03:45.50000S	155:13:37.40000E	74:22:54.50904S	155:13:37.40000E	180.00000	360.00000	200.00000
test172	71:03:45.50000S	155:13:37.40000E	70:47:04.46404S	145:06:01.52879E	270.00000	99.57320	200.00000
test173	71:03:45.50000S	155:13:37.40000E	68:37:38.70618S	161:47:11.03268E	46.00000	219.84014	200.00000
test174	71:03:45.50000S	155:13:37.40000E	72:51:42.35787S	164:14:58.08728E	127.00000	298.41826	200.00000
test175	71:03:45.50000S	155:13:37.40000E	74:09:55.67082S	151:16:06.01068E	199.00000	22.77938	200.00000
test176	71:03:45.50000S	155:13:37.40000E	70:23:23.03906S	145:22:23.31016E	277.00000	106.30428	200.00000
test177	71:03:45.50000S	155:13:37.40000E	71:03:45.39916S	155:19:45.39068E	90.00000	269.90331	2.00000
test178	71:03:45.50000S	155:13:37.40000E	71:01:45.98931S	155:13:37.40000E	360.00000	180.00000	2.00000
test179	71:03:45.50000S	155:13:37.40000E	71:05:45.01026S	155:13:37.40000E	180.00000	0.00000	2.00000
test180	71:03:45.50000S	155:13:37.40000E	71:03:45.39916S	155:07:29.40932E	270.00000	90.09669	2.00000
test181	71:03:45.50000S	155:13:37.40000E	71:02:22.42883S	155:18:01.80054E	46.00000	225.93054	2.00000
test182	71:03:45.50000S	155:13:37.40000E	71:04:57.35874S	155:18:31.58931E	127.00000	306.92270	2.00000
test183	71:03:45.50000S	155:13:37.40000E	71:05:38.48847S	155:11:37.40237E	199.00000	19.03153	2.00000
test184	71:03:45.50000S	155:13:37.40000E	71:03:30.83602S	155:07:32.22736E	277.00000	97.09595	2.00000
test185	71:03:45.50000S	155:13:37.40000E	37:33:28.76348S	130:07:28.60879W	90.00000	204.21144	3000.00000
test186	71:03:45.50000S	155:13:37.40000E	21:04:35.11214S	155:13:37.40000E	360.00000	180.00000	3000.00000
test187	71:03:45.50000S	155:13:37.40000E	59:09:32.80147S	24:46:22.60000W	180.00000	180.00000	3000.00000
test188	71:03:45.50000S	155:13:37.40000E	37:33:28.76348S	80:34:43.40879E	270.00000	155.78856	3000.00000

test189	71:03:45.50000S	155:13:37.40000E	25:50:57.88581S	167:05:40.45264W	46.00000	195.07128	3000.00000
test190	71:03:45.50000S	155:13:37.40000E	49:25:34.58238S	94:31:25.79851W	127.00000	203.51009	3000.00000
test191	71:03:45.50000S	155:13:37.40000E	57:40:40.95961S	2:56:35.65351E	199.00000	168.59567	3000.00000
test192	71:03:45.50000S	155:13:37.40000E	35:23:25.31483S	86:40:04.05968E	277.00000	156.67990	3000.00000

Test Identifier	Geodesic Start Point Latitude	Geodesic Start Point Longitude	Geodesic End Point Latitude	Geodesic End Point Longitude	Test Point Latitude	Test Point Longitude	Length Code	Result
test1	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	41:32:28.56417N	68:47:19.47018W	0	1
test2	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	42:04:35.80000N	68:12:34.70000W	0	1
test3	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	41:47:53.25338N	68:30:44.96922W	0	1
test4	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	41:26:00.91053N	68:54:13.28237W	0	1
test5	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	41:09:22.65915N	69:11:50.60000W	0	1
test6	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	0	1
test7	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	0	1
test8	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:09:22.65915N	69:11:50.60000W	0	1
test9	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	40:10:24.50000N	70:12:45.60000W	0	1
test10	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	38:47:17.80000N	69:11:50.60000W	0	0
test11	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	39:35:17.80000N	69:11:50.60000W	0	0
test12	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	44:47:17.80000N	69:11:50.60000W	0	0
test13	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	41:47:17.80000N	68:11:50.60000E	0	0
test14	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	42:04:35.80000N	70:12:34.70000E	0	1
test15	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	41:47:18.13124N	69:53:49.92815E	0	1
test16	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:29:59.59453N	68:32:40.35274E	0	1
test17	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:29:10.95567N	68:31:50.60000E	0	1
test18	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	0	1
test19	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	40:43:56.24806N	68:47:00.28971E	0	1
test20	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:07:48.28268N	69:11:50.60000E	0	1
test21	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	40:10:24.50000N	68:12:45.60000E	0	1
test22	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	40:27:32.30453N	68:30:09.76991E	0	1
test23	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	38:47:17.80000N	72:11:50.60000E	0	0
test24	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	43:47:17.80000N	72:11:50.60000E	0	0
test25	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	40:12:17.80000S	69:11:50.60000W	0	0
test26	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	39:55:35.80000S	68:12:34.70000W	0	1
test27	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	40:12:53.41991S	68:30:06.40714W	0	1
test28	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	40:34:15.03903S	68:52:01.67681W	0	1
test29	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	40:53:18.36384S	69:11:50.60000W	0	1
test30	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	0	1
test31	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	41:50:24.50000S	70:12:45.60000W	0	1
test32	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:53:18.36384S	69:11:50.60000W	0	1
test33	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	41:50:24.50000S	70:12:45.60000W	0	1
test34	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	42:12:17.80000S	69:11:50.60000W	0	0
test35	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	38:12:17.80000S	69:11:50.60000W	0	0
test36	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	43:12:17.80000S	69:11:50.60000W	0	0
test37	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	40:12:17.80000S	68:11:50.60000E	0	0
test38	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	39:55:35.80000S	70:12:34.70000E	0	1
test39	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	40:13:19.06538S	69:54:40.06070E	0	1
test40	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	40:11:49.41238S	69:56:11.14294E	0	1

test41	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	40:54:53.06605S	69:11:50.60000E	0	1
test42	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	0	1
test43	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	0	1
test44	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	41:47:33.72993S	68:15:50.60000E	0	1
test45	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	41:50:24.50000S	68:12:45.60000E	0	1
test46	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	43:29:17.80000S	69:11:50.60000E	0	0
test47	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	38:29:17.80000S	69:11:50.60000E	0	0
test48	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	41:49:17.80000S	69:11:50.60000E	0	0

WGS84PtIsOnArc Test Results

Test Identifier	Arc Center Latitude	Arc Center Longitude	Arc Radius	Arc Start Azimuth	Arc End Azimuth	Arc Direction	Test Point Latitude	Test Point Longitude	Result
test1	40:10:24.50000N	70:12:45.60000W	100.0	90.0	100.0	-1	39:55:12.84696N	68:04:03.03796W	1
test2	40:10:24.50000N	70:12:45.60000W	100.0	100.0	90.0	1	40:04:24.98785N	68:02:37.73455W	1
test3	40:10:24.50000N	70:12:45.60000W	100.0	100.0	90.0	1	40:27:01.27947N	68:03:50.83114W	0
test4	40:10:24.50000N	70:12:45.60000W	100.0	20.0	120.0	-1	39:39:01.64315N	68:09:21.02760W	1
test5	40:10:24.50000N	70:12:45.60000W	100.0	355.0	10.0	-1	41:50:27.82240N	70:11:34.70000W	1
test6	40:10:24.50000N	70:12:45.60000W	100.0	15.0	350.0	1	41:50:27.82240N	70:11:34.70000W	1
test7	40:10:24.50000N	70:12:45.60000W	100.0	15.0	350.0	-1	41:50:27.82240N	70:11:34.70000W	0
test8	40:10:24.50000N	70:12:45.60000W	100.0	250.0	300.0	-1	40:22:32.07141N	72:22:27.11102W	1
test9	40:10:24.50000N	70:12:45.60000W	100.0	330.0	200.0	1	41:12:48.70166N	71:55:32.15119W	1
test10	40:10:24.50000N	70:12:45.60000W	100.0	200.0	230.0	-1	38:51:33.35407N	68:53:10.34405W	0
test11	40:10:24.50000N	70:12:45.60000E	100.0	90.0	100.0	-1	39:57:28.59246N	72:21:55.36432E	1
test12	40:10:24.50000N	70:12:45.60000E	100.0	100.0	90.0	1	40:04:25.10140N	72:22:53.47612E	1
test13	40:10:24.50000N	70:12:45.60000E	100.0	100.0	90.0	1	40:26:53.80980N	72:21:41.88661E	0
test14	40:10:24.50000N	70:12:45.60000E	100.0	20.0	120.0	-1	39:39:10.70047N	72:16:14.18085E	1
test15	40:10:24.50000N	70:12:45.60000E	100.0	355.0	10.0	-1	41:50:27.82240N	70:11:34.70000E	1
test16	40:10:24.50000N	70:12:45.60000E	100.0	15.0	350.0	1	41:50:27.82240N	70:11:34.70000E	1
test17	40:10:24.50000N	70:12:45.60000E	100.0	15.0	350.0	-1	41:50:27.82240N	70:11:34.70000E	0
test18	40:10:24.50000N	70:12:45.60000E	100.0	250.0	300.0	-1	40:22:28.60052N	68:03:03.59248E	1
test19	40:10:24.50000N	70:12:45.60000E	100.0	330.0	200.0	1	41:13:31.30530N	68:30:43.58125E	1
test20	40:10:24.50000N	70:12:45.60000E	100.0	200.0	230.0	-1	39:05:41.34977N	71:51:29.95766E	0
test21	40:10:24.50000S	70:12:45.60000E	100.0	90.0	100.0	-1	40:12:40.39213S	72:23:13.39076E	1
test22	40:10:24.50000S	70:12:45.60000E	100.0	100.0	90.0	1	40:04:25.10140S	72:22:53.47612E	0
test23	40:10:24.50000S	70:12:45.60000E	100.0	100.0	90.0	1	39:39:10.70047S	72:16:14.18085E	0
test24	40:10:24.50000S	70:12:45.60000E	100.0	20.0	120.0	-1	40:26:53.80980S	72:21:41.88661E	1
test25	40:10:24.50000S	70:12:45.60000E	100.0	355.0	10.0	-1	38:30:19.45513S	70:11:34.70000E	1
test26	40:10:24.50000S	70:12:45.60000E	100.0	15.0	350.0	1	38:30:19.45513S	70:11:34.70000E	1
test27	40:10:24.50000S	70:12:45.60000E	100.0	15.0	350.0	-1	38:30:19.45513S	70:11:34.70000E	0
test28	40:10:24.50000S	70:12:45.60000E	100.0	250.0	300.0	-1	40:23:20.88344S	68:03:11.35606E	1
test29	40:10:24.50000S	70:12:45.60000E	100.0	330.0	200.0	1	39:47:33.58163S	68:06:05.87892E	1
test30	40:10:24.50000S	70:12:45.60000E	100.0	200.0	230.0	-1	41:45:30.73148S	70:53:47.69121E	0
test31	40:10:24.50000S	70:12:45.60000W	100.0	90.0	100.0	-1	40:12:32.98018S	68:02:17.71481W	1
test32	40:10:24.50000S	70:12:45.60000W	100.0	100.0	90.0	1	40:04:11.30750S	68:02:39.04105W	0
test33	40:10:24.50000S	70:12:45.60000W	100.0	100.0	90.0	1	39:23:12.36192S	68:18:22.61369W	0
test34	40:10:24.50000S	70:12:45.60000W	100.0	20.0	120.0	-1	40:39:21.80200S	68:07:26.05449W	1
test35	40:10:24.50000S	70:12:45.60000W	100.0	355.0	10.0	-1	38:30:19.45513S	70:11:34.70000W	1
test36	40:10:24.50000S	70:12:45.60000W	100.0	15.0	350.0	1	38:30:19.45513S	70:11:34.70000W	1
test37	40:10:24.50000S	70:12:45.60000W	100.0	15.0	350.0	-1	38:30:19.45513S	70:11:34.70000W	0
test38	40:10:24.50000S	70:12:45.60000W	100.0	250.0	300.0	-1	40:23:44.12558S	72:22:16.19656W	1
test39	40:10:24.50000S	70:12:45.60000W	100.0	330.0	200.0	1	39:54:28.73386S	72:21:18.43758W	1
test40	40:10:24.50000S	70:12:45.60000W	100.0	200.0	230.0	-1	41:29:48.15752S	68:52:34.09229W	0

WGS84PtIsOnLocus Test Results

Test Identifier	Geodesic Start Latitude	Geodesic Start Longitude	Geodesic End Latitude	Geodesic End Longitude	Locus Start Latitude	Locus StarT Longitude	Locus End Latitude	Locus End Longitude	Locus Start Distance (nm)	Locus E nd Distance (mn)	Test Point Latitude	Test Point Longitude	Result
test1	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:05.00782N	70:51:34.00000W	42:55:01.77259N	70:24:20.88368N	-0.5	-0.5	42:55:05.00175N	70:50:23.28330W	1
test2	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:05.00782N	70:51:34.00000W	42:55:01.77259N	70:24:20.88368N	-0.5	-0.5	42:55:05.00771N	70:51:24.71201W	1
test3	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:35.01559N	70:51:34.00000W	42:55:31.77993N	70:24:20.66356N	-1.0	-1.0	42:55:35.00776N	70:50:13.66761W	1
test4	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:52:34.96830N	70:51:34.00000W	42:52:19.73219N	70:24:22.07127N	2.0	2.2	42:52:34.01413N	70:49:26.93090W	1
test5	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:57:35.04624N	70:51:34.00000W	42:53:31.75031N	70:24:21.54367N	-3.0	1.0	42:56:58.69196N	70:47:27.05896W	1
test6	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:50:34.93590N	70:51:34.00000W	42:50:31.70455N	70:24:22.86205N	4.0	4.0	42:50:34.81843N	70:46:22.99515W	1
test7	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:59:35.07618N	70:51:34.00000W	42:59:01.83008N	70:24:19.12109N	-5.0	-4.5	42:59:28.77609N	70:45:58.16124W	1
test8	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:48:34.90279N	70:51:34.00000W	42:48:07.66680N	70:24:23.91522N	6.0	6.4	42:48:27.53797N	70:43:32.97138W	1
test9	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	43:01:35.10543N	70:51:34.00000W	43:01:31.86459N	70:24:18.01754N	-7.0	-7.0	43:01:34.93635N	70:45:20.32134W	1
test10	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:46:34.86899N	70:51:34.00000W	42:53:31.75031N	70:24:21.54367N	8.0	1.0	42:48:36.37428N	70:43:41.44040W	1
test11	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:05.00782N	70:51:34.00000W	42:55:01.77259N	70:24:20.88368N	-0.5	-0.5	42:53:60.00000N	70:50:23.28330W	0
test12	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:46:34.86899N	70:51:34.00000W	42:46:31.64108N	70:24:24.61658N	8.0	8.0	42:42:00.00000N	70:43:42.62942W	0
test13	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:54:04.99214S	70:51:34.00000W	42:54:01.75778S	70:24:21.32373S	-0.5	-0.5	42:54:04.98608S	70:50:23.30236W	1
test14	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:54:04.99214S	70:51:34.00000W	42:54:01.75778S	70:24:21.32373S	-0.5	-0.5	42:54:04.99204S	70:51:24.70232W	1
test15	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:55:35.01559S	70:51:34.00000W	42:55:31.77993S	70:24:20.66356S	1.0	1.0	42:55:35.00776S	70:50:13.66761W	1
test16	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:52:34.96830S	70:51:34.00000W	42:52:19.73219S	70:24:22.07127S	-2.0	-2.2	42:52:34.01413S	70:49:26.93090W	1
test17	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:57:35.04624S	70:51:34.00000W	42:53:31.75031S	70:24:21.54367S	3.0	-1.0	42:56:58.69196S	70:47:27.05896W	1
test18	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:50:34.93590S	70:51:34.00000W	42:50:31.70455S	70:24:22.86205S	-4.0	-4.0	42:50:34.81843S	70:46:22.99515W	1
test19	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:59:35.07618S	70:51:34.00000W	42:59:01.83008S	70:24:19.12109S	5.0	4.5	42:59:28.77609S	70:45:58.16124W	1
test20	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:48:34.90279S	70:51:34.00000W	42:48:07.66680S	70:24:23.91522S	-6.0	-6.4	42:48:27.53797S	70:43:32.97138W	1
test21	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	43:01:35.10543S	70:51:34.00000W	43:01:31.86459S	70:24:18.01754S	7.0	7.0	43:01:34.93635S	70:45:20.32134W	1
test22	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:46:34.86899S	70:51:34.00000W	42:53:31.75031S	70:24:21.54367S	-8.0	-1.0	42:48:36.37428S	70:43:41.44040W	1
test23	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:54:04.99214S	70:51:34.00000W	42:54:01.75778S	70:24:21.32373S	-0.5	-0.5	42:53:60.00000S	70:50:23.30236W	0
test24	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:46:34.86899S	70:51:34.00000W	42:46:31.64108S	70:24:24.61658S	-8.0	-8.0	42:42:00.00000S	70:43:42.62942W	0

WGS84LocusCrsAtPoint Test Results

Test Identifier	Input	Geodesic Start Latitude	Geodesic Start Longitude	Geodesic End Latitude	Geodesic End Longitude	Locus Start Latitude	Locus Start Longitude	Locus End Latitude	Locus End Longitude	Locus Start Distance (nm)	Locus End Distance (nm)	Test Point Latitude	Test Point Longitude
	Output	Geodesic Point Latitude	Geodesic Point Longitude	Locus Azimuth at Test Point (degrees)	Azimuth from Test Point to Geodesic Point (degrees)								
Test1	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:05.00782N	70:51:34.00000W	42:55:01.77259N	70:24:20.88368N	-0.5	-0.5	42:55:05.00175N	70:50:23.28330W
	Output	42:54:34.99393N	70:50:23.29283W	180.01337	90.01337								
Test2	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:05.00782N	70:51:34.00000W	42:55:01.77259N	70:24:20.88368N	-0.5	-0.5	42:55:05.00771N	70:51:24.71201W
	Output	42:54:34.99990N	70:51:24.71327W	180.00176	90.00176								
Test3	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:35.01559N	70:51:34.00000W	42:55:31.77993N	70:24:20.66356N	-1.0	-1.0	42:55:35.00776N	70:50:13.66761W
	Output	42:54:34.99218N	70:50:13.68926W	180.01519	90.01519								
Test4	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:52:34.96830N	70:51:34.00000W	42:52:19.73219N	70:24:22.07127N	2.0	2.2	42:52:34.01413N	70:49:26.93090W
	Output	42:54:34.98039N	70:49:26.86188W	0.59697	90.59697								
Test5	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:57:35.04624N	70:51:34.00000W	42:53:31.75031N	70:24:21.54367N	-3.0	1.0	42:56:58.69196N	70:47:27.05896W
	Output	42:54:34.92612N	70:47:27.21838W	191.35663	101.35663								
Test6	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:50:34.93590N	70:51:34.00000W	42:50:31.70455N	70:24:22.86205N	4.0	4.0	42:50:34.81843N	70:46:22.99515W
	Output	42:54:34.88240N	70:46:22.65989W	0.05882	90.05882								
Test7	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:59:35.07618N	70:51:34.00000W	42:59:01.83008N	70:24:19.12109N	-5.0	-4.5	42:59:28.77609N	70:45:58.16124W
	Output	42:54:34.86353N	70:45:58.60448W	181.49561	91.49561								
Test8	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:48:34.90279N	70:51:34.00000W	42:48:07.66680N	70:24:23.91522N	6.0	6.4	42:48:27.53797N	70:43:32.97138W
	Output	42:54:34.71836N	70:43:32.17826W	1.23674	91.23674								
test9	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	43:01:35.10543N	70:51:34.00000W	43:01:31.86459N	70:24:18.01754N	-7.0	-7.0	43:01:34.93635N	70:45:20.32134W
	Output	42:54:34.83124N	70:45:21.02628W	180.07067	90.07067								

Test10	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:46:34.86899N	70:51:34.00000W	42:53:31.75031N	70:24:21.54367N	8.0	1.0	42:48:36.37428N	70:43:41.44040W
	Output	42:54:34.72821N	70:43:40.67998W	-19.20067	70.79933								
Test11	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:05.00782N	70:51:34.00000W	42:55:01.77259N	70:24:20.88368N	-0.5	-0.5	42:55:05.00175N	70:50:23.28330W
	Output	42:54:34.99393N	70:50:23.29283W	180.01337	90.01337								
Test12	Input	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:46:34.86899N	70:51:34.00000W	42:46:31.64108N	70:24:24.61658N	8.0	8.0	42:46:34.59884N	70:43:42.62942W
	Output	42:54:34.72928N	70:43:41.61315W	0.08915	90.08915								
Test13	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:54:04.99214S	70:51:34.00000W	42:54:01.75778S	70:24:21.32373S	-0.5	-0.5	42:54:04.98608S	70:50:23.30236W
	Output	42:54:34.99393S	70:50:23.29283W	179.98663	89.98663								
Test14	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:54:04.99214S	70:51:34.00000W	42:54:01.75778S	70:24:21.32373S	-0.5	-0.5	42:54:04.99204S	70:51:24.70232W
	Output	42:54:34.99990S	70:51:24.70107W	179.99824	89.99824								
Test15	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:55:35.01559S	70:51:34.00000W	42:55:31.77993S	70:24:20.66356S	1.0	1.0	42:55:35.00776S	70:50:13.66761W
	Output	42:54:34.99218S	70:50:13.68926W	359.98481	89.98481								
Test16	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:52:34.96830S	70:51:34.00000W	42:52:19.73219S	70:24:22.07127S	-2.0	-2.2	42:52:34.01413S	70:49:26.93090W
	Output	42:54:34.98039S	70:49:26.86188W	179.40303	89.40303								
Test17	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:57:35.04624S	70:51:34.00000W	42:53:31.75031S	70:24:21.54367S	3.0	-1.0	42:56:58.69196S	70:47:27.05896W
	Output	42:54:34.92612S	70:47:27.21838W	348.64337	78.64337								
Test18	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:50:34.93590S	70:51:34.00000W	42:50:31.70455S	70:24:22.86205S	-4.0	-4.0	42:50:34.81843S	70:46:22.99515W
	Output	42:54:34.88240S	70:46:22.65989W	179.94118	89.94118								
Test19	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:59:35.07618S	70:51:34.00000W	42:59:01.83008S	70:24:19.12109S	5.0	4.5	42:59:28.77609S	70:45:58.16124W
	Output	42:54:34.86353S	70:45:58.60448W	358.50439	88.50439								
Test20	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	42:48:34.90279S	70:51:34.00000W	42:48:07.66680S	70:24:23.91522S	-6.0	-6.4	42:48:27.53797S	70:43:32.97138W
	Output	42:54:34.71836S	70:43:32.17826W	178.76326	88.76326								
Test21	Input	42:54:35.00000S	70:51:34.00000W	42:54:31.76521S	70:24:21.10373W	43:01:35.10543S	70:51:34.00000W	43:01:31.86459S	70:24:18.01754S	7.0	7.0	43:01:34.93635S	70:45:20.32134W
	Output	42:54:34.83124S	70:45:21.02628W	359.92933	89.92933								
Test22	Inpu	42:54:35.00	70:51:34.000	42:54:31.76	70:24:21.103	42:46:34.86	70:51:34.000	42:53:31.75	70:24:21.54	-8.0	-1.0	42:48:36.37	70:43:41.440

	t	000S	00W	521S	73W	899S	00W	031S	367S			428S	40W
	Outp ut	42:54:34.72 821S	70:43:40.679 98W	199.20067	109.20067								
Test23	Inpu t	42:54:35.00 000S	70:51:34.000 00W	42:54:31.76 521S	70:24:21.103 73W	42:54:04.99 214S	70:51:34.000 00W	42:54:01.75 778S	70:24:21.32 373S	-0.5	-0.5	42:54:04.98 608S	70:50:23.302 36W
	Outp ut	42:54:34.99 393S	70:50:23.292 83W	179.98663	89.98663								
Test24	Inpu t	42:54:35.00 000S	70:51:34.000 00W	42:54:31.76 521S	70:24:21.103 73W	42:46:34.86 899S	70:51:34.000 00W	42:46:31.64 108S	70:24:24.61 658S	-8.0	-8.0	42:46:34.59 884S	70:43:42.629 42W
	Outp ut	42:54:34.72 928S	70:43:41.613 15W	179.91085	89.91085								

WGS84DiscretizedArcLength Test Results

Test Identifier	Arc Center Latitude	Arc Center Longitude	Arc Radius	Start Azimuth	End Azimuth	Direction	Computed Arc Length (nm)	Direct Computation Result (Section 6.4) (nm)	Difference (meters)
test1	38:13:25.10000N	77:54:23.40000W	5.0	91.0	226.0	-1	11.780968	11.780968	1.60e-007
test2	38:13:25.10000N	77:54:23.40000W	5.0	91.0	226.0	1	19.634947	19.634947	2.60e-008
test3	38:13:25.10000N	77:54:23.40000W	5.0	0.0	0.0	1	31.415915	31.415915	2.17e-007
test4	38:13:25.10000N	77:54:23.40000W	50.0	0.0	0.0	1	314.148211	314.148211	2.83e-006
test5	38:13:25.10000N	77:54:23.40000W	100.0	0.0	0.0	1	628.230102	628.230102	4.62e-005
test6	38:13:25.10000N	77:54:23.40000W	150.0	0.0	0.0	1	942.179365	942.179365	3.33e-004
test7	38:13:25.10000N	77:54:23.40000W	200.0	0.0	0.0	1	1255.929721	1255.929722	1.39e-003
test8	38:13:25.10000N	77:54:23.40000W	250.0	0.0	0.0	1	1569.414934	1569.414936	4.23e-003
test9	38:13:25.10000N	77:54:23.40000W	300.0	0.0	0.0	1	1882.568820	1882.568826	1.05e-002
test10	38:13:25.10000N	77:54:23.40000W	350.0	0.0	0.0	1	2195.325269	2195.325282	2.27e-002
test11	38:13:25.10000N	77:54:23.40000W	400.0	0.0	0.0	1	2507.618252	2507.618275	4.42e-002
test12	38:13:25.10000N	77:54:23.40000W	450.0	0.0	0.0	1	2819.381836	2819.381879	7.95e-002
test13	38:13:25.10000N	77:54:23.40000W	500.0	0.0	0.0	1	3130.550201	3130.550274	1.34e-001
test14	30:34:17.18000N	105:40:50.70000W	4.0	30.0	340.0	1	3.490658	3.490658	1.27e-008
test15	30:34:17.18000N	105:40:50.70000W	4.0	30.0	340.0	-1	21.642078	21.642078	7.24e-008
test16	30:34:17.18000N	105:40:50.70000W	4.0	0.0	0.0	1	25.132736	25.132736	7.62e-008
test17	30:34:17.18000N	105:40:50.70000W	4.0	0.0	0.0	-1	25.132736	25.132736	7.63e-008
test18	30:34:17.18000N	105:40:50.70000E	4.0	30.0	340.0	1	3.490658	3.490658	1.23e-008
test19	30:34:17.18000N	105:40:50.70000E	4.0	30.0	340.0	-1	21.642078	21.642078	7.28e-008
test20	30:34:17.18000N	105:40:50.70000E	4.0	0.0	0.0	1	25.132736	25.132736	7.63e-008
test21	30:34:17.18000N	105:40:50.70000E	4.0	0.0	0.0	-1	25.132736	25.132736	7.62e-008
test22	30:34:17.18000S	105:40:50.70000E	4.0	30.0	340.0	1	3.490658	3.490658	2.65e-008
test23	30:34:17.18000S	105:40:50.70000E	4.0	30.0	340.0	-1	21.642078	21.642078	7.89e-008
test24	30:34:17.18000S	105:40:50.70000E	4.0	0.0	0.0	1	25.132736	25.132736	7.62e-008
test25	30:34:17.18000S	105:40:50.70000E	4.0	0.0	0.0	-1	25.132736	25.132736	7.62e-008
test26	30:34:17.18000S	105:40:50.70000W	4.0	30.0	340.0	1	3.490658	3.490658	2.65e-008
test27	30:34:17.18000S	105:40:50.70000W	4.0	30.0	340.0	-1	21.642078	21.642078	7.89e-008
test28	30:34:17.18000S	105:40:50.70000W	4.0	0.0	0.0	1	25.132736	25.132736	7.62e-008
test29	30:34:17.18000S	105:40:50.70000W	4.0	0.0	0.0	-1	25.132736	25.132736	7.62e-008
test30	30:34:17.18000N	105:40:50.70000W	40.0	30.0	340.0	1	34.905798	34.905798	9.65e-005
test31	30:34:17.18000N	105:40:50.70000W	40.0	30.0	340.0	-1	216.415945	216.415946	9.71e-005
test32	30:34:17.18000N	105:40:50.70000W	40.0	0.0	0.0	1	251.321743	251.321743	5.82e-007
test33	30:34:17.18000N	105:40:50.70000W	40.0	0.0	0.0	-1	251.321743	251.321743	5.82e-007
test34	00:04:00.00000N	90:33:72.0000W	11.1	136.0	380.0	1	22.472820	22.472820	7.34e-008
test35	00:04:00.00000N	90:33:72.0000W	11.1	136.0	380.0	-1	47.270415	47.270415	3.17e-007
test36	00:04:00.00000N	90:33:72.0000W	11.1	0.0	0.0	1	69.743235	69.743235	4.14e-007
test37	00:04:00.00000N	90:33:72.0000W	11.1	136.0	20.0	1	22.472820	22.472820	7.34e-008
test38	00:04:00.00000N	90:33:72.0000W	11.1	136.0	20.0	-1	47.270415	47.270415	3.17e-007
test39	00:04:00.00000N	90:33:72.0000W	11.1	0.0	0.0	1	69.743235	69.743235	4.14e-007
test40	80:00:00.00000N	90:33:72.0000W	11.1	136.0	20.0	1	22.472821	22.472821	2.25e-007
test41	80:00:00.00000N	90:33:72.0000W	11.1	136.0	20.0	-1	47.270416	47.270416	7.27e-007
test42	80:00:00.00000N	90:33:72.0000W	11.1	0.0	0.0	1	69.743237	69.743237	9.51e-007

WGS84CrsIntersect Test Results

Test Identifier	Point 1 Latitude	Point 1 Longitude	Point 2 Latitude	Point 2 Longitude	Azimuth at Point 2 (degrees)	Azimuth from Intersection to Point 1 (degrees)	Distance to Point 1 from Intersection (nm)	Azimuth at Point 2 (degrees)	Azimuth from Intersection to Point 2 (degrees)	Distance to Point 2 from Intersection (nm)	Intersection Latitude	Intersection Longitude
test1	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	90.0	271.09328	77.96062	187.0	6.79842	115.70425	40:09:39.83588N	68:31:04.02698W
test2	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	90.0	273.49211	249.49410	127.0	309.24501	197.11484	40:02:47.62539N	64:47:40.82715W
test3	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	180.0	0.00000	2400.88568	183.0	2.22965	2517.34979	0:01:16.52501N	70:12:45.60000W
test4	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	175.0	355.32391	298.99250	190.0	9.07914	417.80313	35:12:07.90080N	69:41:00.06384W
test5	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	175.0	173.09453	979.39618	170.0	166.54243	877.94705	56:24:04.10502N	72:44:22.05038W
test6	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	170.0	352.06299	1472.94791	175.0	356.13925	1574.29532	15:50:52.84758N	65:55:13.50649W
test7	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	140.0	321.55556	182.84945	175.0	355.30205	256.71971	37:48:35.70387N	67:44:28.20017W
test8	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	35.0	216.45257	170.25572	200.0	200.13304	25.67248	42:28:43.18186N	68:00:48.75631W
test9	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	35.0	215.81864	98.37315	225.0	44.50036	47.79193	41:30:38.37291N	68:57:39.59637W
test10	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	40.0	221.23764	131.59286	200.0	19.92283	15.13463	41:50:21.91143N	68:19:36.20912W
test11	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	40.0	221.33298	141.28719	170.0	350.01830	7.04762	41:57:39.18157N	68:11:02.27771W
test12	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	190.0	9.32285	315.31940	200.0	18.05830	449.41589	34:59:10.92270N	71:19:18.57958W
test13	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	230.0	232.66774	233.26393	250.0	251.36850	95.79181	42:36:17.85665N	66:10:46.71710W
test14	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	300.0	117.24240	217.12520	270.0	85.84998	277.49771	41:54:31.96856N	74:24:39.29939W
test15	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	320.0	135.96039	394.31108	300.0	114.50787	390.41454	45:03:45.85754N	76:10:13.00551W
test16	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	30.0	211.06420	143.97676	300.0	119.74072	19.87930	42:14:30.07630N	68:35:51.38889W
test17	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	30.0	211.32507	177.09156	0.0	180.00000	38.22767	42:42:50.26602N	68:12:40.70000W
test18	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:40.70000W	20.0	202.00674	361.27463	10.0	190.65118	226.90835	45:47:51.26800N	67:16:23.97908W
test19	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	90.0	268.92420	76.71333	187.0	7.21051	125.94256	40:09:41.25343S	68:32:41.62303W
test20	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	90.0	266.46490	252.57903	127.0	304.80422	200.97896	40:02:36.27306S	64:43:40.26353W
test21	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	180.0	0.00000	1101.09725	183.0	4.51831	1229.27714	58:30:33.90883S	70:12:45.60000W
test22	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	175.0	354.66840	244.37912	190.0	10.99389	375.33991	44:13:53.42080S	69:43:09.64545W
test23	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	175.0	176.07150	1613.09944	170.0	171.91685	1500.62255	13:17:28.78613S	72:31:44.37321W
test24	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	170.0	346.59757	915.38118	175.0	353.11720	1027.96638	55:06:51.99323S	65:38:55.06563W
test25	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	140.0	318.34632	173.46551	175.0	354.67361	258.02597	42:21:45.91619S	67:42:22.30757W
test26	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	35.0	213.62474	181.79580	200.0	199.88520	26.04680	37:40:05.03771S	68:01:27.49821W
test27	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	35.0	214.03300	125.42532	225.0	45.29430	31.67886	38:26:57.80473S	68:41:11.55669W
test28	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	40.0	218.83891	134.40675	200.0	20.10452	23.26402	38:26:28.42788S	68:22:48.33817W
test29	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	40.0	218.71155	149.88184	170.0	349.97744	9.94061	38:14:23.79253S	68:10:29.24046W
test30	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	190.0	10.58888	220.37689	200.0	21.89034	366.67130	43:47:20.08397S	71:05:33.40366W
test31	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	230.0	227.56916	241.38324	250.0	248.85250	95.09771	37:31:08.17381S	66:20:20.79110W
test32	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	300.0	123.01996	262.87140	270.0	94.18427	322.48262	37:52:47.65820S	75:00:21.64521W
test33	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	320.0	143.73376	481.89310	300.0	124.81855	472.56869	33:50:26.35101S	76:24:08.89427W
test34	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	30.0	208.96661	155.79494	300.0	120.22233	19.80226	37:54:39.07071S	68:34:20.89766W
test35	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	30.0	208.74599	191.45410	0.0	180.00000	41.16601	37:23:22.97816S	68:12:40.70000W
test36	40:10:24.50000S	70:12:45.60000W	38:04:35.80000S	68:12:40.70000W	20.0	198.17757	450.56059	10.0	189.39006	304.54802	33:03:55.91555S	67:09:49.72585W
test37	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	90.0	268.92596	76.58779	187.0	7.21051	125.94493	40:09:41.39485S	69:52:39.75365E
test38	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	90.0	266.46650	252.46360	127.0	304.80408	200.99143	40:02:36.70030S	73:41:41.93617E
test39	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	180.0	360.00000	1100.01245	183.0	4.51599	1228.18896	58:29:28.97645S	68:12:45.60000E
test40	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	175.0	354.66902	243.96896	190.0	10.99261	374.92389	44:13:28.91712S	68:42:18.37446E
test41	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	175.0	176.07091	1610.92321	170.0	171.91563	1498.42964	13:19:39.62658S	65:53:56.00212E

test42	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	170.0	346.60210	914.56078	175.0	353.11950	1027.16253	55:06:04.19759S	72:46:16.27258E
test43	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	140.0	318.34837	173.26198	175.0	354.67383	257.87324	42:21:36.78854S	70:42:57.94500E
test44	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	35.0	213.62839	181.28240	200.0	199.88718	25.59220	37:40:30.71712S	70:23:42.21581E
test45	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	35.0	214.02959	125.88761	225.0	45.28920	31.13428	38:26:34.79410S	69:44:39.40243E
test46	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	40.0	218.84201	134.03158	200.0	20.10593	23.57520	38:26:45.97904S	70:02:24.89276E
test47	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	40.0	218.71293	149.71326	170.0	349.97713	10.07419	38:14:31.69353S	70:14:53.93008E
test48	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	190.0	10.58725	219.81660	200.0	21.88681	366.07776	43:46:47.03577S	67:20:06.32333E
test49	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	230.0	227.56795	241.51240	250.0	248.84962	95.33926	37:31:02.93863S	72:05:17.59883E
test50	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	300.0	123.01975	262.85184	270.0	94.18239	322.33652	37:52:48.29840S	63:25:10.79761E
test51	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	320.0	143.73218	481.65350	300.0	124.81546	472.23033	33:50:37.96322S	62:01:32.51590E
test52	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	30.0	208.96702	155.72986	300.0	120.22106	19.68914	37:54:42.49075S	69:51:07.91279E
test53	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	30.0	208.74764	191.18346	0.0	180.00000	40.92873	37:23:37.23265S	70:12:40.70000E
test54	40:10:24.50000S	68:12:45.60000E	38:04:35.80000S	70:12:40.70000E	20.0	198.18057	449.67428	10.0	189.39157	303.69451	33:04:46.53740S	71:15:21.73045E
test55	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	90.0	271.09153	77.83566	187.0	6.79843	115.70185	40:09:39.97893N	69:54:17.39524E
test56	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	90.0	273.49022	249.35829	127.0	309.24487	197.10176	40:02:48.12197N	73:37:39.78188E
test57	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	180.0	360.00000	2396.68305	183.0	2.22965	2513.14398	0:05:29.92696N	68:12:45.60000E
test58	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	175.0	355.32338	298.43668	190.0	9.08018	417.24213	35:12:41.19161N	68:44:27.81826E
test59	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	175.0	173.09685	978.62238	170.0	166.54702	877.15717	56:23:18.10799N	65:41:19.19227E
test60	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	170.0	352.06155	1470.73841	175.0	356.13855	1572.10201	15:53:04.69652N	72:29:58.69976E
test61	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	140.0	321.55370	182.61724	175.0	355.30186	256.53723	37:48:46.62826N	70:40:52.06822E
test62	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	35.0	216.44892	169.85183	200.0	200.13123	25.32646	42:28:23.68275N	70:24:22.98760E
test63	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	35.0	215.82362	98.95285	225.0	44.50715	47.13287	41:31:06.58993N	69:28:18.70067E
test64	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	40.0	221.23455	131.27707	200.0	19.92155	15.38722	41:50:07.65641N	70:05:38.28221E
test65	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	40.0	221.33147	141.13344	170.0	350.01860	7.16484	41:57:32.25170N	70:14:20.75633E
test66	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	190.0	9.32443	314.47941	200.0	18.06144	448.54404	35:00:00.73673N	67:06:22.55872E
test67	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	230.0	232.66920	233.38410	250.0	251.37180	96.01994	42:36:22.23058N	72:14:52.24641E
test68	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	300.0	117.24218	217.14214	270.0	85.85158	277.39053	41:54:32.43403N	64:00:50.69032E
test69	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	320.0	135.96191	394.17976	300.0	114.51132	390.18698	45:03:40.19394N	62:15:25.92213E
test70	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	30.0	211.06373	143.91656	300.0	119.74208	19.77535	42:14:26.98106N	69:49:37.30186E
test71	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	30.0	211.32322	176.85994	0.0	180.00000	38.02981	42:42:38.39108N	70:12:40.70000E
test72	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:40.70000E	20.0	202.00309	360.70415	10.0	190.64949	226.37015	45:47:19.54035N	71:08:48.89165E

WGS84ArcIntersect Test Results

Test Identifier	Arc 1 Center Latitude	Arc 1 Center Longitude	Arc 1 Radius	Arc 2 Center Latitude	Arc 2 Center Longitude	Arc 2 Radius	Intersection 1 Latitude	Intersection 1 Longitude	Intersection 2 Latitude	Intersection 2 Longitude
test1	40:10:24.50000N	70:12:45.60000W	100.0	52:04:35.80000N	68:12:40.70000W	270.0	N/A	N/A	N/A	N/A
test2	40:10:24.50000N	70:12:45.60000W	500.0	42:04:35.80000N	68:12:40.70000W	10.0	N/A	N/A	N/A	N/A
test3	0:00:00.00000N	0:00:00.00000E	150.0	0:00:00.00000N	4:59:27.60000W	150.0	0:00:36.09395S	2:29:43.80000W	0:00:36.09395N	2:29:43.80000W
test4	40:10:24.50000N	70:12:45.60000W	500.0	52:04:35.80000N	68:12:40.70000W	270.0	48:22:59.73249N	72:12:38.32104W	47:52:02.19529N	65:45:38.36390W
test5	40:10:24.50000N	70:12:45.60000W	500.0	52:04:35.80000N	68:12:40.70000W	500.0	46:29:29.71744N	77:40:33.97739W	45:10:28.61546N	61:09:37.26553W
test6	40:10:24.50000N	70:12:45.60000W	500.0	52:04:35.80000N	68:12:40.70000W	1000.0	36:14:44.69990N	60:52:32.48344W	37:48:21.06721N	80:28:07.28278W
test7	40:10:24.50000N	70:12:45.60000W	500.0	52:04:35.80000N	68:12:40.70000W	1200.0	32:04:17.90465N	67:44:28.29488W	32:37:16.67926N	74:36:44.61637W
test8	40:10:24.50000N	70:12:45.60000W	500.0	52:04:35.80000N	68:12:40.70000W	1300.0	N/A	N/A	N/A	N/A
test9	40:10:24.50000N	70:12:45.60000W	500.0	52:04:35.80000N	68:12:40.70000W	10.0	N/A	N/A	N/A	N/A
test10	40:10:24.50000S	70:12:45.60000W	500.0	52:04:35.80000S	68:12:40.70000W	270.0	47:52:02.19529S	65:45:38.36390W	48:22:59.73249S	72:12:38.32104W
test11	40:10:24.50000S	70:12:45.60000W	500.0	52:04:35.80000S	68:12:40.70000W	500.0	45:10:28.61546S	61:09:37.26553W	46:29:29.71744S	77:40:33.97739W
test12	40:10:24.50000S	70:12:45.60000W	500.0	52:04:35.80000S	68:12:40.70000W	1000.0	37:48:21.06721S	80:28:07.28278W	36:14:44.69990S	60:52:32.48344W
test13	40:10:24.50000S	70:12:45.60000W	500.0	52:04:35.80000S	68:12:40.70000W	1200.0	32:37:16.67926S	74:36:44.61637W	32:04:17.90465S	67:44:28.29488W
test14	40:10:24.50000S	70:12:45.60000W	500.0	52:04:35.80000S	68:12:40.70000W	1300.0	N/A	N/A	N/A	N/A
test15	40:10:24.50000S	70:12:45.60000W	500.0	52:04:35.80000S	68:12:40.70000W	10.0	N/A	N/A	N/A	N/A
test16	40:10:24.50000S	70:12:45.60000E	500.0	52:04:35.80000S	68:12:40.70000E	270.0	48:22:59.73249S	72:12:38.32104E	47:52:02.19529S	65:45:38.36390E
test17	40:10:24.50000S	70:12:45.60000E	500.0	52:04:35.80000S	68:12:40.70000E	500.0	46:29:29.71744S	77:40:33.97739E	45:10:28.61546S	61:09:37.26553E
test18	40:10:24.50000S	70:12:45.60000E	500.0	52:04:35.80000S	68:12:40.70000E	1000.0	36:14:44.69990S	60:52:32.48344E	37:48:21.06721S	80:28:07.28278E
test19	40:10:24.50000S	70:12:45.60000E	500.0	52:04:35.80000S	68:12:40.70000E	1200.0	32:04:17.90465S	67:44:28.29488E	32:37:16.67926S	74:36:44.61637E
test20	40:10:24.50000S	70:12:45.60000E	500.0	52:04:35.80000S	68:12:40.70000E	1300.0	N/A	N/A	N/A	N/A
test21	40:10:24.50000S	70:12:45.60000E	500.0	52:04:35.80000S	68:12:40.70000E	10.0	N/A	N/A	N/A	N/A
test22	40:10:24.50000N	70:12:45.60000E	500.0	52:04:35.80000N	68:12:40.70000E	270.0	47:52:02.19529N	65:45:38.36390E	48:22:59.73249N	72:12:38.32104E
test23	40:10:24.50000N	70:12:45.60000E	500.0	52:04:35.80000N	68:12:40.70000E	500.0	45:10:28.61546N	61:09:37.26553E	46:29:29.71744N	77:40:33.97739E
test24	40:10:24.50000N	70:12:45.60000E	500.0	52:04:35.80000N	68:12:40.70000E	1000.0	37:48:21.06721N	80:28:07.28278E	36:14:44.69990N	60:52:32.48344E
test25	40:10:24.50000N	70:12:45.60000E	500.0	52:04:35.80000N	68:12:40.70000E	1200.0	32:37:16.67926N	74:36:44.61637E	32:04:17.90465N	67:44:28.29488E
test26	40:10:24.50000N	70:12:45.60000E	500.0	52:04:35.80000N	68:12:40.70000E	1300.0	N/A	N/A	N/A	N/A
test27	40:10:24.50000N	70:12:45.60000E	500.0	52:04:35.80000N	68:12:40.70000E	10.0	N/A	N/A	N/A	N/A
test28	6:10:24.50000S	70:12:45.60000E	500.0	6:04:35.80000N	68:12:40.70000E	500.0	0:57:26.91899S	63:41:24.65688E	0:51:39.75573N	74:44:00.46476E
test29	90:00:00.00000N	70:12:45.60000E	500.0	78:04:35.80000N	68:12:40.70000E	500.0	81:42:32.06863N	112:26:25.42164E	81:42:32.06863N	23:58:55.97836E
test30	90:00:00.00000S	70:12:45.60000E	500.0	78:04:35.80000S	68:12:40.70000E	500.0	81:42:32.06863S	23:58:55.97836E	81:42:32.06863S	112:26:25.42164E

WGS84GeodesicArcIntersect Test Results

Test Identifier	Geodesic Start Latitude	Geodesic Start Longitude	Geodesic Azimuth	Arc Center Latitude	Arc Center Longitude	Arc Radius	Intersection 1 Latitude	Intersection 1 Longitude	Intersection 2 Latitude	Intersection 2 Longitude
test1	40:04:35.80000N	67:12:40.70000W	350.0	40:10:24.50000N	70:12:45.60000W	100.0	N/A	N/A	N/A	N/A
test2	40:04:35.80000N	67:12:40.70000W	200.0	40:10:24.50000N	70:12:45.60000W	100.0	N/A	N/A	N/A	N/A
test3	40:04:35.80000N	68:12:40.70000W	325.0	40:10:24.50000N	70:12:45.60000W	100.0	39:55:07.50121N	68:04:04.19322W	41:49:07.05128N	69:51:08.02313W
test4	40:04:35.80000N	67:12:40.70000W	270.0	40:10:24.50000N	70:12:45.60000W	100.0	40:04:25.03104N	68:02:37.73049W	39:57:42.51976N	72:21:57.92383W
test5	40:04:35.80000N	67:12:40.70000W	300.0	40:10:24.50000N	70:12:45.60000W	100.0	40:26:58.44233N	68:03:50.25317W	41:41:50.22946N	71:06:22.56112W
test6	40:04:35.80000N	67:12:40.70000W	240.0	40:10:24.50000N	70:12:45.60000W	100.0	39:39:05.08426N	68:09:19.50227W	38:31:25.09106N	70:31:48.24036W
test7	42:54:35.80000N	70:11:34.70000W	180.0	40:10:24.50000N	70:12:45.60000W	100.0	41:50:27.82240N	70:11:34.70000W	38:30:19.45513N	70:11:34.70000W
test8	42:54:35.80000N	70:11:34.70000W	148.0	40:10:24.50000N	70:12:45.60000W	100.0	41:37:21.88671N	69:07:30.61751W	40:14:53.46014N	68:02:21.53739W
test9	42:54:35.80000N	70:11:34.70000W	211.0	40:10:24.50000N	70:12:45.60000W	100.0	41:40:11.55047N	71:10:59.87403W	40:05:20.45327N	72:22:58.34527W
test10	40:24:35.80000N	75:11:34.70000W	90.0	40:10:24.50000N	70:12:45.60000W	100.0	40:22:32.07141N	72:22:27.11102W	40:11:17.30268N	68:02:17.43363W
test11	40:24:35.80000N	75:11:34.70000W	71.0	40:10:24.50000N	70:12:45.60000W	100.0	41:12:48.70166N	71:55:32.15119W	41:44:39.12385N	69:28:24.56005W
test12	40:24:35.80000N	75:11:34.70000W	117.0	40:10:24.50000N	70:12:45.60000W	100.0	38:58:10.68147N	71:42:17.04664W	38:34:08.21242N	70:48:01.94345W
test13	37:09:35.80000N	70:21:34.70000W	0.0	40:10:24.50000N	70:12:45.60000W	100.0	38:30:33.27210N	70:21:34.70000W	41:50:14.67279N	70:21:34.70000W
test14	37:09:35.80000N	70:21:34.70000W	34.0	40:10:24.50000N	70:12:45.60000W	100.0	38:51:33.35407N	68:53:10.34405W	39:40:46.86281N	68:08:35.72134W
test15	37:09:35.80000N	70:21:34.70000W	331.0	40:10:24.50000N	70:12:45.60000W	100.0	38:53:33.43923N	71:35:33.98874W	39:55:14.26604N	72:21:28.46764W
test16	40:04:35.80000N	73:12:40.70000E	350.0	40:10:24.50000N	70:12:45.60000E	100.0	N/A	N/A	N/A	N/A
test17	40:04:35.80000N	73:12:40.70000E	200.0	40:10:24.50000N	70:12:45.60000E	100.0	N/A	N/A	N/A	N/A
test18	40:04:35.80000N	72:12:40.70000E	315.0	40:10:24.50000N	70:12:45.60000E	100.0	39:57:28.59246N	72:21:55.36432E	41:49:06.70033N	69:51:05.23564E
test19	40:04:35.80000N	73:12:40.70000E	270.0	40:10:24.50000N	70:12:45.60000E	100.0	40:04:25.10140N	72:22:53.47612E	39:57:42.95307N	68:03:33.19723E
test20	40:04:35.80000N	73:12:40.70000E	300.0	40:10:24.50000N	70:12:45.60000E	100.0	40:26:53.80980N	72:21:41.88661E	41:41:48.45569N	69:19:03.39492E
test21	40:04:35.80000N	73:12:40.70000E	240.0	40:10:24.50000N	70:12:45.60000E	100.0	39:39:10.70047N	72:16:14.18085E	38:31:26.01350N	69:53:35.03132E
test22	42:54:35.80000N	70:11:34.70000E	180.0	40:10:24.50000N	70:12:45.60000E	100.0	41:50:27.82240N	70:11:34.70000E	38:30:19.45513N	70:11:34.70000E
test23	42:54:35.80000N	70:11:34.70000E	148.0	40:10:24.50000N	70:12:45.60000E	100.0	41:38:51.44804N	71:14:26.22964E	40:11:43.96597N	72:23:13.80920E
test24	42:54:35.80000N	70:11:34.70000E	211.0	40:10:24.50000N	70:12:45.60000E	100.0	41:38:52.66082N	69:11:07.98528E	40:08:17.38700N	68:02:21.75495E
test25	40:24:35.80000N	65:11:34.70000E	90.0	40:10:24.50000N	70:12:45.60000E	100.0	40:22:28.60052N	68:03:03.59248E	40:11:08.47196N	72:23:13.71817E
test26	40:24:35.80000N	65:11:34.70000E	71.0	40:10:24.50000N	70:12:45.60000E	100.0	41:13:31.30530N	68:30:43.58125E	41:44:55.52500N	70:56:05.26696E
test27	40:24:35.80000N	65:11:34.70000E	117.0	40:10:24.50000N	70:12:45.60000E	100.0	38:55:28.33410N	68:47:03.42056E	38:35:19.72896N	69:32:28.24986E
test28	37:09:35.80000N	70:21:34.70000E	0.0	40:10:24.50000N	70:12:45.60000E	100.0	38:30:33.27210N	70:21:34.70000E	41:50:14.67279N	70:21:34.70000E
test29	37:09:35.80000N	70:21:34.70000E	31.0	40:10:24.50000N	70:12:45.60000E	100.0	39:05:41.34977N	71:51:29.95766E	39:31:54.37145N	72:12:37.10649E
test30	37:09:35.80000N	70:21:34.70000E	331.0	40:10:24.50000N	70:12:45.60000E	100.0	38:39:57.65316N	69:17:30.06177E	40:20:03.37282N	68:02:45.21636E
test31	40:04:35.80000S	73:12:40.70000E	350.0	40:10:24.50000S	70:12:45.60000E	100.0	N/A	N/A	N/A	N/A
test32	40:04:35.80000S	73:12:40.70000E	200.0	40:10:24.50000S	70:12:45.60000E	100.0	N/A	N/A	N/A	N/A
test33	40:04:35.80000S	72:12:40.70000E	315.0	40:10:24.50000S	70:12:45.60000E	100.0	40:12:40.39213S	72:23:13.39076E	38:30:19.48047S	70:13:59.97421E
test34	40:04:35.80000S	73:12:40.70000E	270.0	40:10:24.50000S	70:12:45.60000E	100.0	40:04:25.10140S	72:22:53.47612E	39:57:42.95307S	68:03:33.19723E
test35	40:04:35.80000S	73:12:40.70000E	300.0	40:10:24.50000S	70:12:45.60000E	100.0	39:39:10.70047S	72:16:14.18085E	38:31:26.01350S	69:53:35.03132E
test36	40:04:35.80000S	73:12:40.70000E	240.0	40:10:24.50000S	70:12:45.60000E	100.0	40:26:53.80980S	72:21:41.88661E	41:41:48.45569S	69:19:03.39492E
test37	38:04:35.80000S	70:11:34.70000E	180.0	40:10:24.50000S	70:12:45.60000E	100.0	38:30:19.45513S	70:11:34.70000E	41:50:27.82240S	70:11:34.70000E
test38	38:04:35.80000S	70:11:34.70000E	148.0	40:10:24.50000S	70:12:45.60000E	100.0	38:31:34.10858S	70:33:03.48677E	40:38:16.13339S	72:18:29.56104E
test39	38:04:35.80000S	70:11:34.70000E	211.0	40:10:24.50000S	70:12:45.60000E	100.0	38:31:47.32219S	69:50:45.35130E	40:40:24.17522S	68:07:50.24284E
test40	40:24:35.80000S	65:51:34.70000E	90.0	40:10:24.50000S	70:12:45.60000E	100.0	40:23:20.88344S	68:03:11.35606E	40:13:31.47512S	72:23:12.41522E
test41	40:24:35.80000S	65:51:34.70000E	71.0	40:10:24.50000S	70:12:45.60000E	100.0	39:47:33.58163S	68:06:05.87892E	38:46:58.13955S	71:24:05.30746E
test42	40:24:35.80000S	65:51:34.70000E	117.0	40:10:24.50000S	70:12:45.60000E	100.0	41:34:54.09546S	69:02:08.00210E	41:46:21.53454S	69:35:18.59270E

test43	43:09:35.80000S	70:21:34.70000E	0.0	40:10:24.50000S	70:12:45.60000E	100.0	41:50:14.67279S	70:21:34.70000E	38:30:33.27210S	70:21:34.70000E
test44	43:09:35.80000S	70:21:34.70000E	34.0	40:10:24.50000S	70:12:45.60000E	100.0	N/A	N/A	N/A	N/A
test45	43:09:35.80000S	70:21:34.70000E	335.0	40:10:24.50000S	70:12:45.60000E	100.0	41:44:46.94173S	69:28:53.61272E	39:33:21.66496S	68:12:06.66151E
test46	40:04:35.80000S	67:12:40.70000W	350.0	40:10:24.50000S	70:12:45.60000W	100.0	N/A	N/A	N/A	N/A
test47	40:04:35.80000S	67:12:40.70000W	200.0	40:10:24.50000S	70:12:45.60000W	100.0	N/A	N/A	N/A	N/A
test48	40:04:35.80000S	68:12:40.70000W	315.0	40:10:24.50000S	70:12:45.60000W	100.0	40:12:32.98018S	68:02:17.71481W	38:30:19.55929S	70:11:21.32978W
test49	40:04:35.80000S	67:12:40.70000W	270.0	40:10:24.50000S	70:12:45.60000W	100.0	40:04:25.03104S	68:02:37.73049W	39:57:42.51976S	72:21:57.92383W
test50	40:04:35.80000S	67:12:40.70000W	300.0	40:10:24.50000S	70:12:45.60000W	100.0	39:39:05.08426S	68:09:19.50227W	38:31:25.09106S	70:31:48.24036W
test51	40:04:35.80000S	67:12:40.70000W	240.0	40:10:24.50000S	70:12:45.60000W	100.0	40:26:58.44233S	68:03:50.25317W	41:41:50.22946S	71:06:22.56112W
test52	38:04:35.80000S	70:11:34.70000W	180.0	40:10:24.50000S	70:12:45.60000W	100.0	38:30:19.45513S	70:11:34.70000W	41:50:27.82240S	70:11:34.70000W
test53	38:04:35.80000S	70:11:34.70000W	148.0	40:10:24.50000S	70:12:45.60000W	100.0	38:31:55.04879S	69:49:49.11075W	40:36:19.17675S	68:06:20.78959W
test54	38:04:35.80000S	70:11:34.70000W	211.0	40:10:24.50000S	70:12:45.60000W	100.0	38:31:27.49080S	70:32:08.75118W	40:42:18.41652S	72:16:54.09843W
test55	40:24:35.80000S	74:11:34.70000W	90.0	40:10:24.50000S	70:12:45.60000W	100.0	40:23:44.12558S	72:22:16.19656W	40:14:45.41675S	68:02:21.20257W
test56	40:24:35.80000S	74:11:34.70000W	71.0	40:10:24.50000S	70:12:45.60000W	100.0	39:54:28.73386S	72:21:18.43758W	38:51:32.35724S	68:53:12.00023W
test57	40:24:35.80000S	74:11:34.70000W	117.0	40:10:24.50000S	70:12:45.60000W	100.0	41:17:23.70708S	71:50:29.04635W	41:50:26.40135S	70:15:52.05998W
test58	43:09:35.80000S	70:21:34.70000W	0.0	40:10:24.50000S	70:12:45.60000W	100.0	41:50:14.67279S	70:21:34.70000W	38:30:33.27210S	70:21:34.70000W
test59	43:09:35.80000S	70:21:34.70000W	34.0	40:10:24.50000S	70:12:45.60000W	100.0	41:29:48.15752S	68:52:34.09229W	40:34:48.23070S	68:05:51.32589W
test60	43:09:35.80000S	70:21:34.70000W	331.0	40:10:24.50000S	70:12:45.60000W	100.0	41:27:45.66110S	71:36:19.10893W	40:21:28.52278S	72:22:35.77672W

WGS84TangentFixedRadiusArc Test Results

Test Identifier	Geodesic 1 Start Latitude	Geodesic 1 Start Longitude	Geodesic 1 Azimuth	Geodesic 2 Start Latitude	Geodesic 2 Start Longitude	Geodesic 2 Azimuth	Arc Radius	Arc Direction	Arc Center Latitude	Arc Center Longitude	Tangent Point 1 Latitude	Tangent Point 1 Longitude	Tangent Point 2 Latitude	Tangent Point 2 Longitude
test1	40:10:24.50000N	70:12:45.60000W	90.0	42:04:35.80000N	68:12:34.70000W	7.0	75.0	1	41:25:26.56571N	69:59:17.04094W	40:10:23.74429N	69:59:31.88877W	41:17:07.03907N	68:20:18.39888W
test2	40:10:24.50000N	70:12:45.60000W	90.0	42:04:35.80000N	68:12:34.70000W	307.0	25.0	1	40:31:46.79892N	66:27:03.20189W	40:06:47.06612N	66:28:25.95221W	40:51:25.07414N	66:06:41.57854W
test3	40:10:24.50000N	70:12:45.60000W	180.0	42:04:35.80000N	68:12:34.70000W	10.0	25.0	1	37:49:18.52460N	69:41:12.45766W	37:49:22.75065N	70:12:45.60000W	37:45:17.76097N	69:10:04.65398W
test4	40:10:24.50000N	70:12:45.60000W	175.0	42:04:35.80000N	68:12:34.70000W	10.0	20.0	1	37:58:58.93078N	69:32:51.13441W	37:57:20.15294N	69:58:03.52834W	37:55:45.22180N	69:07:53.72716W
test5	40:10:24.50000N	70:12:45.60000W	140.0	42:04:35.80000N	68:12:34.70000W	355.0	30.0	1	39:24:32.81954N	68:33:23.26170W	39:05:36.47498N	69:03:21.38752W	39:27:10.17660N	67:54:49.02689W
test6	40:10:24.50000N	70:12:45.60000W	35.0	42:04:35.80000N	68:12:34.70000W	20.0	50.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
test7	40:10:24.50000N	70:12:45.60000W	35.0	42:04:35.80000N	68:12:34.70000W	45.0	50.0	-1	40:57:48.66322N	68:07:20.87268W	41:27:16.30680N	69:00:53.40061W	41:33:03.54197N	68:54:23.62947W
test8	40:10:24.50000N	70:12:45.60000W	40.0	42:04:35.80000N	68:12:34.70000W	20.0	10.0	1	41:55:40.79274N	68:31:10.13947W	41:49:05.67932N	68:21:05.52942W	41:52:16.83907N	68:18:34.47631W
test9	40:10:24.50000N	70:12:45.60000W	40.0	42:04:35.80000N	68:12:34.70000W	350.0	5.0	1	41:59:13.16537N	68:18:06.96458W	41:55:55.15030N	68:13:04.79341W	42:00:05.41038N	68:11:30.78144W
test10	40:10:24.50000N	70:12:45.60000W	190.0	42:04:35.80000N	68:12:34.70000W	20.0	15.0	1	38:10:11.23560N	70:20:17.73040W	38:12:44.89584N	70:39:02.59725W	38:05:21.93366N	70:02:17.49744W
test11	40:10:24.50000N	70:12:45.60000W	300.0	42:04:35.80000N	68:12:34.70000W	90.0	15.0	-1	41:43:02.57956N	73:12:06.06904W	41:29:47.49856N	73:21:29.21152W	41:58:01.44478N	73:13:16.42120W
test12	40:10:24.50000N	70:12:45.60000W	320.0	42:04:35.80000N	68:12:34.70000W	120.0	50.0	-1	42:22:04.52412N	71:13:56.01200W	41:49:17.86811N	72:04:39.94655W	43:06:10.85660N	70:41:56.46903W
test13	40:10:24.50000N	70:12:45.60000W	30.0	42:04:35.80000N	68:12:34.70000W	120.0	15.0	-1	41:54:13.54118N	68:28:45.14229W	42:01:57.90713N	68:45:58.79336W	42:07:14.26829N	68:18:43.75999W
test14	40:10:24.50000N	70:12:45.60000W	30.0	42:04:35.80000N	68:12:34.70000W	180.0	10.0	-1	42:07:16.10426N	68:26:00.95597W	42:12:26.23456N	68:37:31.72202W	42:07:16.89107N	68:12:34.70000W
test15	40:10:24.50000N	70:12:45.60000W	20.0	42:04:35.80000N	68:12:34.70000W	190.0	20.0	-1	42:33:38.00509N	68:33:07.56179W	42:40:47.45417N	68:58:25.31418W	42:30:11.24393N	68:06:28.78422W
test16	40:10:24.50000S	70:12:45.60000W	90.0	38:04:35.80000S	68:12:34.70000W	7.0	75.0	1	38:55:19.66495S	69:57:30.23681W	40:10:23.45763S	69:57:13.42772W	39:05:15.38970S	68:22:08.10115W
test17	40:10:24.50000S	70:12:45.60000W	90.0	38:04:35.80000S	68:12:34.70000W	307.0	25.0	1	39:41:24.87800S	66:18:33.94822W	40:06:24.60062S	66:17:08.09870W	39:21:05.93754S	65:59:42.39589W
test18	40:10:24.50000S	70:12:45.60000W	180.0	38:04:35.80000S	68:12:34.70000W	10.0	25.0	1	41:48:21.64034S	69:39:19.85614W	41:48:26.50432S	70:12:45.60000W	41:53:01.81471S	69:06:28.19550W
test19	40:10:24.50000S	70:12:45.60000W	175.0	38:04:35.80000S	68:12:34.70000W	10.0	20.0	1	41:53:23.08049S	69:33:48.78224W	41:55:13.61589S	70:00:29.02018W	41:57:06.70642S	69:07:29.45776W
test20	40:10:24.50000S	70:12:45.60000W	140.0	38:04:35.80000S	68:12:34.70000W	355.0	30.0	1	40:53:21.50747S	68:32:50.30433W	41:13:01.31780S	69:02:47.99272W	40:50:44.90598S	67:53:26.70965W
test21	40:10:24.50000S	70:12:45.60000W	35.0	38:04:35.80000S	68:12:34.70000W	20.0	50.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
test22	40:10:24.50	70:12:45.60	35.0	38:04:35.80	68:12:34.70	45.0	50.0	-1	38:59:07.56	67:51:47.61	38:31:17.23	68:44:54.62	38:23:43.49	68:36:56.20

	000S	000W		000S	000W				203S	082W	392S	547W	887S	242W
test23	40:10:24.50000S	70:12:45.60000W	40.0	38:04:35.80000S	68:12:34.70000W	20.0	10.0	1	38:21:17.65803S	68:33:50.38808W	38:27:34.84485S	68:23:56.35353W	38:24:44.64049S	68:21:54.05514W
test24	40:10:24.50000S	70:12:45.60000W	40.0	38:04:35.80000S	68:12:34.70000W	350.0	5.0	1	38:12:57.08171S	68:17:09.17935W	38:16:05.07958S	68:12:12.22289W	38:12:05.00846S	68:10:54.32298W
test25	40:10:24.50000S	70:12:45.60000W	190.0	38:04:35.80000S	68:12:34.70000W	20.0	15.0	1	41:21:05.57583S	70:09:04.40926W	41:18:28.19792S	70:28:40.65479W	41:26:30.42675S	69:50:29.08027W
test26	40:10:24.50000S	70:12:45.60000W	300.0	38:04:35.80000S	68:12:34.70000W	90.0	15.0	-1	38:11:39.46782S	73:47:56.44226W	38:24:20.78704S	73:58:07.81572W	37:56:40.09827S	73:46:48.10003W
test27	40:10:24.50000S	70:12:45.60000W	320.0	38:04:35.80000S	68:12:34.70000W	120.0	50.0	-1	37:18:22.45450S	71:50:53.37418W	37:49:40.64492S	72:39:57.99848W	36:35:56.07395S	71:17:47.86633W
test28	40:10:24.50000S	70:12:45.60000W	30.0	38:04:35.80000S	68:12:34.70000W	120.0	15.0	-1	38:15:18.86600S	68:27:05.40167W	38:08:02.37874S	68:43:44.12803W	38:02:19.38377S	68:17:33.22322W
test29	40:10:24.50000S	70:12:45.60000W	30.0	38:04:35.80000S	68:12:34.70000W	180.0	10.0	-1	38:02:17.85831S	68:25:14.17729W	37:57:27.29149S	68:36:18.51623W	38:02:18.53972S	68:12:34.70000W
test30	40:10:24.50000S	70:12:45.60000W	20.0	38:04:35.80000S	68:12:34.70000W	190.0	20.0	-1	37:17:13.88439S	68:27:34.64341W	37:10:42.09265S	68:51:15.15355W	37:20:43.05501S	68:02:53.31084W
test31	40:10:24.50000S	68:12:45.60000E	90.0	38:04:35.80000S	70:12:34.70000E	7.0	75.0	1	38:55:19.71316S	68:27:39.15441E	40:10:23.50671S	68:27:55.56302E	39:05:15.43802S	70:03:01.29112E
test32	40:10:24.50000S	68:12:45.60000E	90.0	38:04:35.80000S	70:12:34.70000E	307.0	25.0	1	39:41:25.57535S	72:06:36.70261E	40:06:25.30217S	72:08:02.42702E	39:21:06.63156S	72:25:28.25205E
test33	40:10:24.50000S	68:12:45.60000E	180.0	38:04:35.80000S	70:12:34.70000E	10.0	25.0	1	41:46:59.98555S	68:46:10.63681E	41:47:04.84568S	68:12:45.60000E	41:51:40.05992S	69:19:01.62673E
test34	40:10:24.50000S	68:12:45.60000E	175.0	38:04:35.80000S	70:12:34.70000E	10.0	20.0	1	41:52:26.37245S	68:51:35.20384E	41:54:16.88004S	68:24:55.35570E	41:56:09.94304S	69:17:54.15406E
test35	40:10:24.50000S	68:12:45.60000E	140.0	38:04:35.80000S	70:12:34.70000E	355.0	30.0	1	40:53:00.52340S	69:52:16.78699E	41:12:40.22975S	69:22:19.13720E	40:50:23.93467S	70:31:40.17600E
test36	40:10:24.50000S	68:12:45.60000E	35.0	38:04:35.80000S	70:12:34.70000E	20.0	50.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
test37	40:10:24.50000S	68:12:45.60000E	35.0	38:04:35.80000S	70:12:34.70000E	45.0	50.0	-1	38:58:15.99199S	70:34:27.34186E	38:30:25.98705S	69:41:20.68237E	38:22:52.33996S	69:49:18.75679E
test38	40:10:24.50000S	68:12:45.60000E	40.0	38:04:35.80000S	70:12:34.70000E	20.0	10.0	1	38:21:56.65274S	69:51:00.76931E	38:28:13.89538S	70:00:54.83463E	38:25:23.66587S	70:02:57.19466E
test39	40:10:24.50000S	68:12:45.60000E	40.0	38:04:35.80000S	70:12:34.70000E	350.0	5.0	1	38:13:14.64955S	70:08:04.12833E	38:16:22.65986S	70:13:01.09183E	38:12:22.57289S	70:14:19.00895E
test40	40:10:24.50000S	68:12:45.60000E	190.0	38:04:35.80000S	70:12:34.70000E	20.0	15.0	1	41:19:48.53358S	68:16:44.73461E	41:17:11.20581S	67:57:08.86172E	41:25:13.27841S	68:35:19.75280E
test41	40:10:24.50000S	68:12:45.60000E	300.0	38:04:35.80000S	70:12:34.70000E	90.0	15.0	-1	38:11:40.61138S	64:37:37.05220E	38:24:21.93390S	64:27:25.68277E	37:56:41.23801S	64:38:45.31315E
test42	40:10:24.50000S	68:12:45.60000E	320.0	38:04:35.80000S	70:12:34.70000E	120.0	50.0	-1	37:18:44.79574S	66:35:00.43984E	37:50:03.14293S	65:45:55.73018E	36:36:18.21450S	67:08:05.70311E
test43	40:10:24.50000S	68:12:45.60000E	30.0	38:04:35.80000S	70:12:34.70000E	120.0	15.0	-1	38:15:26.42644S	69:58:20.50710E	38:08:09.92689S	69:41:41.76083E	38:02:26.92225S	70:07:52.65334E
test44	40:10:24.50000S	68:12:45.60000E	30.0	38:04:35.80000S	70:12:34.70000E	180.0	10.0	-1	38:02:49.25073S	69:59:55.13263E	37:57:58.65008S	69:48:50.73899E	38:02:49.93235S	70:12:34.70000E
test45	40:10:24.50000S	68:12:45.60000E	20.0	38:04:35.80000S	70:12:34.70000E	190.0	20.0	-1	37:19:00.32748S	69:57:10.89521E	37:12:28.38650S	69:33:29.89561E	37:22:29.58087S	70:21:52.79009E
test46	40:10:24.50000N	68:12:45.60000E	90.0	42:04:35.80000N	70:12:34.70000E	7.0	75.0	1	41:25:26.60664N	68:25:52.36461E	40:10:23.78448N	68:25:37.91699E	41:17:07.07993N	70:04:51.00769E

test47	40:10:24.50000N	68:12:45.60000E	90.0	42:04:35.80000N	70:12:34.70000E	307.0	25.0	1	40:31:47.54306N	71:58:04.95738E	40:06:47.80578N	71:56:42.34739E	40:51:25.82191N	72:18:26.57839E
test48	40:10:24.50000N	68:12:45.60000E	180.0	42:04:35.80000N	70:12:34.70000E	10.0	25.0	1	37:51:10.80607N	68:44:19.53963E	37:51:15.03684N	68:12:45.60000E	37:47:09.94546N	69:15:28.10850E
test49	40:10:24.50000N	68:12:45.60000E	175.0	42:04:35.80000N	70:12:34.70000E	10.0	20.0	1	38:00:10.41235N	68:52:32.81783E	37:58:31.60944N	68:27:20.01909E	37:56:56.65308N	69:17:30.61773E
test50	40:10:24.50000N	68:12:45.60000E	140.0	42:04:35.80000N	70:12:34.70000E	355.0	30.0	1	39:24:56.40398N	69:51:43.36317E	39:05:59.95608N	69:21:45.17977E	39:27:33.77651N	70:30:17.81305E
test51	40:10:24.50000N	68:12:45.60000E	35.0	42:04:35.80000N	70:12:34.70000E	20.0	50.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
test52	40:10:24.50000N	68:12:45.60000E	35.0	42:04:35.80000N	70:12:34.70000E	45.0	50.0	-1	40:58:50.90375N	70:19:10.81896E	41:28:19.01585N	69:25:37.89916E	41:34:06.34313N	69:32:08.06055E
test53	40:10:24.50000N	68:12:45.60000E	40.0	42:04:35.80000N	70:12:34.70000E	20.0	10.0	1	41:55:09.03646N	69:53:43.95858E	41:48:33.97658N	70:03:48.54891E	41:51:45.11040N	70:06:19.53131E
test54	40:10:24.50000N	68:12:45.60000E	40.0	42:04:35.80000N	70:12:34.70000E	350.0	5.0	1	41:58:57.74099N	70:07:06.10358E	41:55:39.73901N	70:12:08.27010E	41:59:49.98252N	70:13:42.26099E
test55	40:10:24.50000N	68:12:45.60000E	190.0	42:04:35.80000N	70:12:34.70000E	20.0	15.0	1	38:11:57.14712N	68:05:36.93299E	38:14:30.86947N	67:46:51.62699E	38:07:07.73150N	68:23:37.55015E
test56	40:10:24.50000N	68:12:45.60000E	300.0	42:04:35.80000N	70:12:34.70000E	90.0	15.0	-1	41:43:03.43894N	65:13:22.97799E	41:29:48.35505N	65:03:59.84075E	41:58:02.30748N	65:12:12.70228E
test57	40:10:24.50000N	68:12:45.60000E	320.0	42:04:35.80000N	70:12:34.70000E	120.0	50.0	-1	42:21:48.75747N	67:11:53.44646E	41:49:02.23303N	66:21:09.56547E	43:05:54.90302N	67:43:53.33289E
test58	40:10:24.50000N	68:12:45.60000E	30.0	42:04:35.80000N	70:12:34.70000E	120.0	15.0	-1	41:54:06.60769N	69:56:40.44962E	42:01:50.95973N	69:39:26.81837E	42:07:07.31140N	70:06:41.86897E
test59	40:10:24.50000N	68:12:45.60000E	30.0	42:04:35.80000N	70:12:34.70000E	180.0	10.0	-1	42:06:49.39078N	69:59:08.53808E	42:11:59.48512N	69:47:37.82330E	42:06:50.17739N	70:12:34.70000E
test60	40:10:24.50000N	68:12:45.60000E	20.0	42:04:35.80000N	70:12:34.70000E	190.0	20.0	-1	42:32:22.60485N	69:51:44.28487E	42:39:31.91024N	69:26:26.96605E	42:28:55.91068N	70:18:22.54478E

WGS84GeoLocusIntersect Test Results

Test Identifier	Geodesic Input	Geodesic Start Latitude	Geodesic Start Longitude	Geodesic End Latitude	Geodesic End Longitude						
	Locus Input	Locus Geodesic Start Latitude	Locus Geodesic Start Longitude	Locus Geodesic End Latitude	Locus Geodesic End Longitude	Locus Start Latitude	Locus Start Longitude	Locus End Latitude	Locus End Longitude	Locus Start Distance (nm)	Locus End Distance (nm)
	Output	Intersection Latitude	Intersection Longitude								
test1	Geodesic Input	43:47:17.80000N	69:11:50.60000W	39:34:35.80000N	69:12:34.70000W						
	Locus Input	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:34:51.08997N	70:54:12.49358W	42:29:44.86980N	68:54:29.59541W	-40.0	-40.0
	Output	42:13:22.21447N	69:12:07.67540W								
test2	Geodesic Input	41:47:17.80000N	69:11:50.60000W	42:04:35.80000N	68:12:34.70000W						
	Locus Input	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:16:32.54683N	70:23:04.51876W	42:10:54.51067N	68:23:00.30232W	-10.0	-10.0
	Output	41:57:19.79045N	68:37:45.07858W								
test3	Geodesic Input	41:47:17.80000N	69:11:50.60000W	41:47:17.80000N	65:12:34.70000W						
	Locus Input	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:01:10.70138N	69:57:20.70132W	41:58:16.13817N	68:02:11.16321W	15.0	10.0
	Output	41:48:04.24394N	68:12:34.32299W								
test4	Geodesic Input	41:47:17.80000N	69:11:50.60000W	39:36:04.50000N	67:26:41.20000W						
	Locus Input	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:03:01.62624N	70:00:25.34804W	41:53:11.72828N	67:53:53.81471W	12.0	18.0
	Output	41:11:48.40128N	68:42:35.01577W								
test5	Geodesic Input	41:47:17.80000N	69:11:50.60000W	39:36:04.50000N	69:11:50.60000W						
	Locus Input	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:17:46.04493N	70:25:08.52603W	42:10:54.51067N	68:23:00.30232W	-12.0	-10.0
	Output	41:26:42.33213N	69:11:50.60000W								
test6	Geodesic Input	41:47:17.80000N	69:11:50.60000W	40:10:24.50000N	70:12:45.60000W						
	Locus Input	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:16:32.54683N	70:23:04.51876W	42:17:12.26361N	68:33:27.97949W	-10.0	-20.0
	Output	41:09:26.33503N	69:36:02.59565W								
test7	Geodesic Input	38:47:17.80000N	69:11:50.60000W	42:04:35.80000N	68:12:34.70000W						
	Locus Input	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:58:16.13817N	68:02:11.16322W	40:01:10.70138N	69:57:20.70132W	-10.0	-15.0
	Output	41:40:37.83025N	68:20:06.26330W								
test8	Geodesic Input	38:47:17.80000N	69:11:50.60000W	41:36:04.50000N	69:11:50.60000W						
	Locus Input	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	42:12:10.13809N	68:25:05.67147W	40:16:32.54683N	70:23:04.51876W	12.0	10.0

	Output	41:27:24.30947N	69:11:50.60000W								
test9	Geodesic Input	39:47:17.80000N	69:11:50.60000W	41:10:24.50000N	70:12:45.60000W						
	Locus Input	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:55:44.00859N	67:58:02.32477W	40:04:15.53037N	70:02:28.53823W	-14.0	-10.0
	Output	40:25:30.20295N	69:39:29.15454W								
test10	Geodesic Input	39:47:17.80000N	69:11:50.60000W	41:05:17.80000N	72:11:50.60000W						
	Locus Input	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:39:11.51094N	67:31:12.85281W	39:48:49.10840N	69:36:53.95760W	-40.0	-35.0
	Output	39:55:22.68250N	69:29:41.62067W								
test11	Geodesic Input	39:47:17.80000N	68:31:50.60000W	39:47:17.80000N	72:11:50.60000W						
	Locus Input	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:35:59.92546N	67:26:04.91588W	39:39:30.54353N	69:21:38.70685W	-45.0	-50.0
	Output	39:47:49.91827N	69:13:40.39367W								
test12	Geodesic Input	40:47:17.80000N	68:31:50.60000W	39:15:17.80000N	72:11:50.60000W						
	Locus Input	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:40:28.08041N	67:33:16.16949W	39:42:36.95607N	69:26:43.33456W	-38.0	-45.0
	Output	40:51:17.20232N	68:21:40.00231W								
test13	Geodesic Input	41:47:17.80000N	68:11:50.60000E	42:34:35.80000N	69:12:34.70000E						
	Locus Input	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:34:48.34098N	67:31:15.95275E	42:30:56.94337N	69:28:29.96911E	-40.0	-42.0
	Output	N/A	N/A								
test14	Geodesic Input	41:47:17.80000N	68:11:50.60000E	42:04:35.80000N	70:12:34.70000E						
	Locus Input	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:16:31.86263N	68:02:25.99064E	42:12:09.29285N	70:00:02.80815E	-10.0	-12.0
	Output	42:01:21.05406N	69:48:40.14334E								
test15	Geodesic Input	41:47:17.80000N	68:11:50.60000E	41:47:17.80000N	69:12:34.70000E						
	Locus Input	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:34:48.34098N	67:31:15.95275E	42:29:04.57278N	69:31:40.10061E	-40.0	-39.0
	Output	41:47:21.72812N	68:46:38.51557E								
test16	Geodesic Input	41:47:17.80000N	67:11:50.60000E	39:36:04.50000N	69:26:41.20000E						
	Locus Input	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:16:31.86263N	68:02:25.99064E	42:09:38.28182N	70:04:13.77003E	-10.0	-8.0
	Output	40:37:49.71683N	68:24:40.01729E								
test17	Geodesic Input	41:47:17.80000N	68:31:50.60000E	39:34:35.80000N	68:31:50.60000E						
	Locus Input	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:07:20.47150N	68:17:54.70834E	42:03:20.08407N	70:14:39.72588E	5.0	2.0
	Output	40:21:38.98519N	68:31:50.60000E								
test18	Geodesic Input	41:47:17.80000N	68:41:50.60000E	40:10:24.50000N	68:12:45.60000E						
	Locus	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:16:31.86263N	68:02:25.99064E	42:07:44.92286N	70:07:21.77389E	-10.0	-5.0

	Input										
	Output	40:31:50.20654N	68:19:04.04752E								
test19	Geodesic Input	38:47:17.80000N	68:11:50.60000E	42:04:35.80000N	69:12:34.70000E						
	Locus Input	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:59:32.70797N	70:20:54.30885E	40:04:16.21255N	68:23:03.35373E	-8.0	-10.0
	Output	40:21:27.32287N	68:40:03.99226E								
test20	Geodesic Input	38:47:17.80000N	69:11:50.60000E	41:36:04.50000N	69:11:50.60000E						
	Locus Input	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	42:01:26.43878N	70:17:47.11005E	40:07:57.29566N	68:16:52.92374E	-5.0	-4.0
	Output	41:00:37.22699N	69:11:50.60000E								
test21	Geodesic Input	39:47:17.80000N	69:11:50.60000E	41:10:24.50000N	68:12:45.60000E						
	Locus Input	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	42:00:48.53800N	70:18:49.53023E	40:01:11.72389N	68:28:11.53713E	-6.0	-15.0
	Output	40:22:24.93524N	68:47:13.10535E								
test22	Geodesic Input	38:47:17.80000N	72:11:50.60000E	40:05:17.80000N	69:11:50.60000E						
	Locus Input	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:39:14.30455N	70:53:59.62806E	39:44:31.54766N	68:55:47.78511E	-40.0	-42.0
	Output	40:03:55.52616N	69:15:09.86384E								
test23	Geodesic Input	39:47:17.80000N	72:11:50.60000E	39:47:17.80000N	68:11:50.60000E						
	Locus Input	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:42:25.31152N	70:48:50.79796E	39:44:31.54766N	68:55:47.78511E	-35.0	-42.0
	Output	39:47:56.96798N	68:58:57.69087E								
test24	Geodesic Input	41:47:17.80000N	72:01:50.60000E	40:15:17.80000N	69:01:50.60000E						
	Locus Input	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:45:36.08581N	70:43:41.45993E	39:50:42.75433N	68:45:35.91786E	-30.0	-32.0
	Output	40:24:52.23963N	69:19:46.81959E								
test25	Geodesic Input	40:32:17.80000S	69:31:50.60000W	39:45:35.80000S	68:32:34.70000W						
	Locus Input	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:47:14.99172S	70:17:56.70673W	39:37:07.26246S	68:43:14.91695W	-5.0	-30.0
	Output	40:15:45.41972S	69:10:37.42061W								
test26	Geodesic Input	40:12:17.80000S	69:11:50.60000W	39:55:35.80000S	68:12:34.70000W						
	Locus Input	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:44:05.24805S	70:23:07.30456W	39:48:13.36527S	68:24:52.75546W	-10.0	-12.0
	Output	40:03:21.16483S	68:39:49.20815W								
test27	Geodesic Input	40:12:17.80000S	69:11:50.60000W	40:12:17.80000S	65:12:34.70000W						
	Locus Input	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:40:55.26981S	70:28:17.39464W	39:44:31.65649S	68:31:00.79721W	-15.0	-18.0
	Output	40:12:30.90626S	68:58:24.71946W								
test28	Geodesic Input	40:12:17.80000S	69:11:50.60000W	42:05:35.80000S	67:26:34.70000W						

	Locus Input	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:51:02.37334S	70:11:43.31749W	39:56:49.41116S	68:10:31.43442W	1.0	2.0
	Output	40:35:40.81313S	68:50:43.69996W								
test29	Geodesic Input	40:12:17.80000S	69:11:50.60000W	42:25:35.80000S	69:11:50.60000W						
	Locus Input	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:51:40.23723S	70:10:41.01456W	39:57:26.20299S	68:09:29.77411W	2.0	3.0
	Output	40:57:17.62289S	69:11:50.60000W								
test30	Geodesic Input	40:12:17.80000S	69:11:50.60000W	41:50:24.50000S	70:12:45.60000W						
	Locus Input	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:40:55.26981S	70:28:17.39464W	39:43:17.68107S	68:33:03.33213W	-15.0	-20.0
	Output	40:43:15.13120S	69:30:42.16309W								
test31	Geodesic Input	43:12:17.80000S	69:11:50.60000W	39:55:35.80000S	68:12:34.70000W						
	Locus Input	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	39:58:39.75911S	68:07:26.39841W	41:51:40.23723S	70:10:41.01456W	-5.0	-2.0
	Output	40:06:31.28916S	68:15:42.78110W								
test32	Geodesic Input	43:12:17.80000S	69:11:50.60000W	40:55:35.80000S	69:11:50.60000W						
	Locus Input	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:00:30.02435S	68:04:21.19705W	41:54:49.41461S	70:05:29.19346W	-8.0	-7.0
	Output	41:05:16.19670S	69:11:50.60000W								
test33	Geodesic Input	42:12:17.80000S	69:11:50.60000W	40:50:24.50000S	70:12:45.60000W						
	Locus Input	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	39:48:13.36527S	68:24:52.75546W	41:44:05.24805S	70:23:07.30456W	12.0	10.0
	Output	41:16:14.12186S	69:53:51.98283W								
test34	Geodesic Input	42:12:17.80000S	69:11:50.60000W	40:45:17.50000S	72:11:50.60000W						
	Locus Input	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:13:56.09360S	67:41:37.98194W	42:06:08.48229S	69:46:42.39287W	-30.0	-25.0
	Output	41:59:37.91453S	69:39:10.91231W								
test35	Geodesic Input	42:12:17.80000S	69:11:50.60000W	42:12:17.80000S	72:11:50.60000W						
	Locus Input	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:20:00.99821S	67:31:15.37383W	42:14:16.98565S	69:33:04.43858W	-40.0	-38.0
	Output	42:12:31.30889S	69:31:07.42859W								
test36	Geodesic Input	40:12:17.80000S	67:11:50.60000W	41:30:17.80000S	70:11:50.60000W						
	Locus Input	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:01:06.76102S	68:03:19.42649W	41:55:27.22164S	70:04:26.76787W	-9.0	-8.0
	Output	41:03:44.09408S	69:08:30.81544W								
test37	Geodesic Input	40:42:17.80000S	68:11:50.60000E	39:52:35.80000S	69:12:34.70000E						
	Locus Input	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:25:04.68264S	67:31:27.86642E	39:30:21.55001S	69:30:40.99953E	-40.0	-41.0
	Output	40:15:33.08735S	68:44:47.55891E								
test38	Geodesic	40:12:17.80000S	68:11:50.60000E	39:55:35.80000S	70:12:34.70000E						

	Input										
	Locus Input	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:40:56.32203S	67:57:12.65839E	39:49:27.87799S	70:02:18.78242E	-15.0	-10.0
	Output	39:58:31.84128S	69:52:29.29742E								
test39	Geodesic Input	40:12:17.80000S	68:11:50.60000E	40:12:17.80000S	72:12:34.70000E						
	Locus Input	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:47:15.34302S	68:07:34.11126E	39:51:18.35063S	70:05:23.36577E	-5.0	-7.0
	Output	40:13:16.89179S	69:43:44.03190E								
test40	Geodesic Input	38:01:17.80000S	68:11:50.60000E	40:12:17.80000S	69:56:34.70000E						
	Locus Input	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:40:56.32203S	67:57:12.65839E	39:44:32.88343S	69:54:07.36243E	-15.0	-18.0
	Output	39:55:56.20199S	69:43:03.93718E								
test41	Geodesic Input	38:01:17.80000S	69:11:50.60000E	41:12:17.80000S	69:11:50.60000E						
	Locus Input	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:40:56.32203S	67:57:12.65839E	39:43:19.04394S	69:52:04.68943E	-15.0	-20.0
	Output	40:25:31.95062S	69:11:50.60000E								
test42	Geodesic Input	38:01:17.80000S	69:11:50.60000E	41:50:24.50000S	68:12:45.60000E						
	Locus Input	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:40:56.32203S	67:57:12.65839E	39:44:32.88343S	69:54:07.36243E	-15.0	-18.0
	Output	41:17:14.59269S	68:21:44.54338E								
test43	Geodesic Input	43:29:17.80000S	68:11:50.60000E	39:55:35.80000S	70:12:34.70000E						
	Locus Input	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	40:10:51.57579S	70:38:22.52584E	42:09:14.44140S	68:44:05.27630E	-25.0	-30.0
	Output	41:34:33.35900S	69:18:28.69285E								
test44	Geodesic Input	42:29:17.80000S	69:11:50.60000E	38:55:35.80000S	68:11:50.60000E						
	Locus Input	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	40:00:29.47695S	70:20:48.75282E	41:56:04.38538S	68:22:07.56499E	-8.0	-9.0
	Output	41:26:23.00508S	68:53:29.08873E								
test45	Geodesic Input	42:29:17.80000S	69:11:50.60000E	40:50:24.50000S	68:12:45.60000E						
	Locus Input	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	39:57:25.99787S	70:15:39.83219E	41:53:33.42022S	68:17:57.59846E	-3.0	-5.0
	Output	41:34:00.90066S	68:38:24.24396E								
test46	Geodesic Input	40:29:17.80000S	70:11:50.60000E	38:45:07.50000S	67:11:50.60000E						
	Locus Input	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	39:58:02.71210S	70:16:41.57960E	41:52:17.88059S	68:15:52.73784E	-4.0	-3.0
	Output	40:19:41.24209S	69:54:30.11308E								

WGS84LocusArcIntersect Test Results

Test Identifier	Locus Inputs	Locus Geodesic Start Latitude	Locus Geodesic Start Longitude	Locus Geodesic End Latitude	Locus Geodesic End Longitude	Locus Start Latitude	Locus Start Longitude	Locus End Latitude	Locus End Longitude	Locus Start Distance	Locus End Distance
	Arc Inputs	Arc Center Latitude	Arc Center Longitude	Arc Radius							
	Outputs	Intersection 1 Latitude	Intersection 1 Longitude	Intersection 2 Latitude	Intersection 2 Longitude						
test1	LocusInputs	40:04:35.80000N	67:12:40.70000W	44:59:45.92088N	68:26:00.21137W	39:56:32.24583N	68:10:17.89287W	44:49:00.82197N	69:41:53.85880W	-45.0	-55.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	41:16:20.97483N	68:33:49.64706W	N/A	N/A						
test2	LocusInputs	40:04:35.80000N	67:12:40.70000W	35:21:11.74762N	69:17:59.12450W	40:19:46.76257N	68:07:58.28686W	35:38:35.67860N	70:21:53.80953W	45.0	55.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	38:52:37.32110N	68:51:25.92398W	N/A	N/A						
test3	LocusInputs	40:04:35.80000N	68:12:40.70000W	44:06:29.08145N	72:11:23.83279W	40:10:19.71054N	68:01:59.52680W	44:15:37.90140N	71:54:52.50907W	10.0	15.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	40:10:40.48392N	68:02:17.74643W	41:44:11.11144N	69:26:43.29973W						
test4	LocusInputs	40:04:35.80000N	67:12:40.70000W	39:53:37.86852N	73:42:48.01440W	39:24:33.84810N	67:12:40.70000W	39:13:42.17201N	73:39:02.85208W	-40.0	-40.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	39:24:15.45160N	68:17:38.63126W	39:18:24.79605N	72:03:32.01227W						
test5	LocusInputs	40:04:35.80000N	67:12:40.70000W	42:25:59.29666N	73:03:41.42140W	39:47:15.03035N	67:25:39.04894W	42:03:31.24636N	73:18:28.55441W	-20.0	-25.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	40:02:54.56086N	68:02:47.12641W	41:27:12.33255N	71:37:11.75223W						
test6	LocusInputs	40:04:35.80000N	67:12:40.70000W	37:26:38.49374N	72:39:00.04197W	40:24:30.80802N	67:27:43.97508W	37:47:30.86022N	72:56:21.95509W	23.0	25.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	40:09:14.29595N	68:02:19.62879W	38:40:57.69877N	71:10:40.22633W						
test7	LocusInputs	42:54:35.80000N	70:11:34.70000W	37:54:23.25449N	70:11:34.70000W	42:54:34.63546N	69:55:14.95265W	37:54:22.70515N	70:00:12.39331W	-12.0	-9.0
	ArcInputs	40:10:24.5000	70:12:45.6000	100.0							

		0N	0W								
	Outputs	41:49:41.81253N	69:56:23.66945W	38:30:50.35272N	69:59:38.85328W						
test8	LocusInputs	42:54:35.80000N	70:11:34.70000W	38:36:54.74970N	66:48:53.11210W	42:45:33.45879N	70:31:08.92001W	38:25:55.70018N	67:13:10.97191W	17.0	22.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	41:48:11.21428N	69:44:43.27879W	39:41:58.47789N	68:08:06.44802W						
test9	LocusInputs	42:54:35.80000N	70:11:34.70000W	38:34:20.92985N	73:28:27.37397W	42:47:21.88895N	69:55:16.82351W	38:30:28.69575N	73:19:31.79717W	-14.0	-8.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	41:47:15.33175N	70:45:57.13556W	39:49:26.30016N	72:19:59.93614W						
test10	LocusInputs	40:24:35.80000N	75:11:34.70000W	40:13:30.13260N	68:39:33.29289W	40:09:35.15249N	75:11:34.70000W	39:53:32.47781N	68:41:28.29400W	15.0	20.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	40:05:22.18528N	72:22:58.48688W	N/A	N/A						
test11	LocusInputs	40:24:35.80000N	75:11:34.70000W	41:52:02.63088N	68:51:37.82571W	40:17:01.57931N	75:08:10.50021W	41:46:14.44889N	68:49:34.67458W	8.0	
	ArcInputs	6.0	40:10:24.50000N								
	Outputs	70:12:45.60000W	100.0	41:03:30.88159N	72:04:03.66717W	41:40:47.06916N	69:16:07.93303W				
test12	LocusInputs	40:24:35.80000N	75:11:34.70000W	37:59:52.60403N	69:33:17.73371W	40:34:24.08080N	75:05:01.48924W	38:11:04.65506N	69:24:54.64598W	-11.0	-13.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	39:22:31.10917N	72:06:39.15758W	38:30:24.52137N	70:07:20.17531W						
test13	LocusInputs	37:09:35.80000N	70:21:34.70000W	42:09:50.66942N	70:21:34.70000W	37:09:34.10973N	70:01:33.74416W	42:09:49.71595N	70:06:47.22254W	16.0	11.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	38:30:36.75113N	70:02:54.77447W	41:50:21.16270N	70:06:25.67783W						
test14	LocusInputs	37:09:35.80000N	70:21:34.70000W	41:15:08.98180N	66:39:17.43518W	37:14:37.77298N	70:30:55.36855W	41:19:17.77892N	66:46:46.42762W	-9.0	-7.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							
	Outputs	38:40:34.86821N	69:15:50.39090W	39:59:51.92500N	68:03:11.54227W						
test15	LocusInputs	37:09:35.80000N	70:21:34.70000W	41:29:39.48761N	73:34:58.78500W	37:15:24.56960N	70:08:25.90396W	41:34:48.49958N	73:23:33.80854W	12.0	10.0
	ArcInputs	40:10:24.50000N	70:12:45.60000W	100.0							

	Outputs	38:40:27.45727N	71:09:21.24587W	40:18:13.26914N	72:22:56.80903W						
test16	LocusInputs	40:04:35.80000N	73:12:40.70000E	44:59:45.92088N	71:59:21.18863E	39:48:00.15827N	71:17:40.20472E	44:43:50.98219N	70:09:07.24848E	-90.0	-80.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	41:46:00.68336N	70:51:43.52402E	N/A	N/A						
test17	LocusInputs	40:04:35.80000N	73:12:40.70000E	35:21:11.74762N	71:07:22.27550E	40:36:07.65151N	71:15:28.17727E	35:49:22.22773N	69:22:33.06760E	95.0	90.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	38:30:43.20226N	70:24:16.36558E	N/A	N/A						
test18	LocusInputs	40:04:35.80000N	72:12:40.70000E	43:30:53.45685N	67:21:10.09784E	40:14:29.48962N	72:25:36.35111E	43:49:30.21672N	67:44:10.09926E	14.0	25.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	40:16:35.49023N	72:23:04.19012E	41:49:56.03913N	70:26:23.17962E						
test19	LocusInputs	40:04:35.80000N	73:12:40.70000E	39:53:37.86852N	66:42:33.38560E	39:32:34.26062N	73:12:40.70000E	39:28:40.60461N	66:44:54.61550E	-32.0	-25.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	39:33:23.20779N	72:13:25.35838E	39:31:28.71124N	68:13:08.42930E						
test20	LocusInputs	40:04:35.80000N	73:12:40.70000E	42:25:59.29666N	67:21:39.97860E	39:55:03.56268N	73:05:31.79786E	42:17:00.31604N	67:15:43.86529E	-11.0	-10.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	40:13:44.90572N	72:23:12.06451E	41:35:55.71369N	69:04:18.25538E						
test21	LocusInputs	40:04:35.80000N	73:12:40.70000E	37:26:38.49374N	67:46:21.35803E	40:15:51.48849N	73:04:11.23785E	37:39:10.22938N	67:35:57.37599E	13.0	15.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	39:57:08.54828N	72:21:51.60527E	38:36:13.70124N	69:29:05.91728E						
test22	LocusInputs	42:54:35.80000N	70:11:34.70000E	37:54:23.25449N	70:11:34.70000E	42:54:17.16834N	71:16:53.48450E	37:54:09.52152N	71:08:26.12075E	-48.0	-45.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	41:38:47.56150N	71:14:35.87008E	38:40:33.81918N	71:09:38.04827E						
test23	LocusInputs	42:54:35.80000N	70:11:34.70000E	38:36:54.74970N	73:34:16.28790E	42:45:33.45879N	69:52:00.47999E	38:26:55.82263N	73:12:10.65574E	17.0	20.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	41:48:29.4306	70:38:53.2169	39:41:45.9624	72:17:19.7266						

		6N	6E	1N	9E						
test24	LocusInputs	42:54:35.80000N	70:11:34.70000E	38:34:20.92985N	66:54:42.02603E	42:46:50.80632N	70:29:02.27938E	38:26:06.61768N	67:13:38.98386E	-15.0	-17.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	41:47:43.40196N	69:42:02.50041E	39:42:31.14816N	68:07:53.50977E						
test25	LocusInputs	40:24:35.80000N	65:11:34.70000E	40:13:30.13260N	71:43:36.10711E	39:57:34.60638N	65:11:34.70000E	39:41:33.83675N	71:40:32.63802E	27.0	32.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	39:53:11.08875N	68:04:30.93940E	N/A	N/A						
test26	LocusInputs	40:24:35.80000N	65:11:34.70000E	41:52:02.63088N	71:31:31.57429E	40:13:14.42778N	65:16:40.71507E	41:41:24.26479N	71:35:17.06907E	12.0	11.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	40:58:28.40606N	68:17:39.16683E	41:37:44.27698N	71:17:08.46322E						
test27	LocusInputs	40:24:35.80000N	65:11:34.70000E	37:59:52.60403N	70:49:51.66629E	40:38:51.35239N	65:21:07.27556E	38:11:56.32557N	70:58:53.55929E	-16.0	-14.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	39:25:51.87086N	68:16:33.76002E	38:30:27.42682N	70:19:30.21732E						
test28	LocusInputs	37:09:35.80000N	70:21:34.70000E	42:09:50.66942N	70:21:34.70000E	37:09:12.03214N	71:36:38.04189E	42:09:20.38191N	71:44:56.41786E	60.0	62.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	38:56:06.49229N	71:39:23.30959E	41:22:52.71681N	71:43:31.92819E						
test29	LocusInputs	37:09:35.80000N	70:21:34.70000E	41:24:05.81315N	73:46:45.59830E	37:14:44.72265N	70:10:50.58087E	41:28:28.20339N	73:37:51.07864E	-10.0	-8.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	38:45:47.16793N	71:21:43.16537E	40:00:12.62742N	72:22:22.79266E						
test30	LocusInputs	37:09:35.80000N	70:21:34.70000E	41:29:39.48761N	67:08:10.61500E	37:17:49.45718N	70:40:12.75662E	41:37:22.57804N	67:25:18.75938E	17.0	15.0
	ArcInputs	40:10:24.50000N	70:12:45.60000E	100.0							
	Outputs	38:32:19.44329N	69:47:05.36481E	40:42:42.10179N	68:08:47.23533E						
test31	LocusInputs	40:04:35.80000S	73:12:40.70000E	35:08:30.42508S	72:09:14.02356E	40:07:30.99907S	72:50:51.17492E	35:11:43.38567S	71:45:09.30741E	-17.0	-20.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	N/A	N/A	N/A	N/A						
test32	LocusInp	40:04:35.8000	73:12:40.7000	44:45:10.4951	70:48:49.9031	39:47:12.8682	72:11:43.6127	44:24:55.275	69:38:47.3187	50.0	54.0

	uts	0S	0E	9S	2E	3S	1E	06S	9E		
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	41:39:29.00627S	71:12:51.34782E	N/A	N/A						
test33	LocusInputs	40:04:35.80000S	72:12:40.70000E	36:27:08.38182S	67:49:48.47323E	40:05:18.25476S	72:11:45.42067E	36:28:29.21623S	67:47:58.39809E	-1.0	-2.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	38:30:19.51072S	70:11:27.28055E	N/A	N/A						
test34	LocusInputs	40:04:35.80000S	73:12:40.70000E	39:53:37.86852S	66:42:33.38560E	39:09:33.04483S	73:12:40.70000E	39:08:42.68217S	66:46:46.39327E	55.0	45.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	39:11:05.72257S	71:57:05.49382E	39:11:02.25193S	68:28:29.05646E						
test35	LocusInputs	40:04:35.80000S	73:12:40.70000E	37:26:38.49374S	67:46:21.35803E	40:15:51.48849S	73:04:11.23785E	37:36:39.95775S	67:38:02.45124E	-13.0	-12.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	39:56:39.83307S	72:21:46.06481E	38:35:25.48014S	69:32:05.80065E						
test36	LocusInputs	40:04:35.80000S	73:12:40.70000E	42:25:59.29666S	67:21:39.97860E	39:48:07.10444S	73:00:21.11336E	42:10:42.83913S	67:11:35.58816E	19.0	17.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	40:04:47.04502S	72:22:55.48617E	41:31:16.72059S	68:55:09.20530E						
test37	LocusInputs	38:04:35.80000S	70:11:34.70000E	43:04:47.81441S	70:11:34.70000E	38:04:34.46263S	70:29:18.51824E	43:04:45.46340S	70:34:46.50160E	-14.0	-17.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	38:31:11.62401S	70:29:45.34652E	41:49:14.99630S	70:33:18.33807E						
test38	LocusInputs	38:04:35.80000S	70:11:34.70000E	42:16:02.95041S	73:45:33.85544E	38:24:06.71761S	69:31:39.73455E	42:32:52.83250S	73:12:02.21580E	37.0	30.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	38:33:41.56924S	69:39:34.02709E	41:11:49.98705S	71:56:32.15188E						
test39	LocusInputs	38:04:35.80000S	70:11:34.70000E	42:18:57.42808S	66:43:26.95968E	38:15:23.23243S	70:34:25.87614E	42:27:09.69405S	67:00:23.77562E	-21.0	-15.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	38:30:35.91066S	70:22:22.12255E	40:59:38.89521S	68:18:29.60201E						
test40	LocusInputs	40:24:35.80000S	65:51:34.70000E	40:13:30.13260S	72:23:36.10711E	41:39:38.45017S	65:51:34.70000E	41:23:21.12281S	72:30:27.67815E	75.0	70.0

	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	41:34:42.11106S	69:01:43.31833E	41:26:48.13779S	71:37:49.38289E						
test41	LocusInputs	40:24:35.80000S	65:51:34.70000E	38:37:15.53538S	71:53:43.64116E	40:27:26.10432S	65:52:51.47157E	38:39:06.23077S	71:54:43.10773E	3.0	
	ArcInputs	2.0	40:10:24.50000S								
	Outputs	70:12:45.60000E	100.0	39:50:38.66908S	68:05:10.58480E	38:48:21.65069S	71:26:44.41888E				
test42	LocusInputs	40:24:35.80000S	65:51:34.70000E	42:31:36.14552S	71:53:17.58283E	40:22:48.79823S	65:52:45.98838E	42:30:40.89788S	71:53:49.28758E	-2.0	-1.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	41:30:04.01423S	68:53:01.27732E	41:48:16.79755S	69:45:17.54741E						
test43	LocusInputs	43:09:35.80000S	70:21:34.70000E	38:09:24.03567S	70:21:34.70000E	43:09:34.98423S	70:35:14.47789E	38:09:23.48139S	70:32:59.33158E	10.0	
	ArcInputs	9.0	40:10:24.50000S	70:12:45.60000E							
	Outputs	100.0	41:49:05.47847S	70:34:35.62154E	38:31:34.72650S	70:33:08.46967E					
test44	LocusInputs	42:09:35.80000S	70:21:34.70000E	37:57:18.93348S	73:53:33.13110E	42:09:02.22981S	70:20:27.82742E	37:56:47.34314S	73:52:28.61147E	-1.0	-1.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	41:48:28.50199S	70:38:59.27618E	39:50:56.92924S	72:20:25.64340E						
test45	LocusInputs	43:09:35.80000S	70:21:34.70000E	38:35:33.30636S	67:40:00.75564E	43:11:17.14290S	70:16:37.37426E	38:36:20.67340S	67:37:40.08878E	-4.0	-2.0
	ArcInputs	40:10:24.50000S	70:12:45.60000E	100.0							
	Outputs	41:43:03.84950S	69:22:56.07645E	39:36:34.42863S	68:10:29.08623E						
test46	LocusInputs	40:04:35.80000S	67:12:40.70000W	35:08:30.42508S	68:16:07.37644W	40:11:50.97658S	68:07:56.58748W	35:15:37.84100S	69:10:20.62043W	-43.0	-45.0
	ArcInputs	40:10:24.50000S	70:12:45.60000W	100.0							
	Outputs	39:22:25.63807S	68:18:55.98559W	N/A	N/A						
test47	LocusInputs	40:04:35.80000S	67:12:40.70000W	44:45:10.49519S	69:36:31.49688W	39:48:58.60203S	68:07:33.46836W	44:28:43.55420S	70:33:39.49919W	45.0	44.0
	ArcInputs	40:10:24.50000S	70:12:45.60000W	100.0							
	Outputs	41:33:34.04010S	68:59:26.86286W	N/A	N/A						
test48	LocusInputs	40:04:35.80000S	68:12:40.70000W	36:27:08.38182S	72:35:32.92677W	39:55:23.21575S	68:00:43.79991W	36:19:43.28447S	72:25:28.64583W	13.0	11.0
	ArcInputs	40:10:24.5000	70:12:45.6000	100.0							

		0S	0W								
	Outputs	39:52:21.9892 9S	68:04:43.1350 5W	38:32:16.8257 1S	69:47:22.0623 3W						
test49	LocusInp uts	40:04:35.8000 0S	67:12:40.7000 0W	39:53:37.8685 2S	73:42:48.0144 0W	39:52:35.2435 1S	67:12:40.7000 0W	39:43:38.981 59S	73:41:51.3189 0W	12.0	10.0
	ArcInputs	40:10:24.5000 0S	70:12:45.6000 0W	100.0							
	Outputs	39:52:39.5690 3S	68:04:38.7058 4W	39:47:22.4378 0S	72:19:21.7385 6W						
test50	LocusInp uts	40:04:35.8000 0S	67:12:40.7000 0W	37:26:38.4937 4S	72:39:00.0419 7W	40:12:23.6530 5S	67:18:33.1054 1W	37:33:19.536 73S	72:44:32.3991 0W	-9.0	-8.0
	ArcInputs	40:10:24.5000 0S	70:12:45.6000 0W	100.0							
	Outputs	39:51:22.1708 7S	68:04:58.7312 4W	38:33:52.8622 5S	70:46:51.0549 5W						
test51	LocusInp uts	40:04:35.8000 0S	67:12:40.7000 0W	42:25:59.2966 6S	73:03:41.4214 0W	39:54:11.5185 1S	67:20:28.4948 1W	42:17:54.228 55S	73:09:01.9993 6W	12.0	
	ArcInputs	9.0	40:10:24.5000 0S	70:12:45.6000 0W							
	Outputs	100.0	40:12:56.7452 6S	68:02:18.0598 0W	41:36:12.1797 0S	71:20:37.1459 8W					
test52	LocusInp uts	38:04:35.8000 0S	70:11:34.7000 0W	43:04:47.8144 1S	70:11:34.7000 0W	38:04:33.8280 6S	70:33:06.4772 2W	43:04:45.984 03S	70:32:02.7621 6W	17.0	15.0
	ArcInputs	40:10:24.5000 0S	70:12:45.6000 0W	100.0							
	Outputs	38:31:33.7683 5S	70:33:00.7342 1W	41:49:21.9263 0S	70:32:18.7801 8W						
test53	LocusInp uts	38:04:35.8000 0S	70:11:34.7000 0W	42:16:02.9504 1S	66:37:35.5445 6W	38:08:18.3689 2S	70:19:06.1664 2W	42:18:51.947 05S	66:43:09.5742 2W	7.0	
	ArcInputs	5.0	40:10:24.5000 0S								
	Outputs	70:12:45.6000 0W	100.0	38:30:44.0931 5S	70:01:02.1551 2W	40:43:33.7987 1S	68:09:09.8591 4W				
test54	LocusInp uts	38:04:35.8000 0S	70:11:34.7000 0W	42:18:57.4280 8S	73:39:42.4403 2W	38:11:17.1184 4S	69:57:26.6712 6W	42:24:58.669 38S	73:27:17.2069 4W	-13.0	-11.0
	ArcInputs	40:10:24.5000 0S	70:12:45.6000 0W	100.0							
	Outputs	38:30:19.2704 6S	70:12:08.8825 1W	40:55:39.9262 8S	72:09:46.0694 1W						
test55	LocusInp uts	40:24:35.8000 0S	74:11:34.7000 0W	40:13:30.1326 0S	67:39:33.2928 9W	40:31:36.0887 9S	74:11:34.7000 0W	40:18:29.530 53S	67:39:04.3669 0W	7.0	
	ArcInputs	5.0	40:10:24.5000 0S								
	Outputs	70:12:45.6000 0W	100.0	40:30:09.4866 7S	72:20:57.9109 9W	40:19:54.8752 3S	68:02:44.2857 5W				
test56	LocusInp uts	40:24:35.8000 0S	74:11:34.7000 0W	38:37:15.5353 8S	68:09:25.7588 4W	40:29:19.6318 8S	74:09:26.6875 4W	38:40:01.575 10S	68:07:56.5399 1W	5.0	
	ArcInputs	3.0	40:10:24.5000 0S								

	Outputs	70:12:45.60000W	100.0	39:59:27.59845S	72:22:15.85364W	38:53:50.98943S	68:49:29.99867W				
test57	LocusInputs	40:24:35.80000S	74:11:34.70000W	42:31:36.14552S	68:09:51.81717W	40:18:21.23809S	74:07:25.46446W	42:26:04.62097S	68:06:41.82104W	-7.0	-6.0
	ArcInputs	40:10:24.50000S	70:12:45.60000W	100.0							
	Outputs	41:05:49.43225S	72:02:08.19523W	41:49:47.02230S	69:57:20.41362W						
test58	LocusInputs	43:09:35.80000S	70:21:34.70000W	38:09:24.03567S	70:21:34.70000W	43:09:34.62530S	70:05:10.96760W	38:09:23.35138S	70:08:53.99850W	12.0	10.0
	ArcInputs	40:10:24.50000S	70:12:45.60000W	100.0							
	Outputs	41:50:20.72573S	70:06:13.83966W	38:30:22.24016S	70:08:39.65340W						
test59	LocusInputs	43:09:35.80000S	70:21:34.70000W	38:57:14.60461S	66:46:39.46882W	43:06:47.86496S	70:27:14.25600W	38:55:40.03026S	66:49:55.83317W	-5.0	-3.0
	ArcInputs	40:10:24.50000S	70:12:45.60000W	100.0							
	Outputs	41:36:12.38507S	69:04:54.50326W	40:25:02.16784S	68:03:28.13705W						
test60	LocusInputs	43:09:35.80000S	70:21:34.70000W	38:44:26.17734S	73:27:19.42040W	43:06:11.82930S	70:13:13.26597W	38:42:09.85051S	73:21:37.86961W	7.0	
	ArcInputs	5.0	40:10:24.50000S								
	Outputs	70:12:45.60000W	100.0	41:36:07.22647S	71:20:47.96044W	40:08:27.78107S	72:23:09.88582W				
test61	LocusInputs	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:05.00782N	70:51:34.00000W	42:55:01.77259N	70:24:20.88368W	-0.5	-0.5
	ArcInputs	42:54:35.00000N	70:51:34.00000W								
	Outputs	1.0	42:55:05.00175N	70:50:23.28330W	N/A	N/A					
test62	LocusInputs	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:05.00782N	70:51:34.00000W	42:55:01.77259N	70:24:20.88368W	-0.5	-0.5
	ArcInputs	42:54:35.00000N	70:50:14.00000W								
	Outputs	1.0	42:55:05.00771N	70:51:24.71201W	42:55:04.98026N	70:49:03.26644W					
test63	LocusInputs	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:55:35.01559N	70:51:34.00000W	42:55:31.77993N	70:24:20.66356W	-1.0	-1.0
	ArcInputs	42:55:35.00000N	70:48:52.00000W								
	Outputs	1.0	42:55:35.00776N	70:50:13.66761W	42:55:34.94358N	70:47:30.33244W					
test64	LocusInputs	42:54:35.00000N	70:51:34.00000W	42:54:31.76521N	70:24:21.10373W	42:52:34.96830N	70:51:34.00000W	42:52:31.73523N	70:24:21.98336W	2.0	
	ArcInputs	2.0	42:53:05.00000N								
	Outputs	70:47:32.0000	1.5	42:52:34.9488	70:49:27.3891	42:52:34.8133	70:45:36.6763				

		0W		4N	4W	2N	2W				
test65	LocusInp uts	42:54:35.0000 0N	70:51:34.0000 0W	42:54:31.7652 1N	70:24:21.1037 3W	42:57:35.0462 4N	70:51:34.0000 0W	42:57:31.808 85N	70:24:19.7825 1W	-3.0	-3.0
	ArcInputs	42:56:35.0000 0N	70:46:12.0000 0W								
	Outputs	1.0	42:57:34.9240 4N	70:46:16.5022 7W	42:57:34.9168 7N	70:46:07.3243 2W					
test66	LocusInp uts	42:54:35.0000 0N	70:51:34.0000 0W	42:54:31.7652 1N	70:24:21.1037 3W	42:50:34.9359 0N	70:51:34.0000 0W	42:50:31.704 55N	70:24:22.8620 5W	4.0	
	ArcInputs	4.0	42:51:35.0000 0N								
	Outputs	70:44:52.0000 0W	1.5	42:50:34.8184 3N	70:46:22.9951 5W	42:50:34.6409 8N	70:43:21.2222 5W				
test67	LocusInp uts	42:54:35.0000 0N	70:51:34.0000 0W	42:54:31.7652 1N	70:24:21.1037 3W	42:59:35.0761 8N	70:51:34.0000 0W	42:59:31.837 07N	70:24:18.9005 0W	-5.0	-5.0
	ArcInputs	42:58:35.0000 0N	70:43:32.0000 0W								
	Outputs	2.0	42:59:34.9358 4N	70:45:53.6482 1W	42:59:34.6045 8N	70:41:10.0928 1W					
test68	LocusInp uts	42:54:35.0000 0N	70:51:34.0000 0W	42:54:31.7652 1N	70:24:21.1037 3W	42:48:34.9027 9N	70:51:34.0000 0W	42:48:31.673 17N	70:24:23.7397 8W	6.0	
	ArcInputs	6.0	42:49:35.0000 0N								
	Outputs	70:42:12.0000 0W	1.5	42:48:34.6329 0N	70:43:42.7194 9W	42:48:34.3855 6N	70:40:41.5853 8W				
test69	LocusInp uts	42:54:35.0000 0N	70:51:34.0000 0W	42:54:31.7652 1N	70:24:21.1037 3W	43:01:35.1054 3N	70:51:34.0000 0W	43:01:31.864 59N	70:24:18.0175 4W	-7.0	-7.0
	ArcInputs	43:00:05.0000 0N	70:43:32.0000 0W								
	Outputs	2.0	43:01:34.9363 5N	70:45:20.3213 4W	43:01:34.6829 1N	70:41:43.2892 1W					
test70	LocusInp uts	42:54:35.0000 0N	70:51:34.0000 0W	42:54:31.7652 1N	70:24:21.1037 3W	42:46:34.8689 9N	70:51:34.0000 0W	42:46:31.641 08N	70:24:24.6165 8W	8.0	
	ArcInputs	8.0	42:47:35.0000 0N								
	Outputs	70:42:12.0000 0W	1.5	42:46:34.5988 4N	70:43:42.6294 2W	42:46:34.3516 2N	70:40:41.6754 5W				

WGS84LocusIntersect Test Results

Test Identifier	Locus 1 Inputs	Locus 1 Geodesic Start Latitude	Locus 1 Geodesic Start Longitude	Locus 1 Geodesic End Latitude	Locus 1 Geodesic End Longitude	Locus 1 Start Latitude	Locus 1 Start Longitude	Locus 1 End Latitude	Locus 1 End Longitude	Locus 1 Start Distance	Locus 1 End Distance
	Locus 2 Inputs	Locus 2 Geodesic Start Latitude	Locus 2 Geodesic Start Longitude	Locus 2 Geodesic End Latitude	Locus 2 Geodesic End Longitude	Locus 2 Start Latitude	Locus 2 Start Longitude	Locus 2 End Latitude	Locus 2 End Longitude	Locus 2 Start Distance	Locus 2 End Distance
	Output	Intersection Latitude	Intersection Longitude								
test1	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:34:51.08997N	70:54:12.49358W	42:29:44.86980N	68:54:29.59541W	-40.0	-40.0
	Locus 2 Inputs	43:47:17.80000N	69:11:50.60000W	39:34:35.80000N	69:12:34.70000W	43:47:17.16766N	69:39:27.23479W	39:34:35.45517N	69:38:26.67528W	20.0	20.0
	Output	41:48:06.52416N	69:38:56.60400W								
test2	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:16:32.54683N	70:23:04.51876W	42:10:54.51067N	68:23:00.30232W	-10.0	-10.0
	Locus 2 Inputs	41:47:17.80000N	69:11:50.60000W	42:04:35.80000N	68:12:34.70000W	41:37:59.88025N	69:06:54.98918W	41:55:15.39563N	68:07:46.38917W	10.0	10.0
	Output	41:41:38.52019N	68:54:37.00390W								
test3	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:01:10.70138N	69:57:20.70132W	41:58:16.13817N	68:02:11.16321W	15.0	10.0
	Locus 2 Inputs	41:47:17.80000N	69:11:50.60000W	41:47:17.80000N	65:12:34.70000W	41:37:17.67775N	69:11:32.04562W	41:32:17.60977N	65:13:02.49575W	10.0	15.0
	Output	41:36:57.43292N	68:23:48.56010W								
test4	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:03:01.62624N	70:00:25.34804W	41:53:11.72828N	67:53:53.81471W	12.0	18.0
	Locus 2 Inputs	41:47:17.80000N	69:11:50.60000W	39:36:04.50000N	67:26:41.20000W	41:52:34.94174N	69:00:29.14443W	39:42:12.84894N	67:13:19.99273W	-10.0	-12.0
	Output	41:20:04.46258N	68:32:58.40655W								
test5	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:17:46.04493N	70:25:08.52603W	42:10:54.51067N	68:23:00.30232W	-12.0	-10.0
	Locus 2 Inputs	41:47:17.80000N	69:11:50.60000W	39:36:04.50000N	69:11:50.60000W	41:47:16.05011N	68:51:47.49988W	39:36:03.62845N	68:57:36.71338W	-15.0	-11.0
	Output	41:44:55.25922N	68:51:53.96578W								
test6	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	42:04:35.80000N	68:12:34.70000W	40:16:32.54683N	70:23:04.51876W	42:17:12.26361N	68:33:27.97949W	-10.0	-20.0
	Locus	41:47:17.80000N	69:11:50.60000W	40:10:24.50000N	70:12:45.60000W	41:49:02.24222N	69:16:39.55217W	40:12:31.91500N	70:18:40.06838W	4.0	5.0

	Locus 2 Inputs										
	Output	40:44:08.21825N	69:58:43.82937W								
test7	Locus 1 Inputs	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:58:16.13817N	68:02:11.16322W	40:01:10.70138N	69:57:20.70132W	-10.0	-15.0
	Locus 2 Inputs	38:47:17.80000N	69:11:50.60000W	42:04:35.80000N	68:12:34.70000W	38:50:20.03849N	69:29:19.75003W	42:09:21.41521N	68:40:03.67472W	-14.0	-21.0
	Output	41:03:48.90937N	68:56:49.95173W								
test8	Locus 1 Inputs	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	42:12:10.13809N	68:25:05.67147W	40:16:32.54683N	70:23:04.51876W	12.0	10.0
	Locus 2 Inputs	38:47:17.80000N	69:11:50.60000W	41:36:04.50000N	69:11:50.60000W	38:47:17.45707N	69:20:47.75726W	41:36:03.56507N	69:26:30.32332W	-7.0	-11.0
	Output	41:13:51.01043N	69:25:43.47422W								
test9	Locus 1 Inputs	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:55:44.00859N	67:58:02.32477W	40:04:15.53037N	70:02:28.53823W	-14.0	-10.0
	Locus 2 Inputs	38:47:17.80000N	69:11:50.60000W	40:10:24.50000N	70:12:45.60000W	38:59:28.65387N	68:43:52.41332W	40:20:21.26770N	69:50:05.44188W	25.0	20.0
	Output	40:17:45.13434N	69:47:54.68645W								
test10	Locus 1 Inputs	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:39:11.51094N	67:31:12.85281W	39:48:49.10840N	69:36:53.95760W	-40.0	-35.0
	Locus 2 Inputs	38:47:17.80000N	69:11:50.60000W	40:05:17.80000N	72:11:50.60000W	39:47:44.17230N	68:26:14.20595W	41:02:28.85406N	71:31:12.02592W	70.0	65.0
	Output	40:08:19.82805N	69:15:22.32498W								
test11	Locus 1 Inputs	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:35:59.92546N	67:26:04.91588W	39:39:30.54353N	69:21:38.70685W	-45.0	-50.0
	Locus 2 Inputs	38:47:17.80000N	68:31:50.60000W	38:47:17.80000N	72:11:50.60000W	40:22:21.42255N	68:29:21.10582W	40:07:20.95796N	72:13:56.03192W	95.0	80.0
	Output	40:21:46.09771N	68:40:43.79783W								
test12	Locus 1 Inputs	42:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	41:40:28.08041N	67:33:16.16949W	39:42:36.95607N	69:26:43.33456W	-38.0	-45.0
	Locus 2 Inputs	38:47:17.80000N	68:31:50.60000W	37:15:17.80000N	72:11:50.60000W	40:08:26.72939N	69:25:11.93346W	38:40:51.77139N	73:12:28.75973W	91.0	98.0
	Output	N/A	N/A								
test13	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:34:48.34098N	67:31:15.95275E	42:30:56.94337N	69:28:29.96911E	-40.0	-42.0

	Locus 2 Inputs	41:47:17.80000N	68:11:50.60000E	42:34:35.80000N	69:12:34.70000E	41:17:38.57897N	68:53:19.82604E	42:03:10.50228N	69:56:00.78533E	43.0	45.0
	Output	N/A	N/A								
test14	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:16:31.86263N	68:02:25.99064E	42:12:09.29285N	70:00:02.80815E	-10.0	-12.0
	Locus 2 Inputs	41:47:17.80000N	68:11:50.60000E	42:04:35.80000N	70:12:34.70000E	41:32:35.48231N	68:15:50.24846E	41:48:50.47117N	70:16:21.80709E	15.0	16.0
	Output	41:42:45.75260N	69:29:17.30429E								
test15	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:34:48.34098N	67:31:15.95275E	42:29:04.57278N	69:31:40.10061E	-40.0	-39.0
	Locus 2 Inputs	41:47:17.80000N	68:11:50.60000E	41:47:17.80000N	69:12:34.70000E	41:57:18.05539N	68:11:45.86629E	41:56:18.03064N	69:12:38.95923E	-10.0	-9.0
	Output	41:56:37.06762N	68:56:31.29856E								
test16	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:16:31.86263N	68:02:25.99064E	42:09:38.28182N	70:04:13.77003E	-10.0	-8.0
	Locus 2 Inputs	41:47:17.80000N	67:11:50.60000E	39:36:04.50000N	69:26:41.20000E	41:50:25.61894N	67:17:03.53451E	39:39:42.68648N	69:32:52.00800E	-5.0	-6.0
	Output	40:42:15.66902N	68:29:20.00613E								
test17	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:07:20.47150N	68:17:54.70834E	42:03:20.08407N	70:14:39.72588E	5.0	2.0
	Locus 2 Inputs	41:47:17.80000N	68:31:50.60000E	39:34:35.80000N	68:31:50.60000E	41:47:17.79222N	68:30:30.39292E	39:34:35.73523N	68:27:57.80380E	1.0	3.0
	Output	40:18:31.31171N	68:28:47.22609E								
test18	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	42:04:35.80000N	70:12:34.70000E	40:16:31.86263N	68:02:25.99064E	42:07:44.92286N	70:07:21.77389E	-10.0	-5.0
	Locus 2 Inputs	41:47:17.80000N	68:41:50.60000E	40:10:24.50000N	68:12:45.60000E	41:46:10.22678N	68:48:21.28237E	40:09:05.30829N	68:20:23.68524E	-5.0	-6.0
	Output	40:41:23.80558N	68:29:32.62774E								
test19	Locus 1 Inputs	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:59:32.70797N	70:20:54.30885E	40:04:16.21255N	68:23:03.35373E	-8.0	-10.0
	Locus 2 Inputs	38:47:17.80000N	68:11:50.60000E	42:04:35.80000N	69:12:34.70000E	38:45:43.54228N	68:20:33.98734E	42:02:42.67727N	69:23:00.95832E	7.0	8.0
	Output	40:36:11.72260N	68:54:48.39606E								
test20	Locus 1	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	42:01:26.43878N	70:17:47.11005E	40:07:57.29566N	68:16:52.92374E	-5.0	-4.0

	Inputs										
	Locus 2 Inputs	38:47:17.80000N	69:11:50.60000E	41:36:04.50000N	69:11:50.60000E	38:47:17.77201N	69:14:24.07363E	41:36:04.43046N	69:15:50.52514E	2.0	3.0
	Output	41:04:06.94297N	69:15:33.55517E								
test21	Locus 1 Inputs	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	42:00:48.53800N	70:18:49.53023E	40:06:06.79553N	68:19:58.22200E	-6.0	-7.0
	Locus 2 Inputs	38:47:17.80000N	69:11:50.60000E	40:10:24.50000N	68:12:45.60000E	38:49:41.12802N	69:17:27.85361E	40:13:19.86103N	68:19:36.00018E	5.0	6.0
	Output	40:08:53.27343N	68:22:44.48587E								
test22	Locus 1 Inputs	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:39:14.30455N	70:53:59.62806E	39:48:51.48716N	68:48:39.66995E	-40.0	-35.0
	Locus 2 Inputs	38:47:17.80000N	72:11:50.60000E	40:05:17.80000N	69:11:50.60000E	39:00:16.42738N	72:21:30.40595E	40:27:19.19138N	69:27:20.34409E	15.0	25.0
	Output	40:26:06.25375N	69:29:53.11403E								
test23	Locus 1 Inputs	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:42:25.31152N	70:48:50.79796E	39:48:14.38002N	68:49:40.88406E	-35.0	-36.0
	Locus 2 Inputs	39:47:17.80000N	72:11:50.60000E	39:47:17.80000N	69:11:50.60000E	40:27:19.25403N	72:12:43.27810E	40:25:19.18808N	69:11:00.58042E	40.0	38.0
	Output	40:25:42.09261N	69:27:47.18567E								
test24	Locus 1 Inputs	42:04:35.80000N	70:12:34.70000E	40:10:24.50000N	68:12:45.60000E	41:45:36.08581N	70:43:41.45993E	39:50:42.75433N	68:45:35.91786E	-30.0	-32.0
	Locus 2 Inputs	41:47:17.80000N	72:11:50.60000E	40:15:17.80000N	69:11:50.60000E	42:14:05.92481N	71:48:22.06420E	40:42:18.33009N	68:46:57.62062E	32.0	33.0
	Output	41:38:45.61961N	70:36:24.07170E								
test25	Locus 1 Inputs	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:25:01.88807S	70:54:00.26901W	39:34:01.71595S	68:48:20.02988W	-40.0	-35.0
	Locus 2 Inputs	40:12:17.80000S	69:11:50.60000W	39:25:35.80000S	68:12:34.70000W	40:37:33.30027S	68:38:14.16936W	39:51:57.45011S	67:37:07.05316W	36.0	38.0
	Output	N/A	N/A								
test26	Locus 1 Inputs	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:44:05.24805S	70:23:07.30456W	39:48:13.36527S	68:24:52.75546W	-10.0	-12.0
	Locus 2 Inputs	40:12:17.80000S	69:11:50.60000W	39:55:35.80000S	68:12:34.70000W	40:07:35.34521S	69:14:03.22375W	39:49:58.20740S	68:15:18.03727W	-5.0	-6.0
	Output	39:54:52.24216S	68:31:25.59353W								
test27	Locus	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:40:55.26981S	70:28:17.39464W	39:44:31.65649S	68:31:00.79721W	-15.0	-18.0

	1 Inputs										
	Locus 2 Inputs	40:12:17.80000S	69:11:50.60000W	40:12:17.80000S	65:12:34.70000W	40:02:17.50254S	69:11:33.04859W	40:01:17.47180S	65:12:54.00184W	-10.0	-11.0
	Output	40:02:33.17060S	68:48:36.22812W								
test28	Locus 1 Inputs	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:51:02.37334S	70:11:43.31749W	39:56:49.41116S	68:10:31.43442W	1.0	2.0
	Locus 2 Inputs	40:12:17.80000S	69:11:50.60000W	42:05:35.80000S	67:26:34.70000W	40:10:35.71331S	69:08:37.07963W	42:03:15.74654S	67:22:12.94439W	-3.0	-4.0
	Output	40:33:04.17399S	68:47:59.71025W								
test29	Locus 1 Inputs	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:51:40.23723S	70:10:41.01456W	39:57:26.20299S	68:09:29.77411W	2.0	3.0
	Locus 2 Inputs	40:12:17.80000S	69:11:50.60000W	42:25:35.80000S	69:11:50.60000W	40:12:17.68228S	69:06:37.35813W	42:25:35.60119S	69:05:05.52129W	-4.0	-5.0
	Output	40:51:57.10883S	69:06:10.74013W								
test30	Locus 1 Inputs	41:50:24.50000S	70:12:45.60000W	39:55:35.80000S	68:12:34.70000W	41:40:55.26981S	70:28:17.39464W	39:43:17.68107S	68:33:03.33213W	-15.0	-20.0
	Locus 2 Inputs	40:12:17.80000S	69:11:50.60000W	41:50:24.50000S	70:12:45.60000W	40:11:27.30497S	69:14:12.68764W	41:49:06.86266S	70:16:22.84949W	2.0	3.0
	Output	40:52:52.40604S	69:40:09.58552W								
test31	Locus 1 Inputs	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	39:58:39.75911S	68:07:26.39841W	41:51:40.23723S	70:10:41.01456W	-5.0	-2.0
	Locus 2 Inputs	43:12:17.80000S	69:11:50.60000W	39:55:35.80000S	68:12:34.70000W	43:08:10.82604S	69:35:47.37235W	39:52:20.45272S	68:31:36.29102W	-18.0	-15.0
	Output	40:33:38.43603S	68:44:35.40196W								
test32	Locus 1 Inputs	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:00:30.02435S	68:04:21.19705W	41:54:49.41461S	70:05:29.19346W	-8.0	-7.0
	Locus 2 Inputs	43:12:17.80000S	69:11:50.60000W	40:55:35.80000S	69:11:50.60000W	43:12:17.59574S	69:05:00.40914W	40:55:35.52833S	69:03:55.66338W	5.0	6.0
	Output	40:57:49.85657S	69:03:56.69283W								
test33	Locus 1 Inputs	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:05:23.65941S	67:56:06.51681W	42:01:07.05660S	69:55:04.01517W	-16.0	-17.0
	Locus 2 Inputs	43:12:17.80000S	69:11:50.60000W	41:50:24.50000S	70:12:45.60000W	43:05:27.11300S	68:55:09.55756W	41:41:47.30664S	69:51:38.39963W	14.0	18.0
	Output	41:51:43.92702S	69:45:04.44818W								

test34	Locus 1 Inputs	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:32:07.98119S	67:10:24.55960W	42:24:53.32280S	69:15:09.51219W	-60.0	-55.0
	Locus 2 Inputs	43:12:17.80000S	69:11:50.60000W	41:45:17.50000S	72:11:50.60000W	42:12:48.71741S	68:21:45.17937W	40:42:57.94861S	71:16:28.51249W	70.0	75.0
	Output	42:00:18.17296S	68:47:07.75272W								
test35	Locus 1 Inputs	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:20:00.99821S	67:31:15.37383W	42:14:16.98565S	69:33:04.43858W	-40.0	-38.0
	Locus 2 Inputs	43:12:17.80000S	69:11:50.60000W	43:12:17.80000S	72:11:50.60000W	41:57:17.07312S	69:13:38.69558W	41:52:16.98865S	72:09:55.44922W	75.0	80.0
	Output	41:57:16.43557S	69:14:20.41022W								
test36	Locus 1 Inputs	39:55:35.80000S	68:12:34.70000W	41:50:24.50000S	70:12:45.60000W	40:50:11.29811S	66:38:54.23203W	42:51:30.15103S	68:29:23.51673W	-90.0	-98.0
	Locus 2 Inputs	41:12:17.80000S	67:11:50.60000W	42:30:17.80000S	70:11:50.60000W	40:07:50.59278S	68:02:20.22470W	41:21:13.00297S	71:02:42.74576W	75.0	78.8
	Output	N/A	N/A								
test37	Locus 1 Inputs	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:25:04.68264S	67:31:27.86642E	39:30:21.55001S	69:30:40.99953E	-40.0	-41.0
	Locus 2 Inputs	40:12:17.80000S	68:11:50.60000E	39:22:35.80000S	69:12:34.70000E	40:26:04.93621S	68:30:47.96796E	39:34:51.58798S	69:29:36.49340E	20.0	18.0
	Output	40:02:03.43498S	68:58:38.15474E								
test38	Locus 1 Inputs	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:40:56.32203S	67:57:12.65839E	39:49:27.87799S	70:02:18.78242E	-15.0	-10.0
	Locus 2 Inputs	40:12:17.80000S	68:11:50.60000E	39:55:35.80000S	70:12:34.70000E	40:10:19.37749S	68:11:24.60959E	39:52:38.87779S	70:11:50.67961E	-2.0	-3.0
	Output	39:55:03.75907S	69:56:15.20886E								
test39	Locus 1 Inputs	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:47:15.34302S	68:07:34.11126E	39:51:18.35063S	70:05:23.36577E	-5.0	-7.0
	Locus 2 Inputs	40:12:17.80000S	68:11:50.60000E	40:12:17.80000S	72:12:34.70000E	40:02:17.50440S	68:12:08.25927E	40:00:17.44311S	72:12:13.51920E	-10.0	-12.0
	Output	40:02:27.42225S	69:54:26.29229E								
test40	Locus 1 Inputs	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:40:56.32203S	67:57:12.65839E	39:44:32.88343S	69:54:07.36243E	-15.0	-18.0
	Locus 2 Inputs	38:01:17.80000S	68:11:50.60000E	40:12:17.80000S	69:56:34.70000E	38:01:49.06303S	68:10:45.76086E	40:13:22.25096S	69:54:22.52989E	1.0	2.0

	Output	39:57:32.74476S	69:41:29.82264E								
test41	Locus 1 Inputs	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:40:56.32203S	67:57:12.65839E	39:43:19.04394S	69:52:04.68943E	-15.0	-20.0
	Locus 2 Inputs	38:01:17.80000S	69:11:50.60000E	41:12:17.80000S	69:11:50.60000E	38:01:17.79319S	69:13:06.53044E	41:12:17.76952S	69:14:29.58125E	-1.0	-2.0
	Output	40:23:10.15763S	69:14:07.43973E								
test42	Locus 1 Inputs	41:50:24.50000S	68:12:45.60000E	39:55:35.80000S	70:12:34.70000E	41:40:56.32203S	67:57:12.65839E	39:44:32.88343S	69:54:07.36243E	-15.0	-18.0
	Locus 2 Inputs	38:01:17.80000S	69:11:50.60000E	41:50:24.50000S	68:12:45.60000E	38:00:55.02621S	69:09:21.49922E	41:49:48.38430S	68:08:49.69566E	2.0	3.0
	Output	41:22:22.77502S	68:16:27.47836E								
test43	Locus 1 Inputs	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	40:10:51.57579S	70:38:22.52584E	42:09:14.44140S	68:44:05.27630E	-25.0	-30.0
	Locus 2 Inputs	43:29:17.80000S	68:11:50.60000E	39:55:35.80000S	70:12:34.70000E	43:30:05.86262S	68:14:21.66324E	39:56:44.04610S	70:16:11.26613E	2.0	3.0
	Output	41:25:37.23971S	69:27:12.71895E								
test44	Locus 1 Inputs	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	40:00:29.47695S	70:20:48.75282E	41:56:04.38538S	68:22:07.56499E	-8.0	-9.0
	Locus 2 Inputs	43:29:17.80000S	68:11:50.60000E	39:55:35.80000S	68:11:50.60000E	43:29:16.97488S	68:25:34.80469E	39:55:34.91839S	68:26:08.51484E	10.0	11.0
	Output	41:52:35.54339S	68:25:50.12077E								
test45	Locus 1 Inputs	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	40:01:42.80403S	70:22:52.44969E	41:57:19.81081S	68:24:12.67104E	-10.0	-11.0
	Locus 2 Inputs	43:29:17.80000S	69:11:50.60000E	41:50:24.50000S	68:12:45.60000E	43:23:08.26920S	69:30:36.97906E	41:43:36.31250S	68:33:35.19449E	15.0	17.0
	Output	41:46:49.25922S	68:35:22.68060E								
test46	Locus 1 Inputs	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	40:44:05.62309S	71:35:48.62363E	42:39:04.17634S	69:34:51.53641E	-80.0	-78.0
	Locus 2 Inputs	43:29:17.80000S	69:11:50.60000E	41:45:07.50000S	66:11:50.60000E	42:55:41.16916S	69:46:17.72457E	41:10:04.65932S	66:49:24.86243E	42.0	45.0
	Output	N/A	N/A								
test47	Locus 1 Inputs	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	40:24:48.94167S	71:02:16.73937E	42:21:42.91321S	69:05:08.70917E	-48.0	-50.0
	Locus 2	42:09:17.80000S	70:11:50.60000E	42:09:17.80000S	66:11:50.60000E	41:24:17.29349S	70:10:26.53430E	41:20:17.23054S	66:13:22.04429E	45.0	49.0

	Inputs										
	Output	41:24:17.32470S	70:03:47.79505E								
test48	Locus 1 Inputs	39:55:35.80000S	70:12:34.70000E	41:50:24.50000S	68:12:45.60000E	40:50:05.06559S	71:46:21.29806E	42:51:59.99285S	69:57:19.49762E	-90.0	-99.0
	Locus 2 Inputs	42:29:17.80000S	69:11:50.60000E	44:01:17.80000S	66:11:50.60000E	41:48:42.56241S	68:32:33.37476E	43:15:31.54446S	65:29:49.92129E	50.0	55.0
	Output	N/A	N/A								

WGS84LocusTanFixedRadiusArc Test Results

Test Identifier	Locus 1 Input	Locus 1 Geodesic Start Latitude	Locus 1 Geodesic Start Longitude	Locus 1 Geodesic End Latitude	Locus 1 Geodesic End Longitude	Locus 1 Start Latitude	Locus 1 Start Longitude	Locus 1 End Latitude	Locus 1 End Longitude	Locus 1 Start Distance (nm)	Locus 1 End Distance (nm)	
	Locus 2 Input	Locus 2 Geodesic Start Latitude	Locus 2 Geodesic Start Longitude	Locus 2 Geodesic End Latitude	Locus 2 Geodesic End Longitude	Locus 2 Start Latitude	Locus 2 Start Longitude	Locus 2 End Latitude	Locus 2 End Longitude	Locus 2 Start Distance (nm)	Locus 2 End Distance (nm)	Arc Radius (nm)
	Output	Arc Direction	Arc Center Latitude	Arc Center Longitude	Tangent Point 1 Latitude	Tangent Point 1 Longitude	Tangent Point 2 Latitude	Tangent Point 2 Longitude				
test1	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	65:52:03.22158W	40:11:24.54424N	70:12:45.60000W	40:06:30.74430N	65:51:59.39953W	-1.0	-1.0	
	Locus 2 Inputs	38:45:52.61565N	68:43:43.42897W	42:04:35.80000N	68:12:34.70000W	38:45:59.57764N	68:44:59.62433W	42:04:43.10740N	68:13:54.67112W	-1.0	-1.0	2.0
	Output	1	40:12:42.90980N	68:34:26.17064W	40:10:42.84203N	68:34:29.05890W	40:12:28.74286N	68:31:50.63189W				
test2	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	65:52:03.22158W	40:11:24.54424N	70:12:45.60000W	40:07:30.71740N	65:51:55.57562W	-1.0	-2.0	
	Locus 2 Inputs	38:45:52.61565N	68:43:43.42897W	42:04:35.80000N	68:12:34.70000W	38:46:06.52583N	68:46:15.82380W	42:04:43.10740N	68:13:54.67112W	-2.0	-1.0	2.0
	Output	1	40:13:05.94559N	68:35:07.04402W	40:11:05.86817N	68:35:09.12978W	40:12:51.19787N	68:32:31.58271W				
test3	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	65:52:03.22158W	40:09:24.45559N	70:12:45.60000W	40:04:30.79747N	65:52:07.04176W	1.0	1.0	
	Locus 2 Inputs	38:45:52.61565N	68:43:43.42897W	42:04:35.80000N	68:12:34.70000W	38:45:45.63986N	68:42:27.23774W	42:04:28.47712N	68:11:14.73398W	1.0	1.0	3.0
	Output	1	40:11:41.86765N	68:33:16.75939W	40:08:41.76592N	68:33:21.14059W	40:11:20.55656N	68:29:23.52219W				
test4	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	65:52:03.22158W	40:09:24.45559N	70:12:45.60000W	40:03:30.82374N	65:52:10.86008W	1.0	2.0	
	Locus 2 Inputs	38:45:52.61565N	68:43:43.42897W	42:04:35.80000N	68:12:34.70000W	38:45:38.65027N	68:41:11.05062W	42:04:28.47712N	68:11:14.73398W	2.0	1.0	2.0
	Outputs	1	40:10:16.88671N	68:31:25.71947W	40:08:16.83227N	68:31:29.47643W	40:10:03.24871N	68:28:50.19280W				
test5	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	65:52:03.22158W	40:11:24.54424N	70:12:45.60000W	40:06:30.74430N	65:51:59.39953W	-1.0	-1.0	

	Locus 2 Inputs	38:45:52.61565N	68:43:43.42897W	42:04:35.80000N	68:12:34.70000W	38:45:45.63986N	68:42:27.23774W	42:04:28.47712N	68:11:14.73398W	1.0	1.0	2.0
	Outputs	1	40:12:40.65368N	68:31:48.78239W	40:10:40.58699N	68:31:51.74766W	40:12:26.42800N	68:29:13.25421W				
test6	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	65:52:03.22158W	40:11:24.54424N	70:12:45.60000W	40:07:30.71740N	65:51:55.57562W	-1.0	-2.0	
	Locus 2 Inputs	39:01:03.20612N	64:47:37.88516W	41:04:35.80000N	68:12:34.70000W	38:59:30.11207N	64:49:15.15895W	41:03:47.85119N	68:13:22.43586W	-2.0	-1.0	2.0
	Outputs	1	40:11:11.47812N	66:48:27.88628W	40:09:11.45603N	66:48:33.10050W	40:12:45.83878N	66:46:51.01920W				
test7	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	36:50:12.19034N	70:12:45.60000W	40:10:24.47060N	70:10:09.05140W	36:50:12.18382N	70:11:30.85698W	-2.0	-1.0	
	Locus 2 Inputs	38:10:03.48978N	71:19:20.31330W	41:04:35.80000N	69:12:34.70000W	38:10:32.28515N	71:20:27.08581W	41:05:35.81205N	69:14:52.14842W	-1.0	-2.0	3.0
	Outputs	1	40:02:07.33483N	70:06:18.24880W	40:02:08.38728N	70:10:12.59388W	40:00:39.58907N	70:02:53.61827W				
test8	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	36:50:55.82985N	69:51:03.26240W	40:10:14.00441N	70:15:21.54623W	36:50:50.82261N	69:52:17.75645W	2.0	1.0	
	Locus 2 Inputs	38:02:20.08909N	70:59:31.55324W	41:04:35.80000N	69:12:34.70000W	38:01:55.78214N	70:58:22.10446W	41:03:45.03132N	69:10:10.92536W	1.0	2.0	2.0
	Outputs	1	39:33:03.94733N	70:08:17.79894W	39:32:52.95267N	70:10:52.28475W	39:32:13.76421N	70:05:56.86447W				
test9	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	37:35:08.04987N	67:31:03.26743W	40:11:41.67410N	70:10:45.63905W	37:35:45.28280N	67:30:04.02642W	-2.0	-1.0	
	Locus 2 Inputs	37:45:08.92078N	67:50:36.68693W	41:04:35.80000N	68:12:34.70000W	37:45:03.92163N	67:51:52.07835W	41:04:25.30511N	68:15:12.76089W	-1.0	-2.0	3.0
	Outputs	1	38:09:11.85636N	67:58:23.76723W	38:07:20.13532N	68:01:22.77621W	38:09:27.92001N	67:54:36.46855W				
test10	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	42:52:36.59194N	67:36:46.62423W	40:09:15.60015N	70:10:37.39889W	42:52:00.69938N	67:35:41.22861W	2.0	1.0	
	Locus 2 Inputs	39:55:58.22492N	69:41:27.77537W	43:04:35.80000N	68:12:34.70000W	39:56:37.33295N	69:43:55.28280W	43:04:56.31878N	68:13:51.63678W	-2.0	-1.0	2.0
	Outputs	1	41:21:07.17487N	69:07:28.71056W	41:19:57.56277N	69:05:18.90622W	41:20:26.72878N	69:04:58.69814W				
test11	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	42:41:33.37650N	67:18:27.47257W	40:11:41.67410N	70:14:45.56095W	42:42:13.47196N	67:19:28.01914W	-2.0	-1.0	
	Locus	38:47:21.082	67:28:11.049	42:04:35.800	68:12:34.700	38:47:40.921	67:25:39.675	42:04:46.215	68:11:15.351	2.0	1.0	2.0

	2 Inputs	27N	43W	00N	00W	31N	82W	51N	30W			
	Outputs	1	42:00:55.56489N	68:13:02.90937W	41:59:35.84742N	68:11:02.56225W	42:01:16.98268N	68:10:24.50096W				
test12	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	36:53:06.45688N	70:56:01.64236W	40:10:34.91946N	70:14:02.68842W	36:53:26.36762N	70:58:29.16009W	1.0	2.0	
	Locus 2 Inputs	37:29:19.58128N	71:54:04.49005W	40:04:35.80000N	69:12:34.70000W	37:28:05.07986N	71:52:06.21943W	40:03:57.19927N	69:11:34.83283W	2.0	1.0	2.0
	Outputs	1	38:53:33.20366N	70:29:18.12452W	38:53:54.26304N	70:31:49.44779W	38:52:17.75784N	70:27:18.54619W				
test13	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	41:46:39.60265N	74:04:18.29468W	40:08:40.49257N	70:14:03.84114W	41:45:46.34067N	74:04:55.27667W	-2.0	-1.0	
	Locus 2 Inputs	40:59:32.62580N	72:36:48.38318W	41:04:35.80000N	68:12:34.70000W	41:00:32.58502N	72:36:52.38181W	41:06:35.86947N	68:12:34.70000W	-1.0	-2.0	2.0
	Outputs	-1	40:59:45.33128N	72:06:21.69023W	40:58:00.36264N	72:07:38.62039W	41:01:45.25431N	72:06:29.56162W				
test14	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	43:02:23.57855N	67:56:26.25658W	40:09:24.43355N	70:10:30.05811W	43:01:52.20697N	67:55:16.51206W	2.0	1.0	
	Locus 2 Inputs	43:40:32.94322N	72:11:18.24139W	42:04:35.80000N	68:12:34.70000W	43:42:19.59129N	72:10:02.38529W	42:05:27.78065N	68:11:54.40631W	-2.0	-1.0	2.0
	Outputs	-1	42:12:06.97304N	68:32:37.78057W	42:13:08.44340N	68:34:56.48241W	42:13:50.86269N	68:31:16.86380W				
test15	Locus 1 Inputs	40:10:24.50000N	70:12:45.60000W	39:30:57.68485N	65:58:09.51526W	40:11:23.63181N	70:12:32.00453W	39:32:54.83806N	65:57:35.35782W	-1.0	-2.0	
	Locus 2 Inputs	41:23:57.63585N	67:49:25.73753W	38:04:35.80000N	68:12:34.70000W	41:24:03.11784N	67:50:45.13238W	38:04:46.24310N	68:15:06.10222W	1.0	2.0	2.0
	Outputs	-1	39:51:21.55710N	68:04:58.82454W	39:53:19.41110N	68:04:28.85574W	39:51:10.29889N	68:02:23.68937W				
test16	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	40:05:30.77099S	65:52:03.22158W	40:11:24.54424S	70:12:45.60000W	40:07:30.71740S	65:51:55.57562W	1.0	2.0	
	Locus 2 Inputs	41:23:11.70467S	68:44:56.51207W	38:04:35.80000S	68:12:34.70000W	41:23:27.02365S	68:42:18.38698W	38:04:43.11348S	68:11:19.27704W	2.0	1.0	2.0
	Outputs	1	40:09:04.41861S	68:32:58.98277W	40:11:04.49607S	68:32:56.83433W	40:09:18.87549S	68:30:23.61882W				
test17	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	40:05:30.77099S	65:52:03.22158W	40:09:24.45559S	70:12:45.60000W	40:03:30.82374S	65:52:10.86008W	-1.0	-2.0	
	Locus 2	40:51:02.56824S	65:49:04.57909W	38:04:35.80000S	68:12:34.70000W	40:52:10.59442S	65:51:14.90408W	38:05:08.50946S	68:13:38.43618W	-2.0	-1.0	2.0

	Inputs											
	Outputs	1	40:03:14.47849S	66:37:33.38495W	40:05:14.44565S	66:37:26.29402W	40:02:07.80789S	66:35:23.42243W				
test18	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	43:30:29.87690S	70:12:45.60000W	40:10:24.47060S	70:10:09.05140W	43:30:29.86864S	70:11:23.15209W	-2.0	-1.0	
	Locus 2 Inputs	40:56:44.38623S	70:24:30.08251W	38:04:35.80000S	68:12:34.70000W	40:56:13.10174S	70:25:37.65728W	38:03:35.71346S	68:14:46.28392W	-1.0	-2.0	3.0
	Outputs	1	40:25:56.59723S	70:06:18.82840W	40:25:55.84892S	70:10:14.54714W	40:27:29.08986S	70:02:56.51901W				
test19	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	43:29:41.80326S	69:48:49.55137W	40:10:34.93724S	70:15:21.55954W	43:29:47.30291S	69:50:11.63525W	2.0	1.0	
	Locus 2 Inputs	40:46:58.96510S	70:43:33.36104W	38:04:35.80000S	68:12:34.70000W	40:47:34.75534S	70:42:29.93966W	38:05:44.68644S	68:10:30.17729W	1.0	2.0	2.0
	Outputs	1	40:13:25.07866S	70:12:23.80009W	40:13:36.12195S	70:14:59.80379W	40:14:36.57101S	70:10:17.90579W				
test20	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	42:41:33.37650S	67:18:27.47257W	40:09:07.29111S	70:10:45.71453W	42:40:53.27207S	67:17:26.94763W	-2.0	-1.0	
	Locus 2 Inputs	41:23:57.63585S	68:49:25.73753W	38:04:35.80000S	69:12:34.70000W	41:24:03.11784S	68:50:45.13238W	38:04:46.24310S	69:15:06.10222W	-1.0	-2.0	3.0
	Outputs	1	41:11:40.44578S	68:56:19.65774W	41:13:37.47945S	68:59:20.93278W	41:11:23.24899S	68:52:22.32154W				
test21	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	37:24:53.77602S	67:48:48.29235W	40:11:33.36017S	70:10:37.32686W	37:25:26.92444S	67:47:45.47885W	2.0	1.0	
	Locus 2 Inputs	40:23:45.26180S	71:17:39.82870W	38:04:35.80000S	68:12:34.70000W	40:22:17.49277S	71:19:27.00296W	38:03:53.32348S	68:13:28.42249W	-2.0	-1.0	2.0
	Outputs	-1	38:19:04.22608S	68:29:21.21374W	38:17:57.68753S	68:31:28.14715W	38:17:38.59151S	68:31:08.12837W				
test22	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	37:35:08.04987S	67:31:03.26743W	40:09:07.29111S	70:14:45.48547W	37:34:30.80862S	67:32:02.49205W	-2.0	-1.0	
	Locus 2 Inputs	41:21:34.31610S	67:26:28.97088W	38:04:35.80000S	68:12:34.70000W	41:21:12.42483S	67:23:52.29253W	38:04:25.36303S	68:11:19.87010W	2.0	1.0	2.0
	Outputs	1	38:11:04.15943S	68:12:22.74671W	38:12:19.77140S	68:10:24.46167W	38:10:42.67713S	68:09:53.00775W				
test23	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	43:27:18.01078S	71:00:24.95285W	40:10:14.06628S	70:14:02.68187W	43:26:56.04570S	71:03:06.91312W	1.0	2.0	
	Locus 2 Inputs	42:35:45.27780S	72:06:36.63038W	40:04:35.80000S	69:12:34.70000W	42:37:05.45079S	72:04:35.69054W	40:05:14.39206S	69:11:34.81405W	2.0	1.0	2.0

	Outputs	1	41:09:00.28976S	70:25:29.09105W	41:08:38.53506S	70:28:05.30341W	41:10:18.25757S	70:23:28.27022W				
test24	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	38:26:46.46774S	73:53:15.48461W	40:12:08.49221S	70:14:03.90752W	38:27:37.21779S	73:53:56.33533W	-2.0	-1.0	
	Locus 2 Inputs	38:59:53.21474S	73:29:12.95994W	39:04:35.80000S	69:12:34.70000W	38:58:53.22454S	73:29:09.34242W	39:02:35.68826S	69:12:34.70000W	-1.0	-2.0	2.0
	Outputs	-1	39:02:21.67793S	72:38:46.91955W	39:04:03.70982S	72:40:08.19904W	39:00:21.62999S	72:38:41.87165W				
test25	Locus 1 Inputs	40:10:24.50000S	70:12:45.60000W	37:15:52.75197S	68:07:31.78007W	40:11:24.52218S	70:10:29.99173W	37:16:21.59037S	68:06:25.83960W	2.0	1.0	
	Locus 2 Inputs	36:21:10.67774S	71:47:01.13406W	38:04:35.80000S	68:12:34.70000W	36:19:28.94358S	71:45:42.08355W	38:03:43.77956S	68:11:56.71384W	-2.0	-1.0	2.0
	Outputs	-1	37:57:02.69588S	68:31:21.63789W	37:56:05.07632S	68:33:34.74930W	37:55:19.15511S	68:30:04.71414W				
test26	Locus 1 Inputs	40:10:24.50000S	68:12:45.60000E	40:05:30.77099S	72:33:27.97842E	40:11:24.54424S	68:12:45.60000E	40:07:30.71740S	72:33:35.62438E	1.0	2.0	
	Locus 2 Inputs	41:23:11.70467S	69:40:12.88793E	38:04:35.80000S	70:12:34.70000E	41:23:27.02365S	69:42:51.01302E	38:04:43.11348S	70:13:50.12296E	2.0	1.0	2.0
	Outputs	1	40:09:04.64798S	69:52:10.38091E	40:11:04.72555S	69:52:12.51866E	40:09:19.10487S	69:54:45.74500E				
test27	Locus 1 Inputs	40:10:24.50000S	68:12:45.60000E	40:05:30.77099S	72:33:27.97842E	40:09:24.45559S	68:12:45.60000E	40:03:30.82374S	72:33:20.33992E	-1.0	-2.0	
	Locus 2 Inputs	40:51:02.56824S	72:36:04.82091E	38:04:35.80000S	70:12:34.70000E	40:52:10.59442S	72:33:54.49592E	38:05:08.50946S	70:11:30.96382E	-2.0	-1.0	2.0
	Outputs	1	40:03:15.21615S	71:47:36.65550E	40:05:15.18367S	71:47:43.73613E	40:02:08.54536S	71:49:46.61823E				
test28	Locus 1 Inputs	40:10:24.50000S	68:12:45.60000E	43:30:29.87690S	68:12:45.60000E	40:10:24.47060S	68:15:22.14860E	43:30:29.86864S	68:14:08.04791E	-2.0	-1.0	
	Locus 2 Inputs	40:56:44.38623S	68:00:39.31749E	38:04:35.80000S	70:12:34.70000E	40:56:13.10174S	67:59:31.74272E	38:03:35.71346S	70:10:23.11608E	-1.0	-2.0	3.0
	Outputs	1	40:25:28.59897S	68:19:12.51023E	40:25:27.85071S	68:15:16.81863E	40:27:01.08104S	68:22:34.80466E				
test29	Locus 1 Inputs	40:10:24.50000S	68:12:45.60000E	43:29:41.80326S	68:36:41.64863E	40:10:34.93724S	68:10:09.64046E	43:29:47.30291S	68:35:19.56475E	2.0	1.0	
	Locus 2 Inputs	40:46:58.96510S	67:41:36.03896E	38:04:35.80000S	70:12:34.70000E	40:47:34.75534S	67:42:39.46034E	38:05:44.68644S	70:14:39.22271E	1.0	2.0	2.0
	Outpu	1	40:13:05.036	68:13:04.979	40:13:16.079	68:10:28.987	40:14:16.523	68:15:10.868				

	ts		69S	01E	09S	97E	26S	66E				
test30	Locus 1 Inputs	40:10:24.500 00S	68:12:45.600 00E	42:41:33.376 50S	71:07:03.727 43E	40:09:07.291 11S	68:14:45.485 47E	42:40:53.272 07S	71:08:04.252 37E	-2.0	-1.0	
	Locus 2 Inputs	41:23:57.635 85S	69:35:43.662 47E	38:04:35.800 00S	69:12:34.700 00E	41:24:03.117 84S	69:34:24.267 62E	38:04:46.243 10S	69:10:03.297 78E	-1.0	-2.0	3.0
	Outpu ts	1	41:11:18.773 46S	69:28:47.001 30E	41:13:15.796 50S	69:25:45.730 71E	41:11:01.578 21S	69:32:44.315 95E				
test31	Locus 1 Inputs	40:10:24.500 00S	68:12:45.600 00E	37:24:53.776 02S	70:36:42.907 65E	40:11:33.360 17S	68:14:53.873 14E	37:25:26.924 44S	70:37:45.721 15E	2.0	1.0	
	Locus 2 Inputs	40:23:45.261 80S	67:07:29.571 30E	38:04:35.800 00S	70:12:34.700 00E	40:22:17.492 77S	67:05:42.397 04E	38:03:53.323 48S	70:11:40.977 51E	-2.0	-1.0	2.0
	Outpu ts	-1	38:18:15.297 86S	69:56:51.276 53E	38:17:08.771 55S	69:54:44.356 35E	38:16:49.679 07S	69:55:04.361 25E				
test32	Locus 1 Inputs	40:10:24.500 00S	68:12:45.600 00E	37:35:08.049 87S	70:54:27.932 57E	40:09:07.291 11S	68:10:45.714 53E	37:34:30.808 62S	70:53:28.707 95E	-2.0	-1.0	
	Locus 2 Inputs	41:21:34.316 10S	70:58:40.429 12E	38:04:35.800 00S	70:12:34.700 00E	41:21:12.424 83S	71:01:17.107 47E	38:04:25.363 03S	70:13:49.529 90E	2.0	1.0	2.0
	Outpu ts	1	38:11:21.506 67S	70:12:50.643 10E	38:12:37.123 56S	70:14:48.930 82E	38:11:00.022 97S	70:15:20.391 60E				
test33	Locus 1 Inputs	40:10:24.500 00S	68:12:45.600 00E	43:27:18.010 78S	67:25:06.247 15E	40:10:14.066 28S	68:11:28.518 13E	43:26:56.045 70S	67:22:24.286 88E	1.0	2.0	
	Locus 2 Inputs	42:35:45.277 80S	66:18:32.769 62E	40:04:35.800 00S	69:12:34.700 00E	42:37:05.450 79S	66:20:33.709 46E	40:05:14.392 06S	69:13:34.585 95E	2.0	1.0	2.0
	Outpu ts	1	41:08:35.701 13S	68:00:08.093 19E	41:08:13.948 66S	67:57:31.896 48E	41:09:53.660 93S	68:02:08.910 61E				
test34	Locus 1 Inputs	40:10:24.500 00S	68:12:45.600 00E	38:26:46.467 74S	64:32:15.715 39E	40:12:08.492 21S	68:11:27.292 48E	38:27:37.217 79S	64:31:34.864 67E	-2.0	-1.0	
	Locus 2 Inputs	38:59:53.214 74S	64:55:56.440 06E	39:04:35.800 00S	69:12:34.700 00E	38:58:53.224 54S	64:56:00.057 58E	39:02:35.688 26S	69:12:34.700 00E	-1.0	-2.0	2.0
	Outpu ts	-1	39:02:22.266 16S	65:46:45.495 14E	39:04:04.298 28S	65:45:24.215 95E	39:00:22.217 94S	65:46:50.532 25E				
test35	Locus 1 Inputs	40:10:24.500 00S	68:12:45.600 00E	37:15:52.751 97S	70:17:59.419 93E	40:11:24.522 18S	68:15:01.208 27E	37:16:21.590 37S	70:19:05.360 40E	2.0	1.0	
	Locus 2 Inputs	36:21:10.677 74S	66:38:08.265 94E	38:04:35.800 00S	70:12:34.700 00E	36:19:28.943 58S	66:39:27.316 45E	38:03:43.779 56S	70:13:12.686 16E	-2.0	-1.0	2.0
	Outpu ts	-1	37:57:10.383 18S	69:54:04.258 02E	37:56:12.761 97S	69:51:51.143 91E	37:55:26.839 44S	69:55:21.177 57E				

test36	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	40:05:30.77099N	72:33:27.97842E	40:09:24.45559N	68:12:45.60000E	40:03:30.82374N	72:33:20.33992E	1.0	2.0	
	Locus 2 Inputs	38:52:47.19234N	68:57:43.98857E	42:04:35.80000N	70:12:34.70000E	38:52:13.67562N	69:00:11.54546E	42:04:18.24336N	70:13:51.74273E	2.0	1.0	2.0
	Outputs	1	40:10:43.92255N	69:26:42.17253E	40:08:43.85504N	69:26:39.21907E	40:10:10.37031N	69:29:12.48839E				
test37	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	40:05:30.77099N	72:33:27.97842E	40:11:24.54424N	68:12:45.60000E	40:07:30.71740N	72:33:35.62438E	-1.0	-2.0	
	Locus 2 Inputs	39:13:29.53578N	72:28:55.25646E	42:04:35.80000N	70:12:34.70000E	39:12:28.52052N	72:26:42.26184E	42:04:03.98622N	70:11:26.38299E	-2.0	-1.0	2.0
	Outputs	1	40:11:08.56456N	71:38:56.66811E	40:09:08.54388N	71:38:51.39855E	40:12:09.97080N	71:41:11.24340E				
test38	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	36:50:12.19034N	68:12:45.60000E	40:10:24.47060N	68:15:22.14860E	36:50:12.18382N	68:14:00.34302E	-2.0	-1.0	
	Locus 2 Inputs	39:10:02.81529N	68:04:02.52380E	42:04:35.80000N	70:12:34.70000E	39:10:31.56185N	68:02:54.78528E	42:05:35.80077N	70:10:15.11366E	-1.0	-2.0	3.0
	Outputs	1	39:39:58.78561N	68:19:02.28704E	39:39:59.83137N	68:15:09.19344E	39:38:32.84035N	68:22:27.11164E				
test39	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	36:50:55.82985N	68:34:27.93760E	40:10:14.00441N	68:10:09.65377E	36:50:50.82261N	68:33:13.44355E	2.0	1.0	
	Locus 2 Inputs	39:19:02.15978N	67:44:48.14899E	42:04:35.80000N	70:12:34.70000E	39:18:29.10241N	67:45:52.68873E	42:03:26.92161N	70:14:46.65709E	1.0	2.0	2.0
	Outputs	1	39:55:11.69116N	68:14:35.29494E	39:55:00.63826N	68:11:59.99070E	39:54:04.52166N	68:16:44.57011E				
test40	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	37:35:08.04987N	70:54:27.93257E	40:11:41.67410N	68:14:45.56095E	37:35:45.28280N	70:55:27.17358E	-2.0	-1.0	
	Locus 2 Inputs	38:45:10.91527N	69:34:50.91008E	42:04:35.80000N	69:12:34.70000E	38:45:05.92527N	69:33:34.47694E	42:04:25.30587N	69:09:54.18228E	-1.0	-2.0	3.0
	Outputs	1	39:08:09.55199N	69:27:04.93864E	39:06:16.31747N	69:24:05.04175E	39:08:25.58999N	69:30:55.36592E				
test41	Locus 1 Inputs	40:10:24.50000N	68:12:45.60000E	42:52:36.59194N	70:48:44.57577E	40:09:15.60015N	68:14:53.80111E	42:52:00.69938N	70:49:49.97139E	2.0	1.0	
	Locus 2 Inputs	39:40:36.03510N	67:09:25.73456E	42:04:35.80000N	70:12:34.70000E	39:41:57.92929N	67:07:32.03241E	42:05:18.23971N	70:11:37.71848E	-2.0	-1.0	2.0
	Outputs	-1	41:42:57.59835N	69:45:22.81427E	41:44:07.68026N	69:43:12.69417E	41:44:22.45121N	69:43:29.43785E				
test42	Locus	40:10:24.500	68:12:45.600	42:41:33.376	71:07:03.727	40:11:41.674	68:10:45.639	42:42:13.471	71:06:03.180	-2.0	-1.0	

	1 Inputs	00N	00E	50N	43E	10N	05E	96N	86E			
	Locus 2 Inputs	38:47:21.082 27N	70:56:58.350 57E	42:04:35.800 00N	70:12:34.700 00E	38:47:40.921 31N	70:59:29.724 18E	42:04:46.215 51N	70:13:54.048 70E	2.0	1.0	2.0
	Outpu ts	1	42:00:40.360 69N	70:12:10.192 54E	41:59:20.648 42N	70:14:10.537 96E	42:01:01.777 07N	70:14:48.590 80E				
test43	Locus 1 Inputs	40:10:24.500 00N	68:12:45.600 00E	36:53:06.456 88N	67:29:29.557 64E	40:10:34.919 46N	68:11:28.511 58E	36:53:26.367 62N	67:27:02.039 91E	1.0	2.0	
	Locus 2 Inputs	37:29:19.581 28N	66:31:04.909 95E	40:04:35.800 00N	69:12:34.700 00E	37:28:05.079 86N	66:33:03.180 57E	40:03:57.199 27N	69:13:34.567 17E	2.0	1.0	2.0
	Outpu ts	1	38:54:00.302 76N	67:56:19.259 60E	38:54:21.364 33N	67:53:47.920 86E	38:52:44.849 07N	67:58:18.842 32E				
test44	Locus 1 Inputs	40:10:24.500 00N	68:12:45.600 00E	41:46:39.602 65N	64:21:12.905 32E	40:08:40.492 57N	68:11:27.358 86E	41:45:46.340 67N	64:20:35.923 33E	-2.0	-1.0	
	Locus 2 Inputs	40:59:32.625 80N	64:48:21.016 82E	41:04:35.800 00N	69:12:34.700 00E	41:00:32.585 02N	64:48:17.018 19E	41:06:35.869 47N	69:12:34.700 00E	-1.0	-2.0	2.0
	Outpu ts	-1	41:01:38.016 65N	66:14:41.465 26E	40:59:52.998 91N	66:13:24.616 88E	41:03:37.995 84N	66:14:35.281 50E				
test45	Locus 1 Inputs	40:10:24.500 00N	68:12:45.600 00E	43:02:23.578 55N	70:29:04.943 42E	40:09:24.433 55N	68:15:01.141 89E	43:01:52.206 97N	70:30:14.687 94E	2.0	1.0	
	Locus 2 Inputs	43:40:32.943 22N	66:13:51.158 61E	42:04:35.800 00N	70:12:34.700 00E	43:42:19.591 29N	66:15:07.014 71E	42:05:27.780 65N	70:13:14.993 69E	-2.0	-1.0	2.0
	Outpu ts	-1	42:11:59.998 55N	69:52:47.824 75E	42:13:01.467 06N	69:50:29.125 65E	42:13:43.885 07N	69:54:08.746 43E				

WGS84PerpIntercept Test Results

Test Identifier	Geodesic Start Latitude	Geodesic Start Longitude	Geodesic Azimuth (degrees)	Test Point Latitude	Test Point Longitude	Azimuth From Test Point To Intercept (degrees)	Distance From Test Point To Intercept (nm)	Intercept Latitude	Intercept Longitude
test1	40:10:24.50000N	70:12:45.60000W	38.0	42:04:35.80000N	68:12:40.70000W	129.31642	0.41489	42:04:20.02035N	68:12:14.84062W
test2	40:10:24.50000N	70:12:45.60000W	62.0	42:04:35.80000N	68:12:40.70000W	153.29737	59.66462	41:11:10.62477N	67:37:10.15895W
test3	40:10:24.50000N	70:12:45.60000W	90.0	42:04:35.80000N	68:12:40.70000W	181.29165	115.13091	40:09:25.68132N	68:16:03.75475W
test4	40:10:24.50000N	70:12:45.60000W	127.0	42:04:35.80000N	68:12:40.70000W	218.31581	145.78046	40:09:07.48064N	70:10:32.43942W
test5	40:10:24.50000N	70:12:45.60000W	150.0	42:04:35.80000N	68:12:40.70000W	241.33453	135.01795	40:58:00.14293N	70:49:04.80560W
test6	40:10:24.50000N	70:12:45.60000W	0.0	42:04:35.80000N	68:12:40.70000W	271.34146	89.41691	42:05:38.63720N	70:12:45.60000W
test7	40:10:24.50000N	70:12:45.60000W	335.0	42:04:35.80000N	68:12:40.70000W	246.33745	129.70818	41:10:42.02846N	70:50:01.67112W
test8	40:10:24.50000N	70:12:45.60000W	305.0	42:04:35.80000N	68:12:40.70000W	216.31402	145.61723	40:06:15.57774N	70:05:03.11962W
test9	40:10:24.50000N	70:12:45.60000W	180.0	38:04:35.80000N	72:12:40.70000W	88.76710	94.68092	38:05:36.99418N	70:12:45.60000W
test10	40:10:24.50000N	70:12:45.60000W	230.0	38:04:35.80000N	72:12:40.70000W	318.72576	34.59985	38:30:34.10445N	72:41:45.37882W
test11	40:10:24.50000N	70:12:45.60000W	270.0	38:04:35.80000N	72:12:40.70000W	358.70998	124.63008	40:09:18.54080N	72:16:20.21715W
test12	40:10:24.50000S	70:12:45.60000W	38.0	38:04:35.80000S	68:12:40.70000W	126.73606	2.00964	38:05:47.98305S	68:10:38.28715W
test13	40:10:24.50000S	70:12:45.60000W	62.0	38:04:35.80000S	68:12:40.70000W	150.71427	65.51427	39:01:40.59903S	67:31:33.29933W
test14	40:10:24.50000S	70:12:45.60000W	90.0	38:04:35.80000S	68:12:40.70000W	178.70822	124.62717	40:09:18.36107S	68:09:00.88927W
test15	40:10:24.50000S	70:12:45.60000W	127.0	38:04:35.80000S	68:12:40.70000W	215.73655	156.61476	40:10:50.64448S	70:12:00.36233W
test16	40:10:24.50000S	70:12:45.60000W	150.0	38:04:35.80000S	68:12:40.70000W	238.75798	144.43973	39:17:48.31169S	70:51:45.99999W
test17	40:10:24.50000S	70:12:45.60000W	0.0	38:04:35.80000S	68:12:40.70000W	268.76542	94.80986	38:05:37.16104S	70:12:45.60000W
test18	40:10:24.50000S	70:12:45.60000W	335.0	38:04:35.80000S	68:12:40.70000W	243.76128	138.61172	39:04:08.70412S	70:52:19.87385W
test19	40:10:24.50000S	70:12:45.60000W	305.0	38:04:35.80000S	68:12:40.70000W	213.73448	156.49404	40:13:57.58564S	70:06:08.18853W
test20	40:10:24.50000S	70:12:45.60000W	180.0	42:04:35.80000S	72:12:40.70000W	91.33964	89.29531	42:05:38.46633S	70:12:45.60000W
test21	40:10:24.50000S	70:12:45.60000W	230.0	42:04:35.80000S	72:12:40.70000W	321.30417	30.78578	41:40:30.62405S	72:38:21.72071W
test22	40:10:24.50000S	70:12:45.60000W	270.0	42:04:35.80000S	72:12:40.70000W	1.28990	115.12817	40:09:25.84116S	72:09:17.92603W
test23	40:10:24.50000S	68:12:45.60000E	38.0	38:04:35.80000S	70:12:40.70000E	126.73774	2.11300	38:05:51.69739S	70:14:49.40745E
test24	40:10:24.50000S	68:12:45.60000E	62.0	38:04:35.80000S	70:12:40.70000E	150.71599	65.57735	39:01:43.94797S	70:53:50.37701E
test25	40:10:24.50000S	68:12:45.60000E	90.0	38:04:35.80000S	70:12:40.70000E	178.70998	124.63008	40:09:18.54080S	70:16:20.21715E
test26	40:10:24.50000S	68:12:45.60000E	127.0	38:04:35.80000S	70:12:40.70000E	215.73831	156.53943	40:10:46.85840S	68:13:24.28550E
test27	40:10:24.50000S	68:12:45.60000E	150.0	38:04:35.80000S	70:12:40.70000E	238.75971	144.32946	39:17:44.81540S	67:33:42.64546E
test28	40:10:24.50000S	68:12:45.60000E	0.0	38:04:35.80000S	70:12:40.70000E	268.76710	94.68092	38:05:36.99418S	68:12:45.60000E
test29	40:10:24.50000S	68:12:45.60000E	335.0	38:04:35.80000S	70:12:40.70000E	243.76299	138.49604	39:04:05.58767S	67:33:09.49758E
test30	40:10:24.50000S	68:12:45.60000E	305.0	38:04:35.80000S	70:12:40.70000E	213.73624	156.42241	40:13:53.89461S	68:19:16.11563E
test31	40:10:24.50000S	72:12:45.60000E	180.0	42:04:35.80000S	70:12:40.70000E	91.34146	89.41691	42:05:38.63720S	72:12:45.60000E
test32	40:10:24.50000S	72:12:45.60000E	230.0	42:04:35.80000S	70:12:40.70000E	321.30598	30.70974	41:40:34.16471S	69:47:03.52290E
test33	40:10:24.50000S	72:12:45.60000E	270.0	42:04:35.80000S	70:12:40.70000E	1.29165	115.13091	40:09:25.68132S	70:16:03.75475E
test34	40:10:24.50000N	68:12:45.60000E	38.0	42:04:35.80000N	70:12:40.70000E	129.31459	0.50899	42:04:16.44172N	70:13:12.42516E
test35	40:10:24.50000N	68:12:45.60000E	62.0	42:04:35.80000N	70:12:40.70000E	153.29558	59.71928	41:11:07.73298N	70:48:13.29934E
test36	40:10:24.50000N	68:12:45.60000E	90.0	42:04:35.80000N	70:12:40.70000E	181.28990	115.12817	40:09:25.84116N	70:09:17.92603E
test37	40:10:24.50000N	68:12:45.60000E	127.0	42:04:35.80000N	70:12:40.70000E	218.31405	145.70504	40:09:10.93426N	68:14:52.79291E
test38	40:10:24.50000N	68:12:45.60000E	150.0	42:04:35.80000N	70:12:40.70000E	241.33274	134.91123	40:58:03.16688N	67:36:24.05438E
test39	40:10:24.50000N	68:12:45.60000E	0.0	42:04:35.80000N	70:12:40.70000E	271.33964	89.29531	42:05:38.46633N	68:12:45.60000E
test40	40:10:24.50000N	68:12:45.60000E	335.0	42:04:35.80000N	70:12:40.70000E	246.33565	129.59677	41:10:44.67776N	67:35:27.86348E
test41	40:10:24.50000N	68:12:45.60000E	305.0	42:04:35.80000N	70:12:40.70000E	216.31226	145.54520	40:06:18.96327N	68:20:21.80300E

test42	40:10:24.50000N	72:12:45.60000E	180.0	38:04:35.80000N	70:12:40.70000E	88.76542	94.80986	38:05:37.16104N	72:12:45.60000E
test43	40:10:24.50000N	72:12:45.60000E	230.0	38:04:35.80000N	70:12:40.70000E	318.72407	34.51477	38:30:30.24106N	69:43:40.27830E
test44	40:10:24.50000N	72:12:45.60000E	270.0	38:04:35.80000N	70:12:40.70000E	358.70822	124.62717	40:09:18.36107N	70:09:00.88927E

WGS84LocusPerpIntercept Test Results

Test Identifier	Inputs	Locus Geodesic Start Latitude	Locus Geodesic Start Longitude	Locus Geodesic End Latitude	Locus Geodesic End Longitude	Locus Start Latitude	Locus Start Longitude	Locus End Latitude	Locus End Longitude	Locus Start Distance (nm)	Locus End Distance (nm)	Test Point Latitude	Test Point Longitude
	Outputs	Azimuth From Test Point To Intercept (degrees)	Distance From Test Point To Intercept (nm)	Intercept Latitude	Intercept Longitude								
test1	Inputs	40:10:24.50000N	70:12:45.60000W	42:46:07.45918N	67:25:36.90158W	40:11:01.46238N	70:13:47.29029W	42:46:45.90859N	67:26:39.45541W	-1.0	-1.0	42:04:35.80000N	68:12:34.70000W
	Outputs	309.31753	0.64273	42:05:00.24258N	68:13:14.76673W								
test2	Inputs	40:10:24.50000N	70:12:45.60000W	42:46:07.45918N	67:25:36.90158W	40:09:47.52843N	70:11:43.92830W	42:45:29.00021N	67:24:34.36924W	1.0	1.0	42:04:35.80000N	68:12:34.70000W
	Outputs	129.31753	1.35727	42:03:44.17073N	68:11:10.11749W								
test3	Inputs	40:10:24.50000N	70:12:45.60000W	42:46:07.45918N	67:25:36.90158W	40:09:47.52843N	70:11:43.92830W	42:44:50.53170N	67:23:31.85839W	1.0	2.0	42:04:35.80000N	68:12:34.70000W
	Outputs	129.60401	2.08646	42:03:15.94272N	68:10:25.22603W								
test4	Inputs	40:10:24.50000N	70:12:45.60000W	42:46:07.45918N	67:25:36.90158W	40:11:01.46238N	70:13:47.29029W	42:47:24.34843N	67:27:42.03074W	-1.0	-2.0	42:04:35.80000N	68:12:34.70000W
	Outputs	309.03106	1.37192	42:05:27.64952N	68:14:00.58323W								
test5	Inputs	40:10:24.50000N	70:12:45.60000W	41:40:24.61603N	66:17:03.91251W	40:11:17.51431N	70:13:22.35551W	41:42:13.03866N	66:18:12.69511W	-1.0	-2.0	42:04:35.80000N	68:12:34.70000W
	Outputs	153.01195	57.96492	41:12:49.81350N	67:37:43.49832W								
test6	Inputs	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	65:52:03.22158W	40:08:24.41100N	70:12:45.60000W	40:04:30.79747N	65:52:07.04176W	2.0	1.0	42:04:35.80000N	68:12:34.70000W
	Outputs	181.00609	116.68342	40:07:51.80394N	68:15:14.93906W								
test7	Inputs	40:10:24.50000N	70:12:45.60000W	38:06:56.47029N	66:50:21.71131W	40:12:00.39619N	70:11:11.34983W	38:08:29.64659N	66:48:45.71750W	-2.0	-2.0	42:04:35.80000N	68:12:34.70000W
	Outputs	218.31689	143.82663	40:10:41.23180N	70:08:54.51269W								
test8	Inputs	40:10:24.50000N	70:12:45.60000W	37:15:52.75197N	68:07:31.78007W	40:09:54.47230N	70:13:53.37924W	37:14:55.04445N	68:09:43.61910W	1.0	2.0	40:04:35.80000N	69:12:34.70000W
	Outputs	240.93040	38.37214	39:45:48.10411N	69:56:04.27064W								
test9	Inputs	40:10:24.50000N	70:12:45.60000W	43:25:53.95085N	69:15:43.32087W	40:10:36.97688N	70:14:02.16772W	43:26:20.17044N	69:18:24.04024W	-1.0	-2.0	42:04:35.80000N	68:12:34.70000W
	Outputs	283.05132	65.25203	42:18:48.35558N	69:38:15.57457W								

test10	Inputs	40:10:24.50000N	70:12:45.60000W	43:30:29.87690N	70:12:45.60000W	40:10:24.47060N	70:10:09.05140W	43:30:29.86864N	70:11:23.15209W	2.0	1.0	42:04:35.80000N	68:12:34.70000W
	Outputs	271.05601	88.06612	42:05:12.28968N	70:10:50.66239W								
test11	Inputs	40:10:24.50000N	70:12:45.60000W	43:29:41.80326N	70:36:41.64863W	40:10:19.25950N	70:14:03.57478W	43:29:30.75486N	70:39:25.80395W	-1.0	-2.0	42:04:35.80000N	68:12:34.70000W
	Outputs	266.05671	100.72052	41:56:20.94047N	70:27:13.96006W								
test12	Inputs	40:10:24.50000N	70:12:45.60000W	42:10:25.78109N	73:44:43.81529W	40:11:11.81273N	70:11:57.40023W	42:11:14.53862N	73:43:56.74833W	1.0	1.0	42:04:35.80000N	69:12:34.70000W
	Outputs	218.66979	116.72692	40:32:44.27479N	70:48:14.72623W								
test13	Inputs	40:10:24.50000N	70:12:45.60000W	36:50:12.19034N	70:12:45.60000W	40:10:24.49265N	70:11:27.32569W	36:50:12.16424N	70:10:16.11397W	-1.0	-2.0	38:04:35.80000N	72:12:34.70000W
	Outputs	88.48154	96.22417	38:06:05.77988N	70:10:42.38354W								
test14	Inputs	40:10:24.50000N	70:12:45.60000W	37:58:59.08359N	73:26:32.36055W	40:11:56.48089N	70:14:26.26527W	37:59:43.69324N	73:27:23.18593W	2.0	1.0	38:04:35.80000N	72:12:34.70000W
	Outputs	318.44031	35.88843	38:31:24.84927N	72:42:54.95851W								
test15	Inputs	40:10:24.50000N	70:12:45.60000W	40:05:30.77099N	74:33:27.97842W	40:08:24.41100N	70:12:45.60000W	40:04:30.79747N	74:33:24.15824W	-2.0	-1.0	38:04:35.80000N	72:12:34.70000W
	Outputs	358.99772	123.10364	40:07:47.67496N	72:15:23.10907W								
test16	Inputs	20:10:24.50000N	70:12:45.60000W	22:47:42.88332N	67:59:32.62915W	20:11:01.57566N	70:13:35.86376W	22:48:20.61693N	68:00:23.22901W	-1.0	-1.0	22:04:35.80000N	68:12:34.70000W
	Outputs	308.72881	18.49323	22:16:11.68878N	68:28:07.95660W								
test17	Inputs	20:10:24.50000N	70:12:45.60000W	22:47:42.88332N	67:59:32.62915W	20:09:47.42031N	70:11:55.34284W	22:47:05.14519N	67:58:42.03703W	1.0	1.0	22:04:35.80000N	68:12:34.70000W
	Outputs	308.72881	16.49323	22:14:56.50252N	68:26:26.90385W								
test18	Inputs	20:10:24.50000N	70:12:45.60000W	22:47:42.88332N	67:59:32.62915W	20:09:47.42031N	70:11:55.34284W	22:46:27.40256N	67:57:51.45264W	1.0	2.0	22:04:35.80000N	68:12:34.70000W
	Outputs	309.01529	15.69835	22:14:30.29919N	68:25:43.56946W								
test19	Inputs	20:10:24.50000N	70:12:45.60000W	22:47:42.88332N	67:59:32.62915W	20:11:01.57566N	70:13:35.86376W	22:48:58.34604N	68:01:13.83660W	-1.0	-2.0	22:04:35.80000N	68:12:34.70000W
	Outputs	308.44233	19.28768	22:16:37.00430N	68:28:51.98766W								
test20	Inputs	20:10:24.50000N	70:12:45.60000W	21:42:55.04997N	67:03:07.16284W	20:11:17.67400N	70:13:15.54639W	21:44:42.47168N	67:04:05.42224W	-1.0	-2.0	22:04:35.80000N	68:12:34.70000W
	Outputs	152.41757	46.88028	21:22:52.16995N	67:49:19.19587W								
test21	Inputs	20:10:24.50000N	70:12:45.60000W	20:08:16.10563N	66:40:11.24376W	20:08:24.05152N	70:12:45.60000W	20:07:15.89488N	66:40:12.60255W	2.0	1.0	22:04:35.80000N	68:12:34.70000W
	Outputs	180.40439	115.88931	20:08:17.39840N	68:13:26.84791W								
test2	Input	20:10:24.5	70:12:45.60	18:08:16.6	67:25:03.87	20:12:00.6	70:11:28.81	18:09:51.6	67:23:46.42	-2.0	-2.0	22:04:35.8	68:12:34.70

2	s	0000N	000W	0075N	343W	8945N	766W	3861N	707W			0000N	000W
	Outputs	217.71425	156.60521	19:59:44.51317N	69:54:16.80106W								
test23	Inputs	20:10:24.50000N	70:12:45.60000W	17:16:01.61500N	68:28:18.10827W	20:09:54.38551N	70:13:40.83341W	17:15:02.38476N	68:30:07.30583W	1.0	2.0	20:04:35.80000N	69:12:34.70000W
	Outputs	240.62790	47.41380	19:41:09.80503N	69:56:21.99784W								
test24	Inputs	20:10:24.50000N	70:12:45.60000W	23:26:37.86400N	69:27:33.93765W	20:10:37.01823N	70:13:47.98905W	23:27:03.45735N	69:29:41.45246W	-1.0	-2.0	22:04:35.80000N	68:12:34.70000W
	Outputs	282.46352	87.05417	22:23:01.23192N	69:44:17.95270W								
test25	Inputs	20:10:24.50000N	70:12:45.60000W	23:31:06.93560N	70:12:45.60000W	20:10:24.48716N	70:10:38.03712W	23:31:06.93179N	70:11:40.31639W	2.0	1.0	22:04:35.80000N	68:12:34.70000W
	Outputs	270.46647	110.19089	22:04:46.78090N	70:11:13.20586W								
test26	Inputs	20:10:24.50000N	70:12:45.60000W	23:30:20.06967N	70:31:42.81974W	20:10:19.24793N	70:13:49.13814W	23:30:09.31498N	70:33:52.85078W	-1.0	-2.0	22:04:35.80000N	68:12:34.70000W
	Outputs	265.46611	122.69379	21:53:59.00085N	70:24:06.45107W								
test27	Inputs	20:10:24.50000N	70:12:45.60000W	22:12:35.69228N	73:02:34.77881W	20:11:11.95601N	70:12:06.32892W	22:13:23.79135N	73:01:55.88211W	1.0	1.0	22:04:35.80000N	69:12:34.70000W
	Outputs	218.36943	123.21147	20:27:18.81236N	70:34:01.01617W								
test28	Inputs	20:10:24.50000N	70:12:45.60000W	16:49:37.49349N	70:12:45.60000W	20:10:24.49679N	70:11:41.81856W	16:49:37.48292N	70:10:40.49187W	-1.0	-2.0	18:04:35.80000N	72:12:34.70000W
	Outputs	89.09350	115.76556	18:05:47.86911N	70:11:03.51621W								
test29	Inputs	20:10:24.50000N	70:12:45.60000W	18:00:09.46178N	72:53:29.02106W	20:11:56.76327N	70:14:07.60925W	18:00:55.00817N	72:54:10.22384W	2.0	1.0	18:04:35.80000N	72:12:34.70000W
	Outputs	319.05008	23.26620	18:22:13.64861N	72:28:36.69646W								
test30	Inputs	20:10:24.50000N	70:12:45.60000W	20:08:16.10563N	73:45:19.95624W	20:08:24.05152N	70:12:45.60000W	20:07:15.89488N	73:45:18.59745W	-2.0	-1.0	18:04:35.80000N	72:12:34.70000W
	Outputs	359.59765	123.21213	20:08:16.82998N	72:13:29.86100W								

WGS84PointToArcTangents

Test Identifier	Point Latitude	Point Longitude	Arc Center Latitude	Arc Center Longitude	Arc Radius	Tangent Point 1 Latitude	Tangent Point 1 Longitude	Tangent Point 2 Latitude	Tangent Point 2 Longitude
test1	40:04:35.80000N	68:12:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	N/A	N/A	N/A	N/A
test2	40:04:35.80000N	67:12:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	38:58:50.99979N	68:42:19.92957W	41:17:02.57149N	68:34:37.49185W
test3	40:04:35.80000N	60:42:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	38:33:51.49399N	69:38:46.59230W	41:48:38.13537N	69:47:36.01065W
test4	40:04:35.80000N	47:18:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	38:32:36.38289N	69:45:21.56093W	41:50:24.89752N	70:17:02.95660W
test5	42:54:35.80000N	70:11:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	41:10:08.36776N	68:27:18.83665W	41:10:59.53083N	71:57:22.47464W
test6	64:54:35.80000N	70:11:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	40:15:27.76756N	68:02:23.12392W	40:15:31.95981N	72:23:07.86461W
test7	52:54:35.80000N	70:11:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	40:21:58.95584N	68:02:59.46118W	40:22:10.22316N	72:22:30.19164W
test8	40:24:35.80000N	75:11:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	41:43:51.26621N	70:59:57.14126W	38:44:18.56935N	71:18:35.69631W
test9	40:24:35.80000N	85:11:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	41:50:23.42412N	70:17:57.13255W	38:33:20.77969N	70:44:13.68450W
test10	40:24:35.80000N	80:11:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	41:49:34.92720N	70:30:17.76805W	38:34:51.79348N	70:51:10.47505W
test11	37:09:35.80000N	70:21:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	39:17:29.76121N	72:02:47.41811W	39:11:04.58987N	68:28:26.79906W
test12	30:09:35.80000N	70:21:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	39:53:58.01340N	72:21:11.40785W	39:51:26.97905N	68:04:57.44757W
test13	25:09:35.80000N	70:21:34.70000W	40:10:24.50000N	70:12:45.60000W	100.0	39:59:12.99136N	72:22:13.50689W	39:57:25.86494N	68:03:36.34196W
test14	40:04:35.80000N	72:12:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	N/A	N/A	N/A	N/A
test15	40:04:35.80000N	73:12:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	38:58:59.31128N	71:43:22.32134E	41:16:52.48137N	71:51:05.39764E
test16	40:04:35.80000N	80:12:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	38:33:38.85748N	70:45:44.00068E	41:48:54.91998N	70:35:56.19986E
test17	40:04:35.80000N	85:12:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	38:32:40.44989N	70:40:33.55927E	41:50:14.09817N	70:21:45.92010E
test18	42:54:35.80000N	70:11:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	41:10:59.53083N	71:57:22.47464E	41:10:08.36776N	68:27:18.83666E
test19	52:54:35.80000N	70:11:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	40:22:10.22315N	72:22:30.19164E	40:21:58.95586N	68:02:59.46118E
test20	57:54:35.80000N	70:11:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	40:18:20.82175N	72:22:56.15166E	40:18:13.61636N	68:02:34.42092E
test21	40:24:35.80000N	65:11:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	41:43:58.89962N	69:26:00.45951E	38:44:06.31619N	69:07:22.38700E
test22	40:24:35.80000N	55:11:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	41:50:23.55695N	70:07:38.55861E	38:33:20.46158N	69:41:19.14594E
test23	40:24:35.80000N	60:11:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	41:49:35.71820N	69:55:21.25651E	38:34:50.41383N	69:34:26.43627E
test24	37:09:35.80000N	70:21:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	39:11:04.58989N	68:28:26.79904E	39:17:29.76123N	72:02:47.41812E
test25	32:09:35.80000N	70:21:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	39:47:00.76207N	68:06:16.51285E	39:50:03.52790N	72:20:10.72389E
test26	27:09:35.80000N	70:21:34.70000E	40:10:24.50000N	70:12:45.60000E	100.0	39:55:34.77439N	68:03:58.36606E	39:57:35.60852N	72:21:56.65907E
test27	40:04:35.80000S	72:12:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	N/A	N/A	N/A	N/A
test28	40:04:35.80000S	73:12:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	41:16:52.48137S	71:51:05.39763E	38:58:59.31128S	71:43:22.32134E
test29	40:04:35.80000S	83:12:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	41:49:55.55059S	70:26:29.37475E	38:32:53.74966S	70:41:49.38811E
test30	40:04:35.80000S	80:12:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	41:48:54.91998S	70:35:56.19985E	38:33:38.85748S	70:45:44.00069E
test31	38:04:35.80000S	70:11:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	38:49:55.28970S	71:29:33.42172E	38:50:48.30732S	68:54:26.10830E
test32	28:04:35.80000S	70:11:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	39:55:27.43830S	72:21:31.28285E	39:55:44.66533S	68:03:56.29379E
test33	33:04:35.80000S	70:11:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	39:45:36.78731S	72:18:46.32802E	39:46:03.95424S	68:06:35.51577E
test34	40:24:35.80000S	65:51:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	38:48:24.38501S	68:58:41.71027E	41:41:16.63837S	69:17:31.03298E
test35	40:24:35.80000S	60:51:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	38:35:16.36317S	69:32:41.49524E	41:49:20.73591S	69:53:01.97091E
test36	40:24:35.80000S	55:51:34.70000E	40:10:24.50000S	70:12:45.60000E	100.0	38:33:26.36693S	69:40:49.11846E	41:50:20.97633S	70:06:20.58405E
test37	43:09:35.80000S	69:38:25.30000E	40:10:24.50000S	70:12:45.60000E	100.0	40:52:32.16687S	68:13:48.41601E	41:16:01.63700S	71:52:03.48811E
test38	48:09:35.80000S	69:38:25.30000E	40:10:24.50000S	70:12:45.60000E	100.0	40:25:12.33606S	68:03:29.94912E	40:34:39.67829S	72:19:42.54233E
test39	53:09:35.80000S	69:38:25.30000E	40:10:24.50000S	70:12:45.60000E	100.0	40:19:08.92651S	68:02:39.52957E	40:24:28.22924S	72:22:08.94257E
test40	40:04:35.80000S	68:12:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	N/A	N/A	N/A	N/A
test41	40:04:35.80000S	66:47:25.30000W	40:10:24.50000S	70:12:45.60000W	100.0	41:26:06.94082S	68:46:38.84215W	38:51:27.83161S	68:53:19.53080W
test42	40:04:35.80000S	56:47:25.30000W	40:10:24.50000S	70:12:45.60000W	100.0	41:50:00.49059S	70:00:06.82169W	38:32:50.15608S	69:44:01.95578W
test43	40:04:35.80000S	59:47:25.30000W	40:10:24.50000S	70:12:45.60000W	100.0	41:49:07.32741S	69:51:10.22069W	38:33:29.54331S	69:40:33.17198W
test44	38:04:35.80000S	70:11:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	38:50:48.30732S	68:54:26.10830W	38:49:55.28969S	71:29:33.42171W

test45	28:04:35.80000S	70:11:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	39:55:44.66533S	68:03:56.29379W	39:55:27.43828S	72:21:31.28285W
test46	33:04:35.80000S	70:11:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	39:46:03.95424S	68:06:35.51577W	39:45:36.78730S	72:18:46.32802W
test47	40:24:35.80000S	74:11:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	38:51:54.10807S	71:32:55.13292W	41:39:02.49151S	71:13:58.65781W
test48	40:24:35.80000S	84:11:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	38:33:30.19485S	70:45:01.28168W	41:50:19.19941S	70:19:56.15761W
test49	40:24:35.80000S	80:11:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	38:34:51.79347S	70:51:10.47504W	41:49:34.92720S	70:30:17.76806W
test50	43:09:35.80000S	70:21:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	41:02:16.59197S	72:05:02.69299W	41:08:20.56609S	68:25:37.35380W
test51	48:09:35.80000S	70:21:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	40:28:45.82853S	72:21:17.78853W	40:31:11.70040S	68:04:49.12313W
test52	53:09:35.80000S	70:21:34.70000W	40:10:24.50000S	70:12:45.60000W	100.0	40:21:08.09707S	72:22:38.37153W	40:22:30.13116S	68:03:03.81110W

WGS84PerpTangentPoints Test Results

Test Identifier	Geodesic Start Latitude	Geodesic Start Longitude	Geodesic Azimuth (degrees)	Arc Center Latitude	Arc Center Longitude	Arc Radius	Intercept 1 Latitude	Intercept 1 Longitude	Intercept 2 Latitude	Intercept 2 Longitude	Tangent Point 1 Latitude	Tangent Point 1 Longitude	Tangent Point 2 Latitude	Tangent s Point 2 Longitude
test1	40:04:35.80000N	65:12:40.70000W	350.0	40:10:24.50000N	70:12:45.60000W	50.0	41:45:15.42301N	65:36:23.05394W	40:06:32.80959N	65:13:07.57044W	40:59:04.91370N	70:27:57.32812W	39:21:40.43861N	69:58:02.47943W
test2	40:04:35.80000N	65:12:40.70000W	200.0	40:10:24.50000N	70:12:45.60000W	50.0	38:14:05.43205N	66:03:35.08024W	39:48:31.53705N	65:20:15.65454W	39:22:29.68372N	70:31:27.94338W	40:58:17.46091N	69:53:43.69995W
test3	40:04:35.80000N	68:12:40.70000W	325.0	40:10:24.50000N	70:12:45.60000W	100.0	42:13:23.37083N	70:14:57.87719W	39:30:24.62906N	67:41:50.28458W	41:30:34.37380N	71:31:37.17040W	38:49:17.65513N	68:57:04.57474W
test4	40:04:35.80000N	65:12:40.70000W	270.0	40:10:24.50000N	70:12:45.60000W	50.0	39:55:02.92066N	71:16:44.98301W	40:00:38.90564N	69:06:53.45783W	40:07:17.85127N	71:17:50.28392W	40:12:54.82728N	69:07:35.57088W
test5	40:04:35.80000N	65:12:40.70000W	300.0	40:10:24.50000N	70:12:45.60000W	50.0	42:06:05.22048N	70:09:48.79496W	41:20:00.99595N	68:11:12.42020W	40:32:38.56283N	71:11:21.28560W	39:47:38.67195N	69:14:49.94129W
test6	40:04:35.80000N	65:12:40.70000W	240.0	40:10:24.50000N	70:12:45.60000W	50.0	37:57:45.76917N	69:38:55.15062W	38:51:12.13212N	67:51:14.22782W	39:42:50.60770N	71:07:01.04721W	40:37:35.17545N	69:17:48.54937W
test7	44:54:35.80000N	70:11:34.70000W	180.0	40:10:24.50000N	70:12:45.60000W	50.0	39:20:22.07307N	70:11:34.70000W	41:00:26.50523N	70:11:34.70000W	39:20:22.06721N	70:12:44.75738W	41:00:26.49902N	70:12:46.49381W
test8	44:54:35.80000N	70:11:34.70000W	148.0	40:10:24.50000N	70:12:45.60000W	50.0	40:44:55.03008N	66:49:02.96925W	42:11:35.30495N	67:55:46.12774W	39:27:50.18529N	69:38:39.28546W	40:52:46.19633N	70:47:39.16449W
test9	44:54:35.80000N	70:11:34.70000W	211.0	40:10:24.50000N	70:12:45.60000W	50.0	40:39:20.90907N	73:30:31.26204W	42:06:51.06530N	72:25:51.03824W	39:27:22.55669N	70:45:52.63953W	40:53:14.53640N	69:38:52.20992W
test10	40:24:35.80000N	75:11:34.70000W	90.0	40:10:24.50000N	70:12:45.60000W	50.0	40:15:00.17740N	69:06:59.49277W	40:20:38.68482N	71:17:28.91405W	40:07:17.14968N	69:07:40.97872W	40:12:55.02357N	71:17:55.61784W
test11	40:24:35.80000N	75:11:34.70000W	71.0	40:10:24.50000N	70:12:45.60000W	50.0	41:42:40.03737N	69:38:05.90758W	41:14:59.29549N	71:45:59.60155W	40:23:40.58611N	69:09:45.81981W	39:56:32.34252N	71:15:19.64207W
test12	40:24:35.80000N	75:11:34.70000W	117.0	40:10:24.50000N	70:12:45.60000W	50.0	38:21:19.52582N	70:19:44.57750W	39:10:39.07842N	72:11:03.63508W	39:45:02.93329N	69:16:42.08956W	40:35:20.61719N	71:09:29.12730W
test13	37:09:35.80000N	70:21:34.70000W	0.0	40:10:24.50000N	70:12:45.60000W	50.0	41:00:26.84065N	70:21:34.70000W	39:20:22.39722N	70:21:34.70000W	41:00:26.49479N	70:12:38.92986W	39:20:22.07107N	70:12:51.88818W
test14	37:09:35.80000N	70:21:34.70000W	34.0	40:10:24.50000N	70:12:45.60000W	50.0	39:57:02.53883N	67:53:34.67323W	38:35:09.95589N	69:07:43.83953W	40:51:46.48176N	69:35:52.67111W	39:28:52.04803N	70:48:56.68220W
test15	37:09:35.80000N	70:21:34.70000W	331.0	40:10:24.50000N	70:12:45.60000W	50.0	40:07:42.80472N	72:30:57.33906W	38:41:00.31862N	71:26:24.86130W	40:54:09.57283N	70:44:34.61853W	39:26:31.66858N	69:41:34.39676W
test16	40:04:35.80000N	75:12:34.70000E	350.0	40:10:24.50000N	70:12:45.60000E	50.0	41:45:12.67315N	74:48:53.01070E	40:06:30.07882N	75:12:08.45696E	40:59:04.94944N	69:57:34.06882E	39:21:40.40510N	70:27:28.53420E
test17	40:04:35.80000N	75:12:34.70000E	200.0	40:10:24.50000N	70:12:45.60000E	50.0	38:14:08.75549N	74:21:41.80893E	39:48:34.82983N	75:05:01.29260E	39:22:29.72463N	69:54:03.08054E	40:58:17.41786N	70:31:47.68622E
test18	40:04:35.80000N	72:12:34.70000E	315.0	40:10:24.50000N	70:12:45.60000E	100.0	42:02:53.59978N	69:31:25.90082E	39:43:08.75530N	72:40:17.05485E	41:18:51.03968N	68:36:46.64551E	39:00:35.86938N	71:45:27.62796E
test19	40:04:35.80000N	73:12:34.70000E	270.0	40:10:24.50000N	70:12:45.60000E	50.0	40:00:17.63529N	69:08:04.99603E	40:03:39.33076N	71:18:12.14247E	40:08:25.20509N	69:07:35.90168E	40:11:47.29572N	71:17:58.51179E
test20	40:04:35.80000N	73:12:34.70000E	300.0	40:10:24.50000N	70:12:45.60000E	50.0	41:28:31.69569N	69:52:44.13264E	40:40:49.88638N	71:49:00.24598E	40:33:41.08619N	69:14:51.20890E	39:46:37.81172N	71:09:59.27305E
test2	40:04:35.	73:12:34.	240.0	40:10:24.	70:12:45.	50.	38:39:26.	70:09:47.	39:31:32.	71:59:30.	39:43:45.	69:17:44.	40:36:38.	71:08:28.

1	80000N	70000E		50000N	60000E	0	28959N	67412E	39864N	22696E	18199N	08525E	84939N	77660E
test22	42:54:35.80000N	70:11:34.70000E	180.0	40:10:24.50000N	70:12:45.60000E	50.0	39:20:22.07307N	70:11:34.70000E	41:00:26.50523N	70:11:34.70000E	39:20:22.06721N	70:12:44.75738E	41:00:26.49902N	70:12:46.49381E
test23	42:54:35.80000N	70:11:34.70000E	148.0	40:10:24.50000N	70:12:45.60000E	50.0	40:12:21.71012N	72:22:44.76027E	41:38:14.00626N	71:14:56.56898E	39:27:51.50743N	70:46:54.69271E	40:52:45.72705N	69:37:51.05930E
test24	42:54:35.80000N	70:11:34.70000E	211.0	40:10:24.50000N	70:12:45.60000E	50.0	40:10:13.49744N	68:03:47.64473E	41:36:57.43421N	69:09:38.18678E	39:27:25.16505N	69:39:32.86210E	40:53:12.66240N	70:46:43.04537E
test25	40:24:35.80000N	65:11:34.70000E	90.0	40:10:24.50000N	70:12:45.60000E	50.0	40:14:52.70121N	71:18:31.30185E	40:20:33.87049N	69:08:02.27516E	40:07:15.81920N	71:17:50.10192E	40:12:56.35847N	69:07:35.65928E
test26	40:24:35.80000N	65:11:34.70000E	71.0	40:10:24.50000N	70:12:45.60000E	50.0	41:43:07.73081N	70:47:18.27558E	41:15:29.46607N	68:39:22.65865E	40:23:39.25925N	71:15:45.84597E	39:56:33.64852N	69:10:11.05812E
test27	40:24:35.80000N	65:11:34.70000E	117.0	40:10:24.50000N	70:12:45.60000E	50.0	38:20:32.33083N	70:05:08.22153E	39:09:53.57178N	68:13:51.51407E	39:45:01.83231N	71:08:48.26146E	40:35:21.75120N	69:16:02.91762E
test28	37:09:35.80000N	70:21:34.70000E	0.0	40:10:24.50000N	70:12:45.60000E	50.0	41:00:26.84065N	70:21:34.70000E	39:20:22.39722N	70:21:34.70000E	41:00:26.49479N	70:12:38.92986E	39:20:22.07107N	70:12:51.88818E
test29	37:09:35.80000N	70:21:34.70000E	31.0	40:10:24.50000N	70:12:45.60000E	50.0	40:01:09.54385N	72:36:33.75760E	38:36:16.81276N	71:28:10.67923E	40:53:16.92717N	70:46:33.80034E	39:27:23.36126N	69:39:36.80041E
test30	37:09:35.80000N	70:21:34.70000E	331.0	40:10:24.50000N	70:12:45.60000E	50.0	40:13:21.86911N	68:07:53.03613E	38:46:42.27396N	69:12:35.67163E	40:54:04.71013N	69:40:45.15677E	39:26:36.29194N	70:44:07.71534E
test31	40:14:35.80000S	76:12:34.70000E	350.0	40:10:24.50000S	70:12:45.60000E	40.0	38:52:44.97680S	75:54:07.21038E	40:11:52.39692S	76:11:57.12656E	39:30:36.53650S	70:07:10.29772E	40:50:12.39327S	70:18:21.70242E
test32	40:04:35.80000S	75:12:34.70000E	200.0	40:10:24.50000S	70:12:45.60000E	50.0	42:16:12.64050S	74:07:57.72436E	40:42:17.22780S	74:54:32.53991E	40:56:18.37182S	69:46:38.66583E	39:24:22.40493S	70:38:11.32653E
test33	40:04:35.80000S	72:12:34.70000E	315.0	40:10:24.50000S	70:12:45.60000E	100.0	38:09:45.50471S	69:49:01.12662E	40:32:44.31824S	72:49:35.77432E	38:57:32.89527S	68:44:05.92033E	41:22:09.83417S	71:44:30.08384E
test34	40:04:35.80000S	73:12:34.70000E	270.0	40:10:24.50000S	70:12:45.60000E	50.0	40:00:17.63529S	69:08:04.99603E	40:03:39.33076S	71:18:12.14247E	40:08:25.20509S	69:07:35.90168E	40:11:47.29572S	71:17:58.51179E
test35	40:04:35.80000S	73:12:34.70000E	300.0	40:10:24.50000S	70:12:45.60000E	50.0	38:39:26.28959S	70:09:47.67412E	39:31:32.39864S	71:59:30.22696E	39:43:45.18199S	69:17:44.08525E	40:36:38.84939S	71:08:28.77660E
test36	40:04:35.80000S	73:12:34.70000E	240.0	40:10:24.50000S	70:12:45.60000E	50.0	41:28:31.69569S	69:52:44.13264E	40:40:49.88638S	71:49:00.24598E	40:33:41.08619S	69:14:51.20890E	39:46:37.81172S	71:09:59.27305E
test37	38:04:35.80000S	70:11:34.70000E	180.0	40:10:24.50000S	70:12:45.60000E	50.0	41:00:26.50523S	70:11:34.70000E	39:20:22.07307S	70:11:34.70000E	41:00:26.49902S	70:12:46.49381E	39:20:22.06721S	70:12:44.75738E
test38	38:04:35.80000S	70:11:34.70000E	148.0	40:10:24.50000S	70:12:45.60000E	50.0	40:17:07.13084S	72:00:20.55877E	38:52:56.85946S	70:50:18.83964E	40:52:45.70508S	70:47:40.18638E	39:27:53.54845S	69:38:32.22868E
test39	38:04:35.80000S	70:11:34.70000E	211.0	40:10:24.50000S	70:12:45.60000E	50.0	40:18:46.00666S	68:25:41.54164E	38:53:38.70009S	69:33:47.56507E	40:53:14.02637S	69:38:51.10513E	39:27:25.77604S	70:45:59.66955E
test40	40:24:35.80000S	65:51:34.70000E	90.0	40:10:24.50000S	70:12:45.60000E	50.0	40:16:52.78726S	71:18:36.57794E	40:21:48.85747S	69:08:01.28224E	40:07:38.35059S	71:17:52.01922E	40:12:33.75700S	69:07:34.45828E
test41	40:24:35.80000S	65:51:34.70000E	71.0	40:10:24.50000S	70:12:45.60000E	50.0	38:59:21.92563S	70:45:28.67998E	39:36:03.21874S	68:45:36.55313E	39:51:34.97299S	71:13:03.49121E	40:28:43.60957S	69:11:55.38110E
test42	40:24:35.80000S	65:51:34.70000E	117.0	40:10:24.50000S	70:12:45.60000E	50.0	42:01:19.14270S	70:19:39.19192E	41:19:26.82819S	68:18:23.75678E	40:30:35.82765S	71:12:35.50340E	39:49:40.20801S	69:13:32.78935E
test43	43:09:35.80000S	69:38:25.30000E	0.0	40:10:24.50000S	70:12:45.60000E	50.0	39:20:27.07217S	69:38:25.30000E	41:00:31.67824S	69:38:25.30000E	39:20:22.12663S	70:12:21.11372E	41:00:26.43381S	70:13:11.57361E
test44	43:09:35.80000S	69:38:25.30000E	34.0	40:10:24.50000S	70:12:45.60000E	50.0	40:10:58.21027S	72:13:54.61283E	41:35:13.91157S	71:02:44.04238E	39:28:37.32353S	70:48:27.91118E	40:51:59.02911S	69:36:16.97478E
test45	43:09:35.80000S	69:38:25.30000E	335.0	40:10:24.50000S	70:12:45.60000E	50.0	40:06:15.66891S	67:47:39.73289E	41:37:39.92668S	68:41:26.00208E	39:25:07.21618S	69:45:10.03499E	40:55:33.61492S	70:41:01.20850E

test46	40:24:35.80000S	65:12:40.70000W	350.0	40:10:24.50000S	70:12:45.60000W	40.0	38:58:11.44004S	65:32:11.35937W	40:17:14.24083S	65:14:22.36760W	39:30:39.49061S	70:18:54.59385W	40:50:09.33911S	70:06:34.13853W
test47	40:04:35.80000S	67:12:40.70000W	200.0	40:10:24.50000S	70:12:45.60000W	50.0	41:43:04.52714S	68:00:35.08875W	40:09:08.86953S	67:14:50.23285W	40:56:45.65430S	70:37:27.46544W	39:23:56.63322S	69:48:40.85141W
test48	40:04:35.80000S	68:12:40.70000W	315.0	40:10:24.50000S	70:12:45.60000W	100.0	38:09:39.42011S	70:36:21.58383W	40:32:38.43897S	67:35:47.44055W	38:57:32.70200S	71:41:25.01247W	41:22:10.04449S	68:41:01.39841W
test49	40:04:35.80000S	66:47:19.30000W	270.0	40:10:24.50000S	70:12:45.60000W	50.0	39:59:20.91374S	71:17:19.47416W	40:03:11.27515S	69:07:15.00811W	40:08:10.83970S	71:17:54.39452W	40:12:01.69154S	69:07:33.13622W
test50	40:04:35.80000S	66:47:19.30000W	300.0	40:10:24.50000S	70:12:45.60000W	50.0	38:30:35.82998S	70:08:06.75040W	39:22:59.34750S	68:18:50.55549W	39:43:33.42333S	71:07:37.37083W	40:36:50.98023S	69:17:12.16414W
test51	40:04:35.80000S	66:47:19.30000W	240.0	40:10:24.50000S	70:12:45.60000W	50.0	41:36:36.30412S	70:27:37.90336W	40:49:14.86902S	68:30:52.22885W	40:33:27.89443S	71:10:48.90600W	39:46:50.64641S	69:15:22.88056W
test52	38:04:35.80000S	70:11:34.70000W	180.0	40:10:24.50000S	70:12:45.60000W	50.0	41:00:26.50523S	70:11:34.70000W	39:20:22.07307S	70:11:34.70000W	41:00:26.49902S	70:12:46.49381W	39:20:22.06721S	70:12:44.75738W
test53	38:04:35.80000S	70:11:34.70000W	148.0	40:10:24.50000S	70:12:45.60000W	50.0	40:16:18.90281S	68:23:29.95567W	38:52:08.17125S	69:33:30.08556W	40:52:46.41906S	69:37:52.49907W	39:27:52.86878S	70:46:57.54788W
test54	38:04:35.80000S	70:11:34.70000W	211.0	40:10:24.50000S	70:12:45.60000W	50.0	40:19:33.41765S	71:58:06.74176W	38:54:26.53851S	70:49:59.19702W	40:53:13.33180S	70:46:41.59808W	39:27:26.43690S	69:39:30.09147W
test55	40:24:35.80000S	74:11:34.70000W	90.0	40:10:24.50000S	70:12:45.60000W	50.0	40:17:53.93865S	69:06:53.05426W	40:22:24.75464S	71:17:31.47355W	40:07:50.95861S	69:07:38.20443W	40:12:21.11411S	71:17:57.31644W
test56	40:24:35.80000S	74:11:34.70000W	71.0	40:10:24.50000S	70:12:45.60000W	50.0	39:05:20.87464S	69:36:38.15858W	39:41:42.34805S	71:36:49.98435W	39:51:46.35643S	69:12:21.64904W	40:28:31.97625S	71:13:41.67519W
test57	40:24:35.80000S	74:11:34.70000W	117.0	40:10:24.50000S	70:12:45.60000W	50.0	41:54:54.96618S	70:02:37.71975W	41:12:42.82714S	72:03:28.17431W	40:30:47.80049S	69:13:02.54949W	39:49:28.51990S	71:11:51.36671W
test58	43:09:35.80000S	70:21:34.70000W	0.0	40:10:24.50000S	70:12:45.60000W	50.0	39:20:22.39722S	70:21:34.70000W	41:00:26.84065S	70:21:34.70000W	39:20:22.07107S	70:12:51.88818W	41:00:26.49479S	70:12:38.92986W
test59	43:09:35.80000S	70:21:34.70000W	34.0	40:10:24.50000S	70:12:45.60000W	50.0	40:20:09.24057S	67:53:40.37644W	41:44:20.61162S	69:05:11.16171W	39:28:45.24018S	69:36:47.75179W	40:51:50.71125S	70:49:30.38048W
test60	43:09:35.80000S	70:21:34.70000W	331.0	40:10:24.50000S	70:12:45.60000W	50.0	40:10:21.52153S	72:30:11.26250W	41:38:48.88727S	71:28:25.57541W	39:26:35.31407S	70:44:05.41422W	40:54:03.53921S	69:40:42.41911W

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Appendix B. Initial Climb Area (ICA) Concept

1. Initial Climb Area (ICA). The ICA is an area centered on the runway centerline extended used to evaluate obstacle clearance during the climb to 400 feet above DER (minimum climb gradient 200 ft/NM).

a. ICA terms.

(1) ICA baseline (ICAB). The ICAB is a line extending perpendicular to the RCL ± 500 at DER. If a clearway is present, the ICAB is a line perpendicular to the extended RCL at the clearway end. It is the origin of the ICA (see figure B-1).

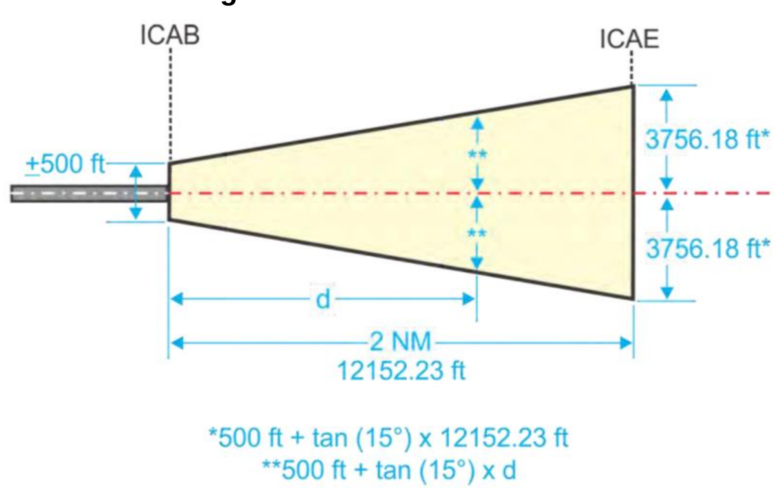
(2) ICA end-line (ICAE). The ICAE is a line at the end of the ICA perpendicular to the RCL extended. The splay of 15 degrees and length of the ICA determine its width (see figure B-1).

b. Area.

(1) Length. The ICA length is normally 2 NM, measured from the ICAB to the ICAE along RCL extended. It may be less than 2 NM in length for early turns by publishing a climb gradient. The ICA may be extended beyond 2 NM to maximum length of 10 NM. A specified altitude (typically 400 feet above DER) or the interception of Positive Course Guidance (PCG) route must identify the ICAE.

(2) Width. The ICA origin is 1000 feet (± 500 perpendicular RCL) wide at its origin. The area splays outward at a rate of 15 degrees relative to the departure course (normally RCL extended)

Figure B-1. Initial Climb Area



(3) OCS. The OCS originates at the ICAB, at the OCS start elevation (see paragraph 2). Apply the OCS by measuring along the RCL from the ICAB to a point where the obstacle is perpendicular to the RCL and evaluate per paragraph 2. The MSL elevation of the ICAE is calculated using formula B-1.

Formula B-1. ICAE Elevation ($\mathbf{ICAE_{elev}}$)

$$\mathrm{ICAE_{elev}} = a + \left(\frac{b}{c}\right)$$

Where:

a = OCS start elevation
b = ICA length (feet)
c = OCS slope (normally 40:1)

2. Departure OCS Application. Evaluate the 40:1 departure OCS originating at the DER threshold at DER elevation (see figure B-2). If a clearway exists, then evaluate a 40:1 departure OCS originating at the end of the clearway at an elevation determined by application of formula B-2. See figure B-3 for application of OCS when a clearway is present. Departure operations are unrestricted if the OCS is clear. Where obstructions penetrate the OCS, see TP308 Vol 1, paragraph 203.

Note: A clearway is present when the Take-Off Distance Available (TODA) exceeds the Take-Off Run Available (TORA). When TODA exceeds TORA, the airport will declare and publish these values within the applicable Airport/Facility Directory.

Formula B-2. OCS Start Elevation (Runways with Clearway)

$$\mathrm{OCS}_{Start} = \frac{\mathrm{TODA} - \mathrm{TORA}}{\mathrm{c}80} + \mathrm{DER}_{elev}$$

Where:

DER_{elev} = DER elevation

Figure B-2. OCS Starting Elevation

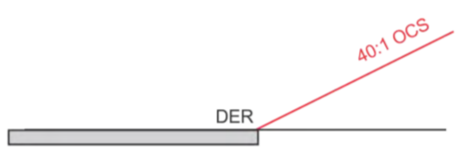
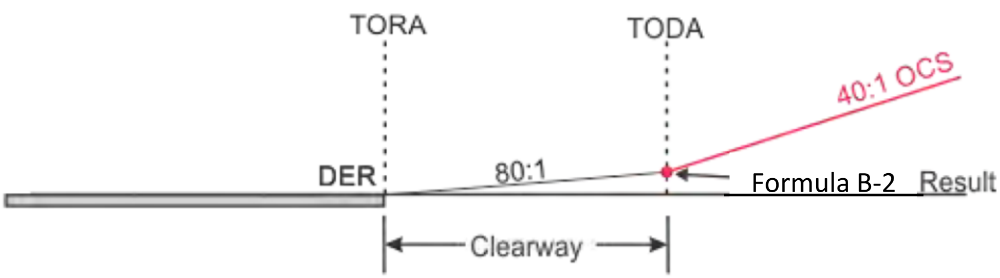


Figure B-3. OCS Starting Elevation With Clearway



a. Low, close-in OCS penetrations. Do not publish a CG to a height of 200 feet or less above the OCS start elevation.

b. Calculating OCS height. The OCS height is based on the distance measured from the OCS origin along the shortest distance to an obstacle within the segment. See paragraph 1b(3) for measuring obstacles located within the ICA.

(1) Primary area. The OCS slope is 40:1. Use formula B-3 to calculate the OCS elevation.

Formula B-3. Primary OCS Elevation

$$\mathrm{h_{ocs}} = \frac{d}{40} + \mathrm{e}$$

Where:

d = shortest distance (feet) from OCS origin to obstacle
e = OCS origin elevation

(2) Secondary area. (Applicable only when PCG is identified.) The OCS slope is 12:1. The secondary OCS elevation is the sum of the 40:1 OCS rise in the primary area to a point the obstacle is perpendicular to the departure course, and the secondary OCS rise from the edge of the primary OCS to the obstacle (see figure B-4). Use formula B-4 to calculate the secondary OCS elevation.

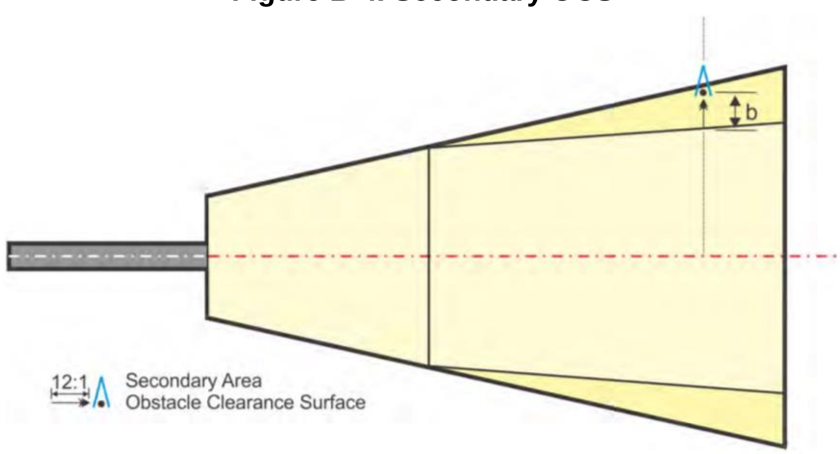
Formula B-4. Secondary OCS Elevation

$$\mathrm{h_{SECONDARY}} = \mathrm{h_{ocs}} + \frac{b}{12}$$

Where:

$\mathrm{h_{ocs}}$ = primary OCS height
b = perpendicular distance (feet) from edge of primary

Figure B-4. Secondary OCS



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Government of Canada Gouvernement du Canada

CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

VOLUME 3

PRECISION APPROACH (PA) PROCEDURE CONSTRUCTION

TRANSPORT CANADA
NATIONAL DEFENSE

5 January 2017

Canada

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GENERAL INFORMATION

1.0 Purpose

This volume contains final and initial missed approach segment construction criteria applicable to instrument approach procedures that provide positive glidepath guidance. Apply this criteria to approaches based on instrument landing system (ILS), microwave landing system (MLS), precision approach radar (PAR), and transponder landing system (TLS). See volume 2 for WAAS and LAAS.

1.1. BACKGROUND

The ILS defined the navigational aid (NAVAID) performance standard for precision vertical and lateral guidance systems. Several different NAVAID's providing positive vertical guidance have evolved since the inception of ILS.

- NAVAID's capable of supporting Category I landing minimums are: ILS, PAR, MLS, TLS, WAAS, and LAAS.
- NAVAID's capable of providing Category II/III landing minimums are: ILS, MLS, and LAAS.

A NAVAID capable of supporting Category I/II/III minimums does not qualify as a precision approach (PA) system without supporting ground infrastructure. Certain airport and obstruction clearance requirements are mandatory for the system to be considered a PA system and achieve the LOWEST minimums. These requirements are contained in TP 312 Aerodrome Standards, and appropriate military directives. When mandatory ground infrastructure requirements are not met, these NAVAID's may provide a vertically guided stabilized final approach descent, but command higher landing minimums.

1.2. DEFINITIONS

1.2.1. Approach Surface Base Line (ASBL). A horizontal line tangent to the surface of the earth at the runway threshold (RWT) point, aligned with the final approach course (see Figure 1-1).

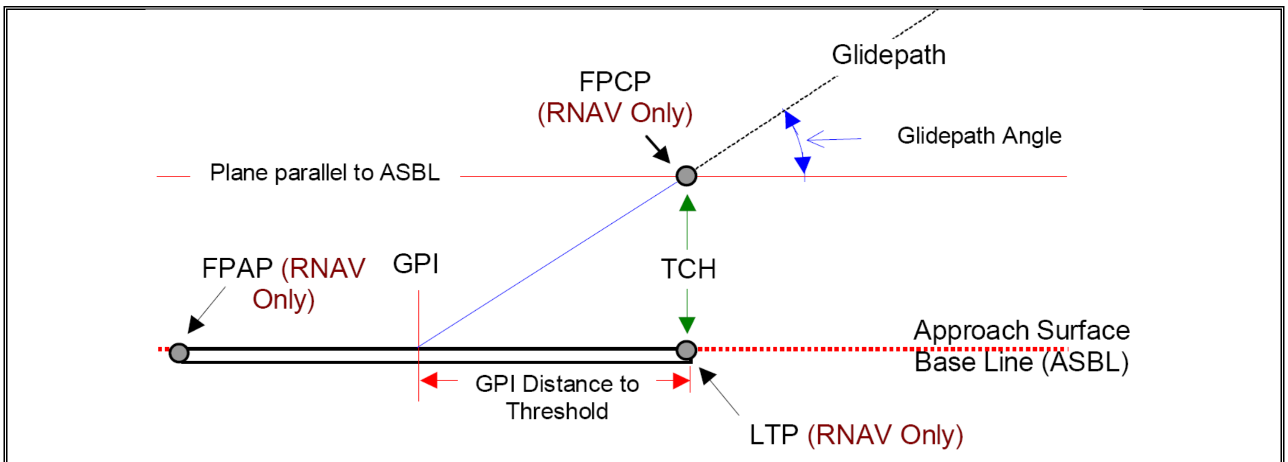


Figure 1-1: Precision Terms. Para 1.2.

1.2.2. Barometric Altitude. Altitude above the orthometric Geoid surface (i.e., mean sea level (MSL), based on atmospheric pressure measured by an aneroid barometer). This is the most common method of determining aircraft altitude.

1.2.3. Barometric Vertical Navigation (Baro-VNAV). RNAV and Non-RNAV. Positive vertical guidance relative to a computed glidepath that is based on the difference between published altitudes at two specified points or fixes.

1.2.4. Decision Altitude (DA). A specified altitude in reference to mean sea level in an approach with vertical guidance at which a missed approach must be initiated if the required visual references to continue the approach have not been established.

1.2.5. Departure End of Runway (DER). The end of the runway that is opposite the landing threshold. It is sometimes referred to as the stop end of runway.

1.2.6. Fictitious Threshold Point (FTP). The equivalent of the landing threshold point (LTP), when the final approach course is offset from runway centreline. It is the intersection of the final course and a line perpendicular to the final course that passes through the LTP. FTP elevation is the same as the LTP (see Figure 1-2).

1.2.7. Flight Path Alignment Point (FPAP) [RNAV Only]. The FPAP is a 3D point defined by World Geodetic System-84 (WGS-84)/North American Datum-83 (NAD-83) latitude, longitude, MSL elevation (see Figures 1-1 and 1-3). The FPAP is used in conjunction with the LTP and the geometric centre of the WGS-84 ellipsoid to define the vertical plane of a PA RNAV final approach course. The approach course may be offset up to 3° by establishing the FPAP left or right of centreline along an arc centred on the LTP.

1.2.8. Flight Path Control Point (FPCP) [RNAV Only]. An imaginary point above the LTP from which the glidepath mathematically emanates. It is in a vertical plane containing the LTP and FPAP. The FPCP has the same geographic coordinates as the LTP. The elevation of the FPCP is the sum of LTP elevation and the TCH value (see Figure 1-3).

1.2.9. Geoid Height (GH) [RNAV Only]. The height of the Geoid (reference surface for orthometric or MSL heights) relative to the WGS-84 ellipsoid. It is a positive value when the Geoid is above the WGS-84 ellipsoid and negative when it is below. The value is used to convert an MSL elevation to an ellipsoidal or geodetic height - the height above ellipsoid.

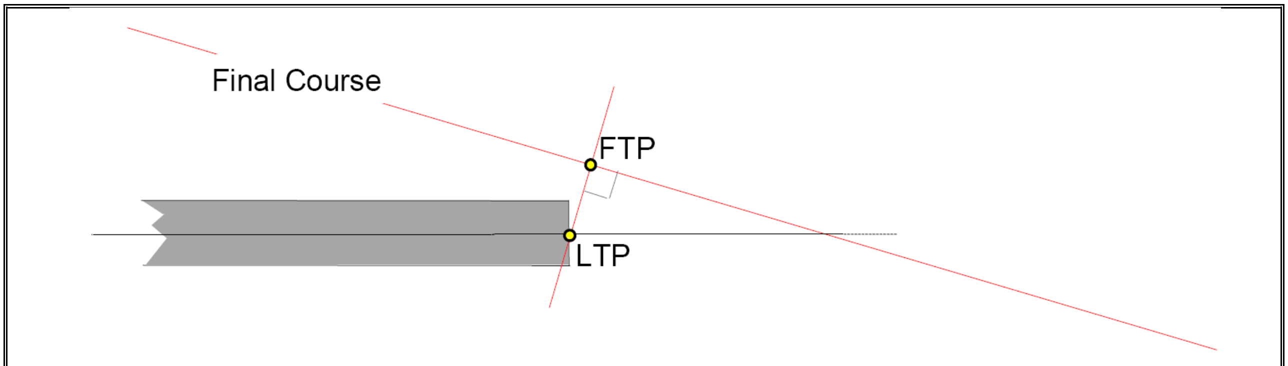


Figure 1-2: Fictitious Threshold Point. Para 1.2.

1.2.10. Glidepath Angle (GPA). The angular displacement of the glidepath from a horizontal plane that passes through the LTP/FTP. This angle is published on approach charts (e.g., 3.00°, 3.20°, etc.).

1.2.11. Ground Point of Intercept (GPI). A point in the vertical plane containing the glidepath where the vertical path intercepts the ASBL. GPI is expressed as a distance from RWT (see Figure 1-4).

1.2.12. Height Above Ellipsoid (HAE) [RNAV Only]. A height expressed in feet above the WGS-84 ellipsoid. This value differs from a height expressed in feet above the geoid (essentially MSL) because the reference surfaces (WGS-84 Ellipsoid and the Geoid) do not coincide. To convert an MSL height to an HAE height, algebraically add the geoid height value to the MSL value. HAE elevations are not used for instrument procedure construction, but are documented for inclusion in airborne receiver databases.

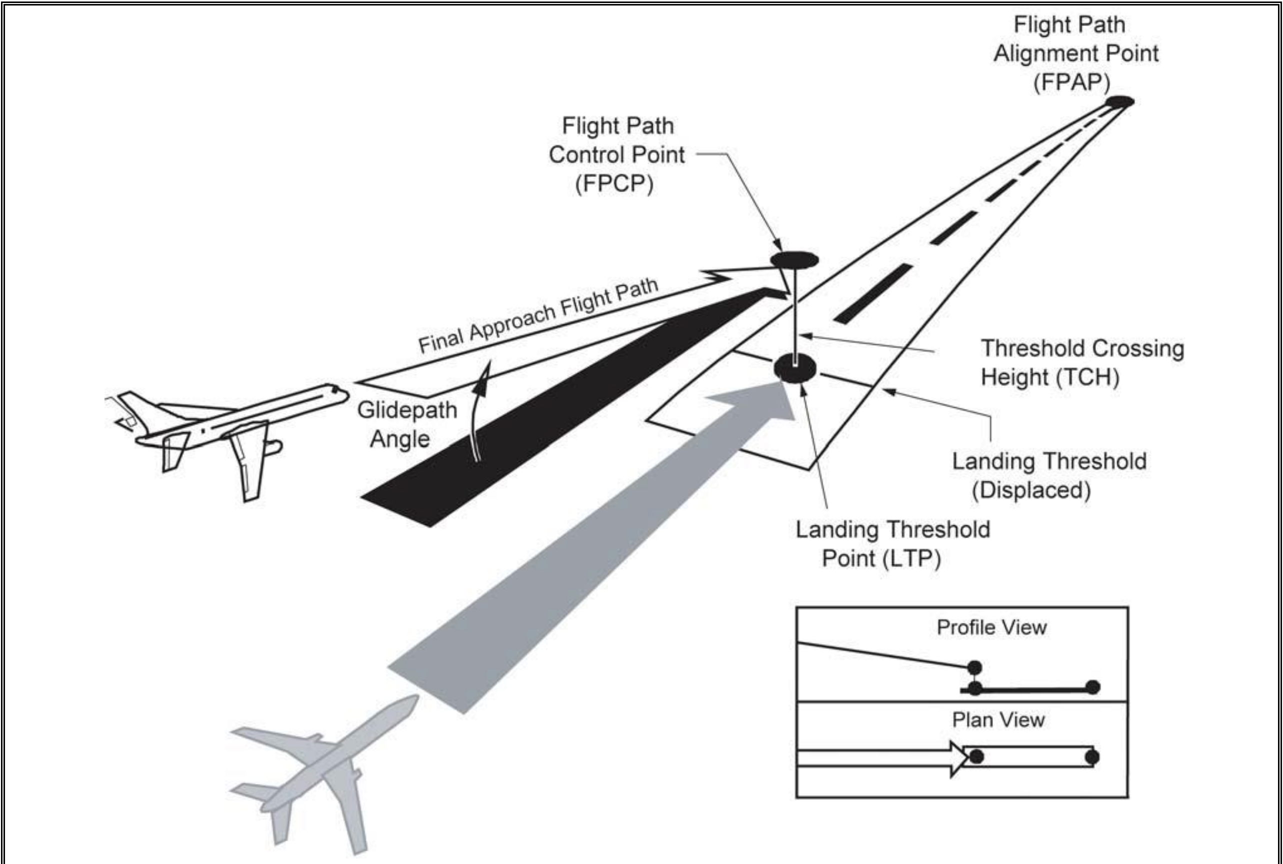


Figure 1-3: Precision Approach Path Points (Straight-In). Para 1.2.

EXAMPLE:

Given: KOUN RWY 35	Runway ID
N 35 14 31.65	Latitude
W 97 28 22.84	Longitude
1177.00MSL	Elevation
-87.29 feet (-26.606 m)	Geoid Height (GH)

HAE = MSL + GH
HAE = 1177 + (-87.29)
HAE = 1089.71

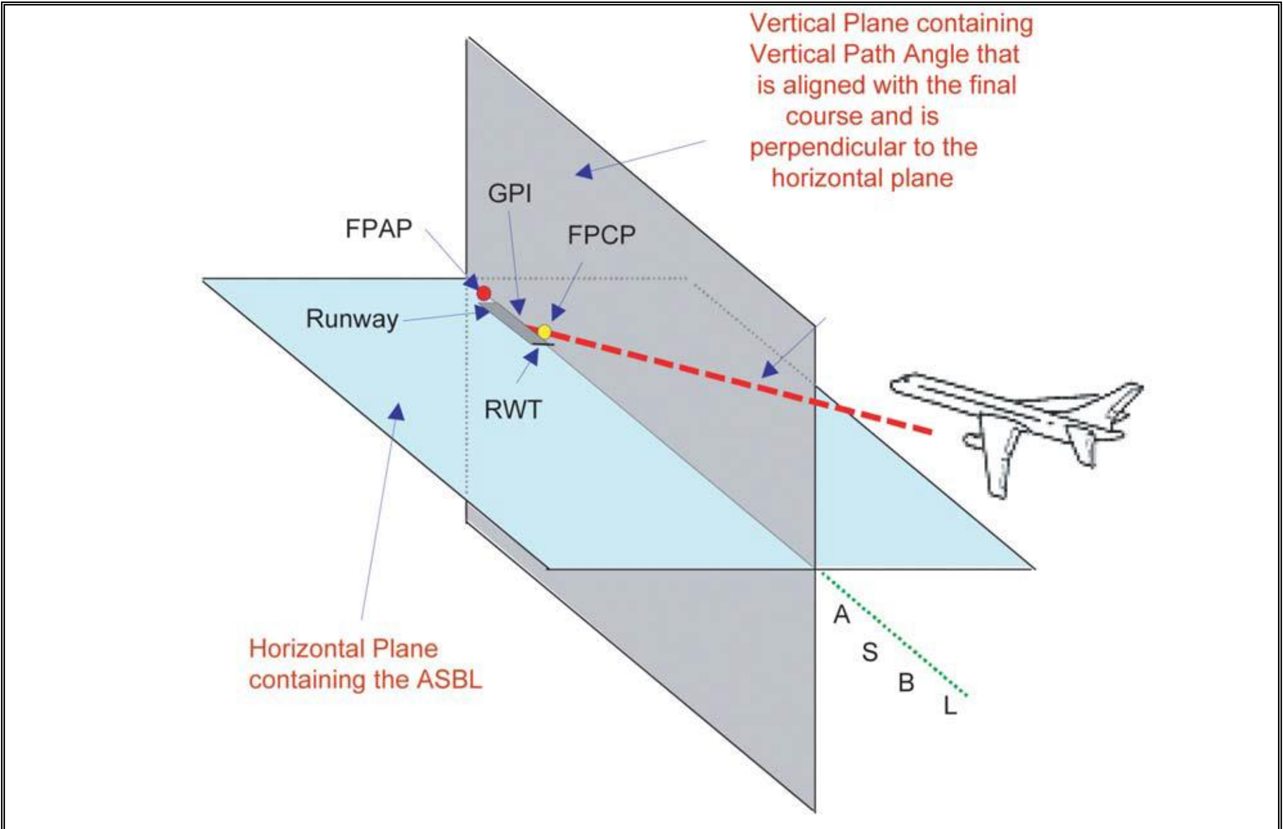


Figure 1-4: 3D Path & Course. Para 1.2.

1.2.13.Height Above Touchdown (HAT). The HAT is the height of the DA above touchdown zone elevation (TDZE).

1.2.14.Reserved

1.2.15.Reserved.

1.2.16.Landing Threshold Point (LTP). The LTP is a 3D point at the intersection of the runway centreline and the runway threshold. It is defined by WGS-84/NAD-83 latitude, longitude, MSL elevation, and Geoid height (see Figure 1-1). It is used in conjunction with the FPAP and the geometric centre of the WGS-84 ellipsoid to define the vertical plane of an RNAV final approach course. LTP elevation applies to the FTP when the final approach course is offset from runway centreline.

1.2.17.Lateral Navigation (LNAV) [RNAV Only]. Azimuth navigation without positive vertical guidance. This type of navigation is associated with non precision approach procedures.

1.2.18.Reserved.

1.2.19.Object Free Zone (OFZ). The airspace above the Precision Obstacle Free Zone, Approach Surface, Inner Transitional Surface, and that portion of the strip bounded by these surfaces, which is not penetrated by any obstacle, except for frangible visual NAVAIDs that need to be located in the OFZ because of their function.

1.2.20.Obstacle Clearance Surface (OCS). An inclined obstacle evaluation surface associated with a glidepath. The separation between this surface and the glidepath angle at any given distance from GPI defines the MINIMUM required obstruction clearance at that point.

1.2.21.Positive Vertical/Horizontal Guidance. Glidepath or course guidance based on instrumentation indicating magnitude and direction of deviation from the prescribed glidepath or course on which obstruction clearance is based.

1.2.22.Precision Approach (PA). An approach based on a navigation system that provides positive course and vertical path guidance conforming to ILS or MLS system performance standards contained in ICAO Annex 10. To achieve lowest minimums, the ground infrastructure must meet requirements contained in TP312 Aerodrome Standards and TP308/GPH209 Volume 3.

1.2.23.Precision Approach Radar (PAR). A ground radar system displaying an aircraft on final approach in plan and profile views in relation to glidepath and course centrelines. Air traffic controllers issue course line and glidepath information to the pilot. The pilot alters course and rate of descent in response to gain course and glidepath alignment. Military pilots may achieve 100 foot HAT and 1/4 mile visibility minimums with PAR.

1.2.24. Precision Final Approach Fix (PFAF). (Applicable to all PA approach procedures.) A 2D point located on the final approach course at a distance from LTP/FTP where the GPA intercepts the intermediate segment altitude (glidepath intercept altitude). The PFAF marks the outer end of the PA final segment.

1.2.25. Pseudo Ground Point of Intercept (PGPI). Phantom location abeam the GPI when the approach course is offset. PGPI elevation is the same as ASBL (see Figure 1-5).

1.2.26. Radio Altimeter Height (RA). An indication of the vertical distance between a point on the nominal glidepath at DA and the terrain directly beneath this point.

1.2.27. Required Navigation Performance (RNP). A statement of the navigation performance accuracy necessary for operation within a defined airspace. Note that there are additional requirements, beyond accuracy, applied to a particular RNP type.

1.2.28. Runway Threshold (RWT). The RWT marks the beginning of that part of the runway usable for landing (see Figure 1-6). It extends the full width of the runway. The RWT geographic coordinates identify the point the runway centreline crosses the RWT.

1.2.29. Three-Dimensional (3D) Point/Waypoint [RNAV Only]. A waypoint defined by WGS-84 latitude and longitude coordinates, MSL elevation, and GH.

1.2.30. Touchdown Zone Elevation (TDZE). The highest elevation in the first 3,000 feet of the landing surface.

1.2.31. Two-Dimensional (2D) Point/Waypoint [RNAV Only]. A waypoint defined by WGS-84 latitude and longitude coordinates.

1.2.32. Wide Area Augmentation System (WAAS) [RNAV Only]. A method of navigation based on the GPS. Ground correction stations transmit position corrections that enhance system accuracy and add VNAV features.

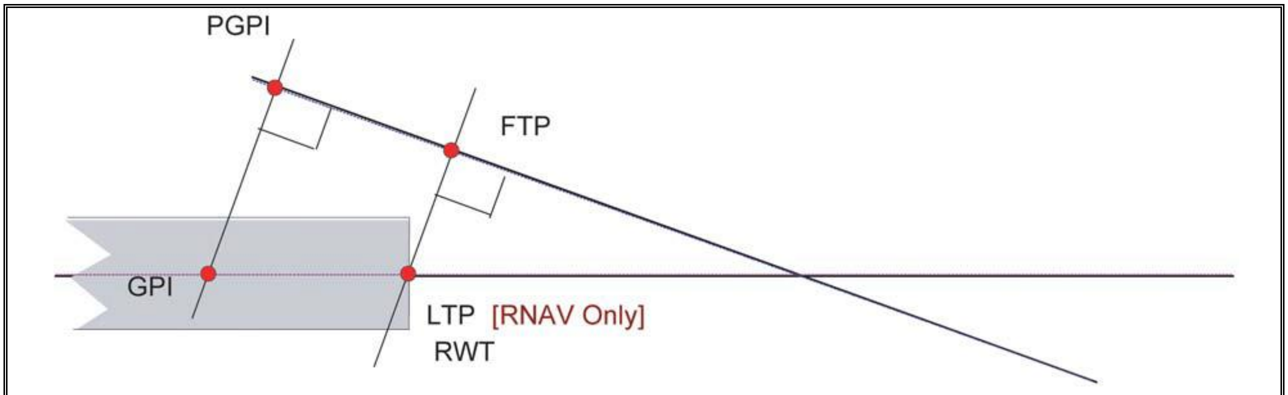


Figure 1-5: PGPI and FTP Locations. Para 1.2.

Figure 1-6: Threshold. Para 1.2.

CHAPTER 2. GENERAL CRITERIA

2.0 General

This chapter contains information common to all precision procedures.

2.1 Data Resolution

Perform calculations using at least 0.01 unit of measure. Document latitudes and longitudes to the nearest one hundredth (0.01") arc second; elevations to the nearest hundredth (0.01') foot; courses, descent and glidepath angles to the nearest one hundredth (0.01°) degree, and distances to the nearest hundredth (0.01) unit. Where other publications require different units and/or lesser resolution, use established conversion and rounding methods.

2.2 Procedure Identification

Procedure identification shall be in accordance with Volume 1.

2.3 En Route, Initial, And Intermediate Segments

Apply criteria in Volume 1 to non-RNAV approaches. Apply criteria in Volume 2 to construct the RNAV approaches.

2.3.1 Minimum Intermediate Segment Length

The intermediate segment blends the initial approach segment into the final approach segment. It begins at the IF and extends along the final approach course extended to the PFAF. Where a turn from the initial course to the final approach course extended is required, the initial course shall intercept at or before the IF.

a. Length. The MINIMUM length of the intermediate segment is 2 NM. Minimum segment length varies where a turn is required at the IF. The length is determined by the magnitude of heading change in the turn on to the final approach course extended (see Figure 2-1A). The maximum angle of intersection is 90° unless a lead radial as specified in Volume 1, Para 232a, is provided and the length of the intermediate segment is increased as specified in Volume 1, Table 2-3.

b. Width. The intermediate trapezoid begins at the width of the initial segment at the latest point the IF can be received, to the width of the final segment at the plotted position of the PFAF (see Figure 2-1B).

2.3.2 Determining FAC Intercept Angle Where DME Source Is Not Collocated With FAC facility

Determine the intercept initial/intermediate segment intercept angle on approach procedures utilizing ARC initial segments using the following formulas.

a. DME source on the same side of course as the aircraft (see Figure 2-2).

90 - | A - B | = Intercept Angle, Example: 90 - |270 – 285 | = 75º

b. DME source on opposite side of course as the aircraft (see Figure 2-3).

90 + | A - B | = Intercept Angle, Example: 90 + |270 – 285 | = 105º

2.4 Reserved

2.5 Maximum Authorized GPAs

Table 2-2A lists the MAXIMUM allowable GPAs by aircraft category. Design all approach procedures to the same runway with the same glidepath angle and TCH. The optimum (design standard) GPA is 3.0 degrees. GPAs greater than 3.0 degrees that conform to table 2-2A are authorized without Flight Standards/ military authority approval only when obstacles prevent use of 3.0 degrees. Flight Standards or military authority approval is required for angles less than 3.0 degrees or for angles greater than the minimum angle required for obstacle clearance.

2.5.1 RNAV Glidepath Angles

If a non-RNAV PA system (ILS, MLS, TLS, or PAR) serves the same runway as an RNAV PA system, the RNAV glidepath angle and TCH should match the non-RNAV system.

2.5.2 VGSI Angles

A VGSI is recommended for all runways to which an instrument approach is published. Where installed, the VGSI angle and TCH should match the glidepath angle of vertically guided approach procedures to the runway.

2.6 Glide Slope Threshold Crossing Height Requirements

2.6.1 Category I Threshold Crossing Height (TCH) Requirements

a. Standard. The glide slope should be located considering final approach obstructions and achieving TCH values associated with the greatest Table 2-3 wheel height group applicable to aircraft normally expected to use the runway. The TCH should provide a 30-foot wheel crossing height (WCH).

b. Deviations from Standard. The TCH shall provide a WCH of no less than 20 feet or greater than 50 feet for the appropriate wheel height group. These limits shall not be exceeded unless formally approved by a Ministerial Authorization, or a deviation issued by Transport Canada or the appropriate Military Authority.

Note: 60 feet is the maximum TCH.

c. Displaced Threshold Considerations. The TCH over a displaced threshold can result in a WCH value of 10 feet if the TCH over the beginning of the full strength runway pavement suitable for landing meets Table 2-3 TCH requirements.

Supplementary Note: These displaced threshold considerations (para 2.6.1 c) are to deal with obstacles that are temporary in nature. The WCH of 10 ft is considered a minimum figure.

2.6.2 Category II and III TCH Requirements

a. Standard. The commissioned TCH shall be between 50 and 60 feet with the optimum being 55 feet.

b. Deviations from the Standard. Any deviation must be formally approved by; a Ministerial Authorization, a deviation issued by Transport Canada, or the appropriate Military Authority.

2.6.3 Required TCH Values

Publish a note indicating "**VGSI not coincident with the procedure GPA**" when the VGSI angle is more than 0.2° from the GPA, or when the VGSI TCH is more than 3 feet from the procedure TCH.

2.7 Ground Point Of Intercept (GPI)

Calculate GPI distance using the following formula:

$$GPI = \frac{TCH}{\text{Tan (GPA)}}$$

2.8 Determining FPAP Coordinates. (RNAV Only)

The geographic relationship between the LTP and the FPAP determines the final approach ground track. Geodetically calculate the latitude and longitude of the FPAP using the LTP as a starting point, the desired final approach course (OPTIMUM course is the runway bearing) as a forward azimuth value, and an appropriate distance. If an ILS or MLS serves the runway, the appropriate distance in feet is the distance from the LTP to the localizer antenna minus 1,000 feet, or the distance from the LTP to the DER, whichever is greater. Apply Table 2-4 to determine the appropriate distance for runways not served by an ILS or MLS.

2.9 Determining PFAF/FAF Coordinates

See Figure 2–4.

Geodetically calculate the latitude and longitude of the PFAF/FAF using the horizontal distance (D-GPI) from the LTP or FTP to the point the glidepath intercepts the intermediate segment altitude. Determine D using the following formulas: (step 2 formula includes earth curvature)

Step 1: Formula: z = A – F

Example: z = 2,100 – 562.30 = 1,537.70

Step 2: Formula: $D = 364{,}609 \times \left(90 - \theta - sin^{-1}\left(\frac{20{,}890{,}537 * sin(90+\theta)}{z+20{,}890{,}537}\right)\right)$

Example: $D = 364{,}609 \times \left(90 - \theta - sin^{-1}\left(\frac{20{,}890{,}537 * sin(90+\theta)}{1537.7+20{,}890{,}537}\right)\right)$

D = 28,956.03

Where: A = PFAF/FAF Altitude in feet (example 2,100)

F = LTP elevation in feet (example 562.30)

θ = Glidepath angle (example 3.00°)

z = PFAF/FAF Altitude above ASBL

Note: 1) Step 2 formula includes earth curvature.

2) In order to determine glidepath altitude at a fix refer to Volume 2 Chapter 7, Para 7.1.40)

2.9.1 Distance Measuring Equipment (DME)

When installed with ILS, DME may be used to designate the FAF. When a unique requirement exists, DME information derived from a separate facility, as specified in Volume 1, Para 282, may also be used to provide ARC initial approaches, a FAF for back course (BC) approaches, or as a substitute for the outer marker. When used as a substitute for the outer marker, the plotted position of the fix must be ≤ 16.66 NM from the DME facility and the angular divergence at the fix must NOT exceed 6°.

Note: The restriction on angular divergence only applies to a DME fix used in lieu of OM for the precision approach. For localizer approaches not combined with an ILS, Vol. 1, chapter 2, paragraph 282, applies.

Supplementary Note: NDB as GP check altitude

When installed with the ILS, the NDB must meet the accuracy standards of the Marker Beacon (ICAO Annex 10, Vol 1 - difference filed) (i.e. the NDB must be under the centerline of localizer beam). Cross bearings (from NDB, VORs, etc) to the FAF do not meet accuracy standards for the GP check altitudes.

2.10 Common Fixes (RNAV Only)

Design all procedures published on the same chart to use the same sequence of charted fixes.

2.11 Glidepath Qualification Surface (GQS)

The GQS extends from the runway threshold along the runway centreline extends to the DA point. It limits the height of obstructions between DA and runway threshold (RWT). When obstructions exceed the height of the GQS, an approach procedure with positive vertical guidance (ILS, PAR, MLS, TLS, LPV, LNAV/VNAV, etc.) is not authorized.

Note: Obstacles excluded by paragraph 2.11.1d may penetrate the GQS without penalty. When other obstacles penetrate the GQS, vertically guided approach operations may be authorized when mitigated (e.g., approach restricted to Height Group 1 and 2 aircraft). Contact Transport Canada, (or appropriate military equivalent) for case-by-case analysis.

2.11.1 Area

a. Origin and Length. The sloping qualification surface originates at either the RWT or a specified distance from RWT (X_{OFFSET}). The surface origin height is either THRe or a specified height above THRe (V_{OFFSET}). The value of V_{OFFSET} and X_{OFFSET} are dependent on the TCH and Glidepath angle (θ).

Where the TCH > 50; V_{OFFSET} = [TCH - 50] and X_{OFFSET} = zero [0]

Where the TCH $\geqslant$ 40 and $\leqslant$ 50; V_{OFFSET} and X_{OFFSET} = zero [0]

Where the TCH < 40, V_{OFFSET} = zero [0] and $X_{OFFSET} = \frac{40-TCH}{\tan\left(\theta\frac{\pi}{180}\right)}$

The area between the RWT and point "X_{offset}" is a level surface and must be clear of obstacles except obstacles permitted by the applicable airport design standard (see Vol. 3, chapter 3, paragraph 2.11.1d).

b. Width. The GQS lateral boundary is 100 ft from the runway edge at RWT. It expands uniformly to "E" feet (half-width) at DA (figures 2-5b and 2-5c).

Calculate the GQS half-width "E" at the DA point measured along the runway centerline extended using formula 2-2a

Calculate the GQS half-width at RWT using formula 2-2b.

Calculate the GQS half-width (w) at any distance "d" from RWT coordinates using formula 2-2c.

$$E = 0.036(D - 200) + 400$$

Where: D = the distance (ft) measured along RCL extended from RWT to the DA point
E = GQS half-width (ft) at DA

c. If the course is offset from the runway centreline more than 3° (RNAV Only), expand the GQS area on the side of the offset as follows referring to Figure 2-5D and 2-5E:

STEP 1. Construct **BC**. Locate point "**B**" at the intersection of the runway centerline extended and a line perpendicular to the final approach course at the DA point. Calculate the half-width (**E**) of the GQS for the distance from point "**B**" to the RWT coordinates. Locate point "**C**" at distance "**E**" on a line perpendicular to the final approach course. Connect points "**B**" and "**C**."

STEP 2. Construct **CD**. Locate point "**D**" abeam the RWT coordinates on a line perpendicular to runway centerline at a point 100 ft from the runway edge. Connect points "**C**" and "**D**."

STEP 3. Construct **DF**. Locate point "**F**" abeam the RWT coordinates on a line perpendicular to runway centerline at a point 100 ft from the runway edge. (opposite point "**D**"). Connect points **"D**" and "**F**."

STEP 4. Construct **AF**. Locate point "**A**" on a line perpendicular to the runway centerline extended at distance "**E**" from point "**B**". Connect points "**A**" and "**F**."

STEP 5. Construct **AB**. Connect point "**A**" to point "**B**".

Calculate the width of the **offset side** of the GQS trapezoid using formula 2-2d (see Vol. 3, chapter 2, figure 2-5f). Calculate the width of the **non-offset side** using formula 2-2a, except "D" = distance from RWT to Point B.:

d. Clearance Surface. See Vol. 3, chapter 2, figure 2-5A. The GQS vertical characteristics reflect the glidepath characteristics of the procedure (e.g., the ILS/GLS/MLS/TLS/LPV vertical path is a straight line in space and the baro-VNAV vertical path (RNAV and RNP LNAV/VNAV) is a curved line in space). Obstacles must not penetrate the GQS [see paragraph Vol. 3, chapter 2, paragraph 2.11.1d exceptions]. Calculate the height of the sloping GQS above THRe at any distance "d" (greater than XOFFSET) measured from runway threshold (RWT) coordinates along runway centerline (RCL) extended to a point abeam the obstacle using the appropriate formula (Formula 2-3A).

(1) For LPV (and ILS/GLS/MLS/TLS) procedures, the OCS is a flat plane (does not follow earth curvature); therefore, the height of the GQS at any point is equal to the height of surface on the runway centerline abeam it. Since the earth's surface also curves away on the lateral as well as the longitudinal axis, the MSL elevation (OBSMSL) of an obstacle is reduced to account for earth curvature. This reduced value is termed the obstacle effective MSL elevation (OEE). Calculate OEE using formula 2-4 and compare to GQS height above THRe or LTP.

(2) Obstacles permitted by Aerodrome Standards and Recommended Practices (or equivalent DND airport design standard at military airfields) are excluded from GQS evaluation as follows.

(a) Obstacles with an effective height at or below an 80:1 surface (or DND equivalent) originating at RWT coordinates (at THRe) and extending a distance of 1,000-ft (figure 2-5G) are considered acceptable obstacles.

(b) Above-ground objects permitted by TP312 (or applicable DND directives) are considered acceptable obstacles and are excluded from GQS evaluation.

2.12 ILS Antenna Mast Height Limitations for Obstacle Clearance

The standard for locating the ILS antenna mast or monitor is a MINIMUM distance of 400 feet from the runway, measured perpendicular to RCL. The antenna mast should not exceed 55 feet in height above the elevation of the runway centreline nearest it (see Figure 2-7). At locations where it is not feasible for technical or economic reasons to meet this standard, the height and location of the antenna is restricted according to formula 2-0.

Table 2-1: RESERVED

Category	GPA
A (80 knots or less)	6.4
A (81 – 90 knots)	5.7
B	4.2
C	3.6
D & E	3.1

Table 2-2A: Maximum GPA's. Para 2.5 and 3.5.3.

Representative Aircraft type	Approximate Glidepath to Wheel Height	Recommended TCH +/- 5 Feet	Remarks
<u>Height Group 1</u> General Aviation, Small Commuters, Corporate Turbojets, T-37, T-38, C-12, C-20, C-21, T-1, Fighter Jets, UC-35, T-3, T-6	10 Feet or less	40 Feet	Many runways less than 6,000 feet long with reduced widths and/or restricted weight bearing which would normally prohibit landings by larger aircraft.
<u>Height Group 2</u> F-28, CV-340/440/580, B-737, C-9, DC-9, C-130, T-43, B-2, S-3	15 Feet	45 Feet	Regional airport with limited air carrier service.
<u>Height Group 3</u> B-727/707/720/757, B-52, C-135, C-141, C-17, E-3, P-3, E-8, C-32, A-300/310, A-319/320/321	20 Feet	50 feet	Primary runways not normally used by aircraft with ILS glidepath-to-wheel heights exceeding 20 feet.
<u>Height Group 4</u> B-747/767/777, L-1011, DC-10, A-330, A-340, A-380 (planned), B-1, KC-10, E-4, C-5, VC-25	25 Feet	55 Feet	Most primary runways at major airports.

<u>Notes:</u>

1. To determine the minimum allowable TCH, add 20 feet to the glidepath-to-wheel height.
2. To determine the maximum allowable TCH, add 50 feet to the glidepath-to-wheel height (PA not to exceed 60 ft.)
3. Publish a note indicating VGSI not coincident with the procedure GPA when the VGSI angle is more than 0.2° from the GPA, or when the VGSI TCH is more than 3 feet from the procedure TCH.

Table 2-3: TCH Requirements. Para 2.3.1.a and 2.6.1.

Runway Length	FPAP Distance from LTP	Splay	± Width
≤ 9,023’	9,023’	2.0°	350’
> 9,023’ and ≤ 12,366’	to DER	$ArcTan\left(\frac{350}{RWYLength+1,000}\right)$	350’
> 12,366 and ≤ 16,185’	to DER	1.5°	$Tan(1.5)(RWYLength+1,000)$
> 16,185’ (AFS or Appropriate Military Agency Approval)	to DER or as specified by approving agency	1.5°	$Tan(1.5)(RWYLength+1,000)$

Table 2-4: Runways Not Served By An ILS. Para 2.8.

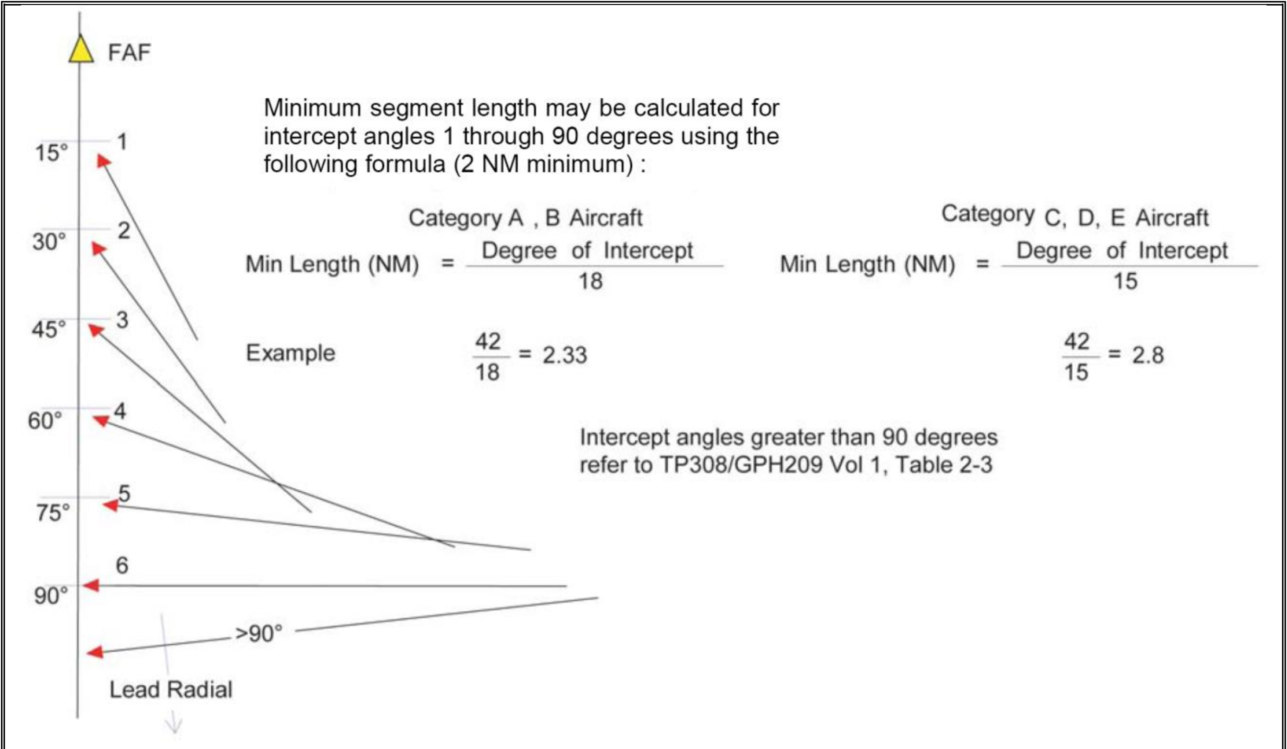


Figure 2-1A: Minimum Intermediate Segment. Para 2.3.1.a.

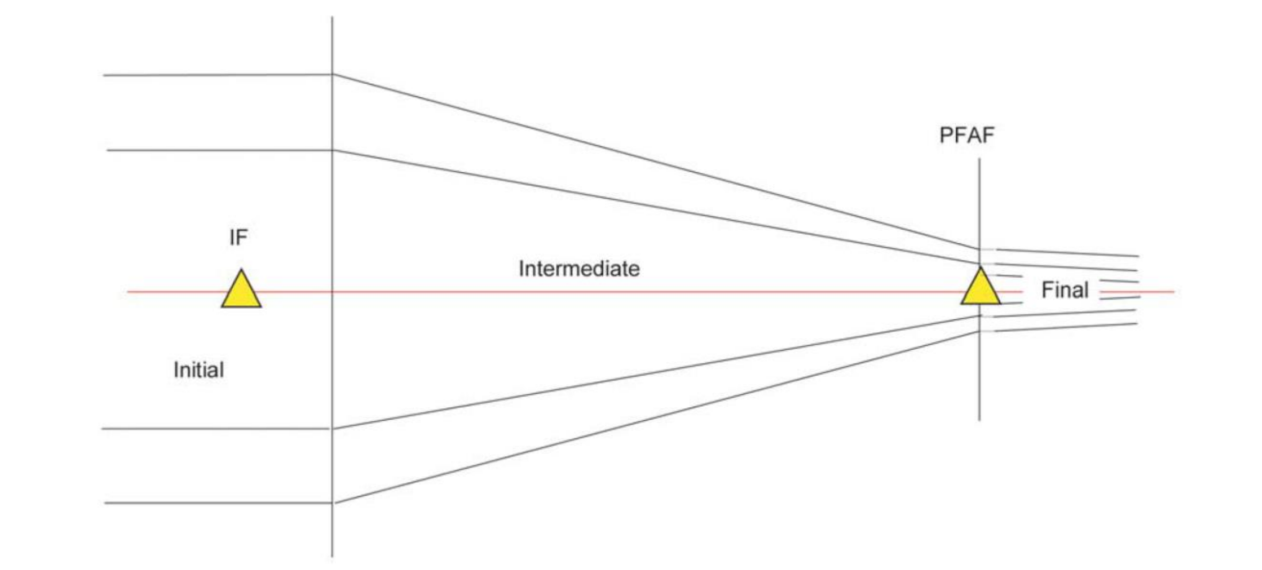


Figure 2-1B: Intermediate Segment Width. Para 2.3.1.b.

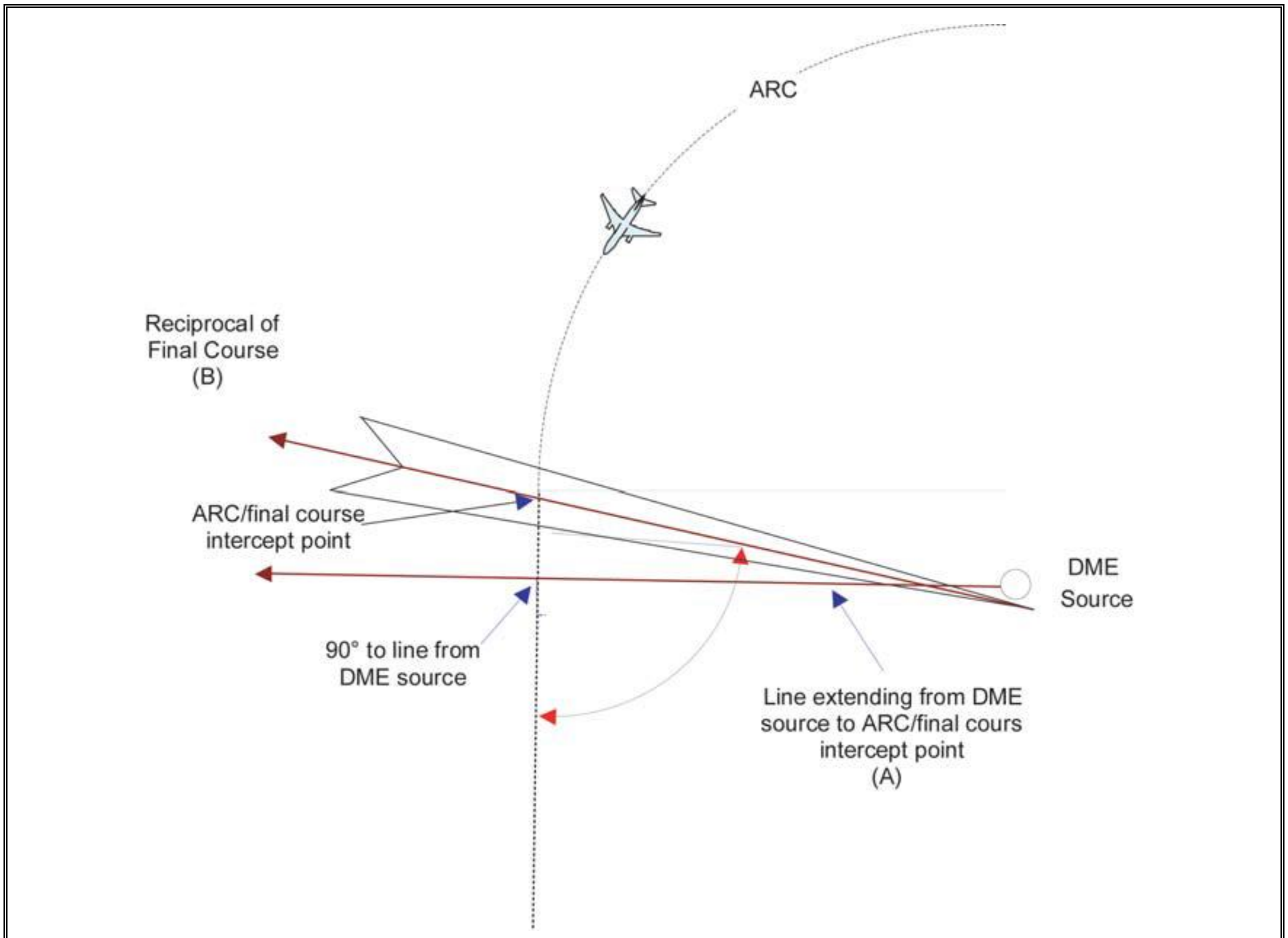


Figure 2-2: Aircraft On The Same Side Of Localizer As DME Sources. Para 2.3.2.a.

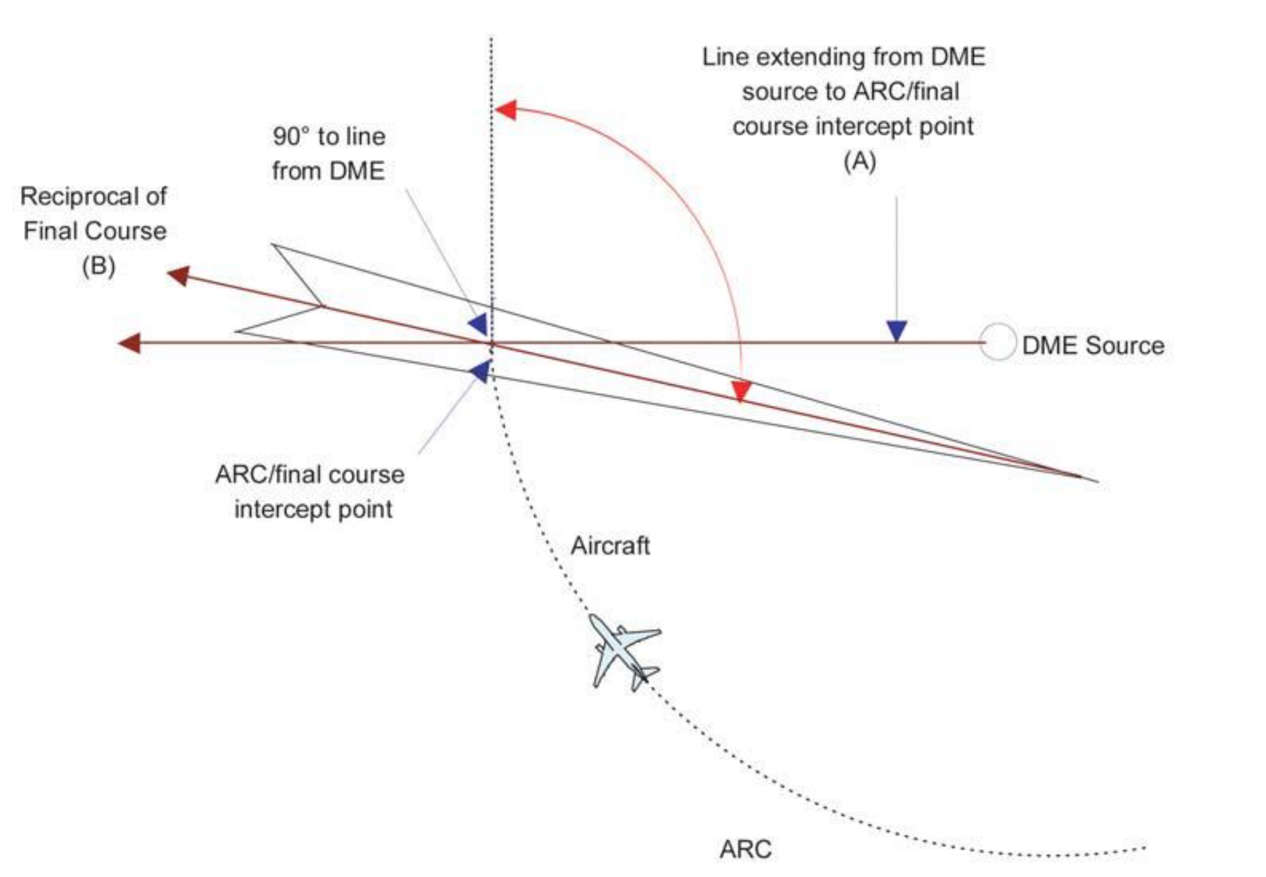


Figure 2-3: Aircraft On The Opposite Side Of Localizer From DME Sources. Para 2.3.2.b.

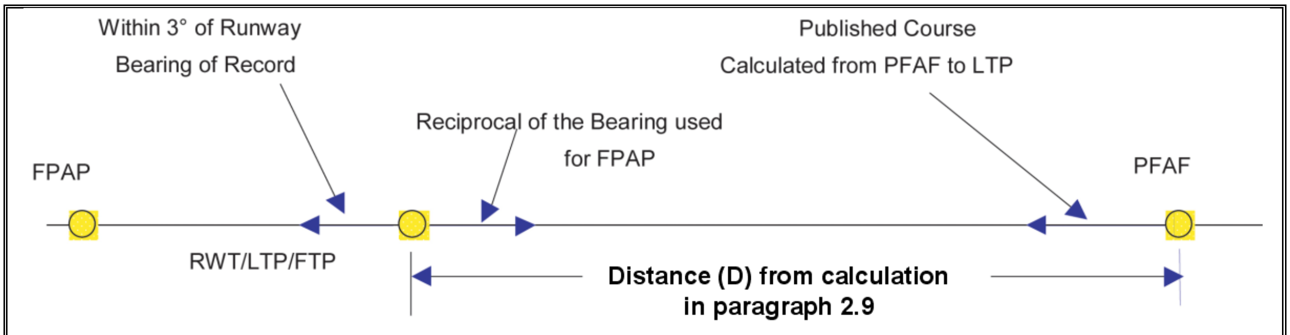


Figure 2-4: Determining PFAF Location. Para 2.9.

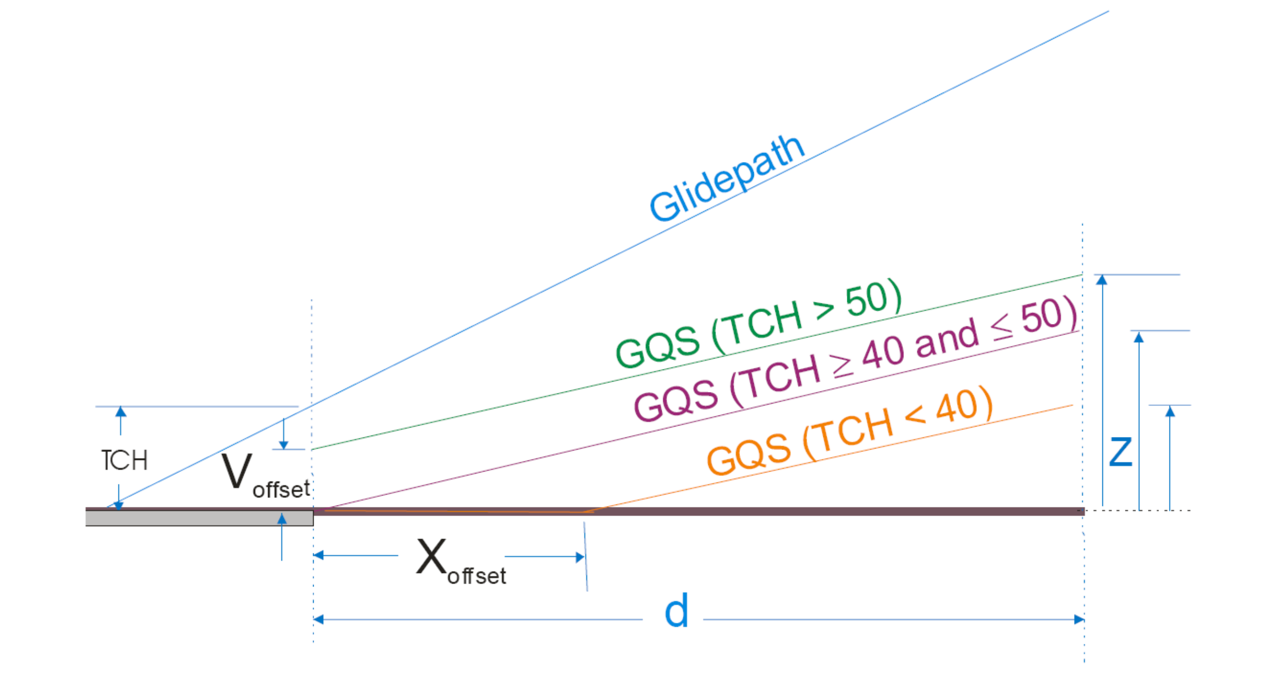


Figure 2-5A: GQS. Para 2.11.

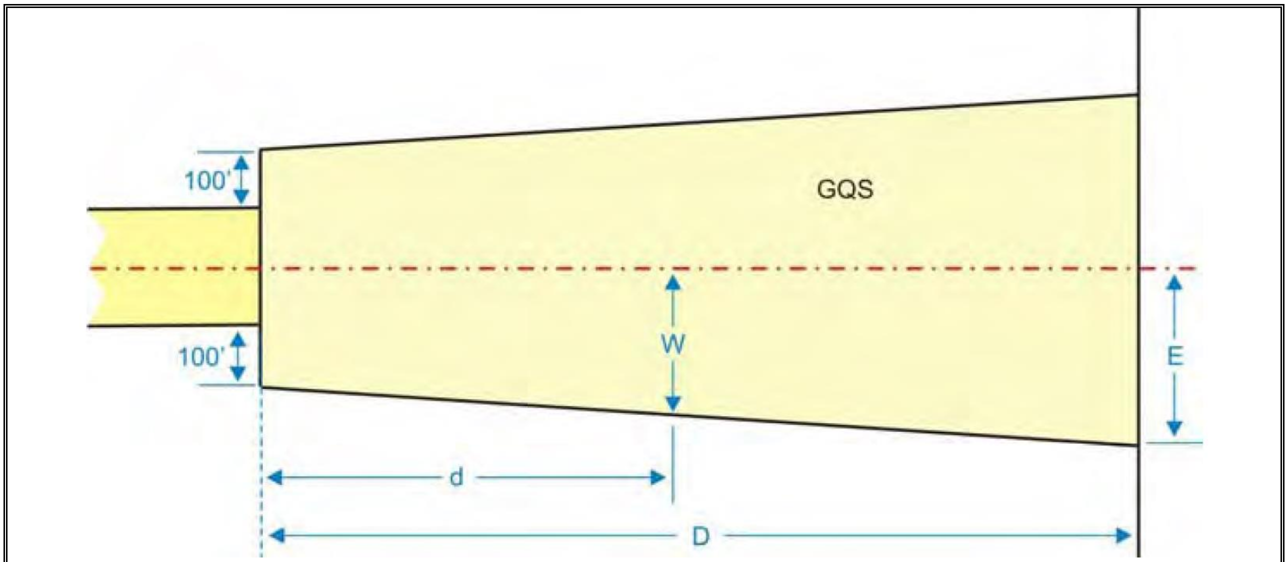


Figure 2-5B: Example: TCH ≥ 40 ft.

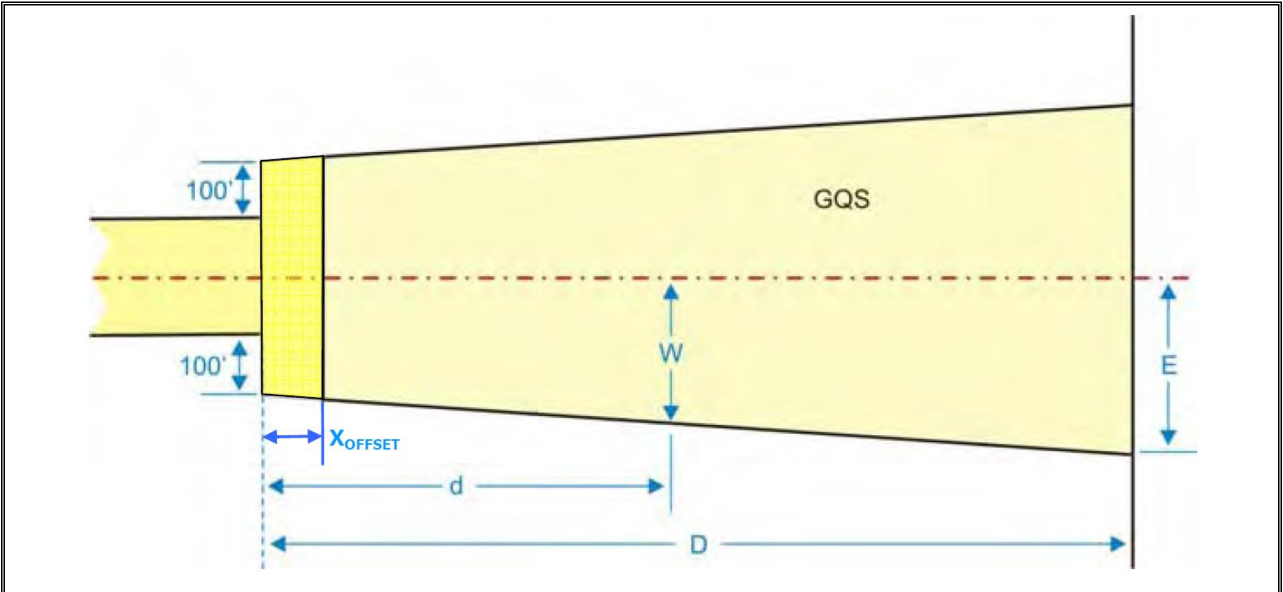


Figure 2-5C: Example: TCH < 40 ft.

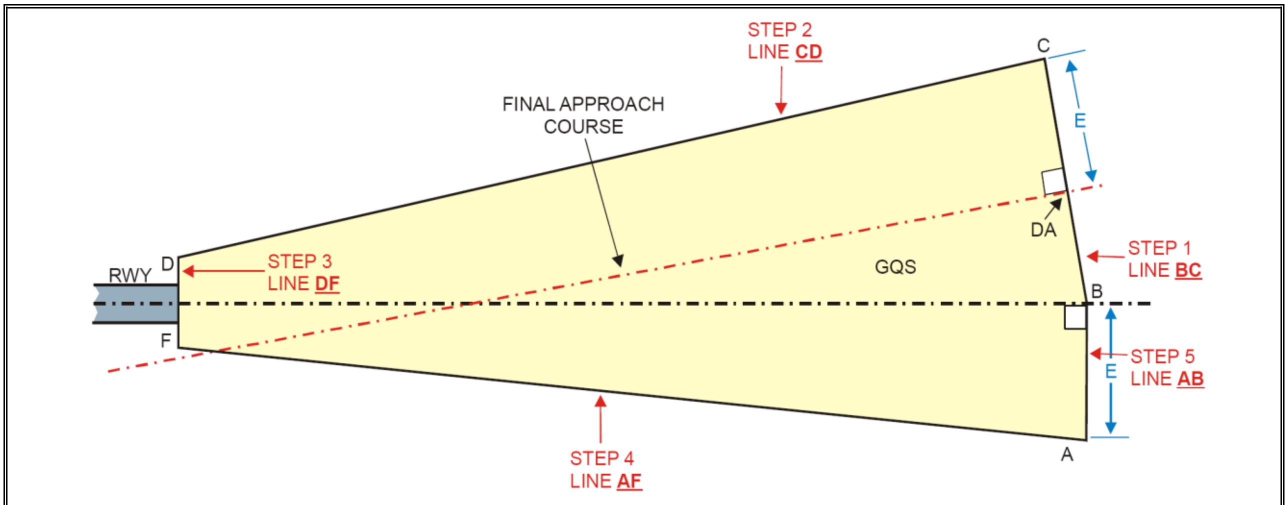


Figure 2-5D: Example: TCH ≥ 40 ft.

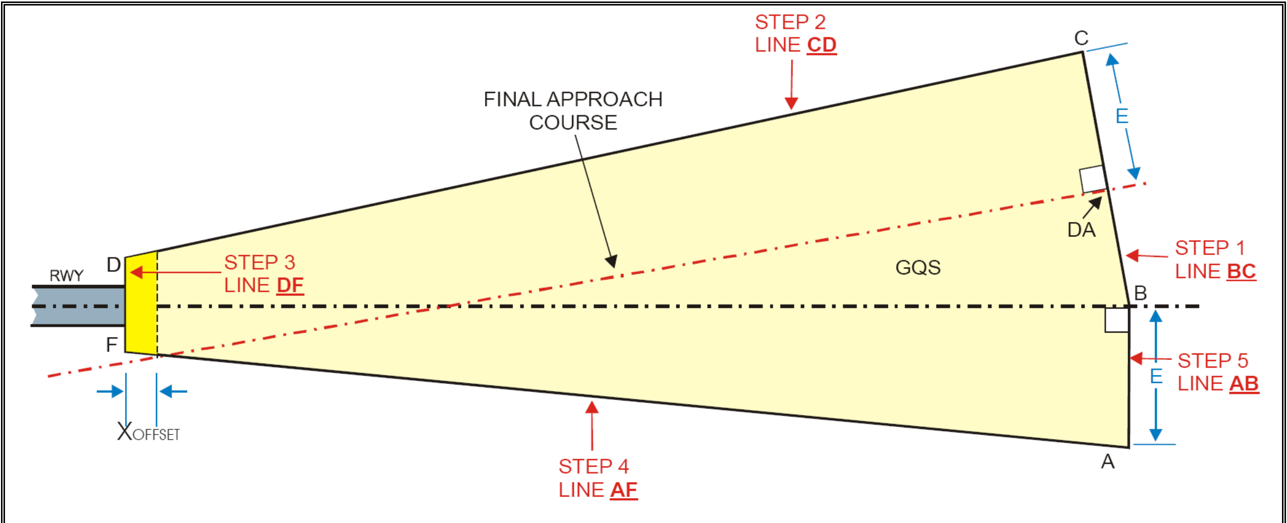


Figure 2-5E. Example: TCH < 40 ft.

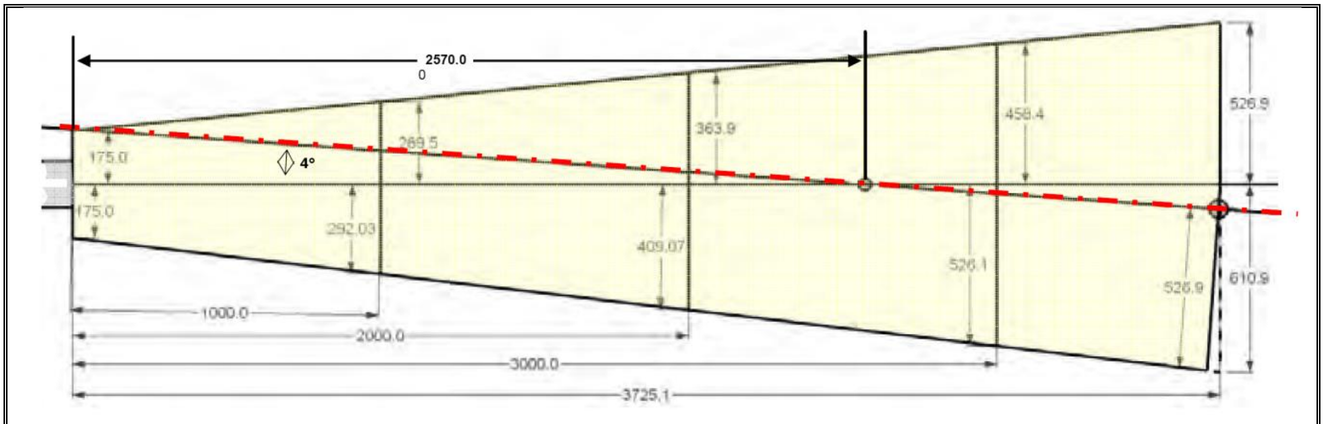


Figure 2-5F. Offset Calculation Example.

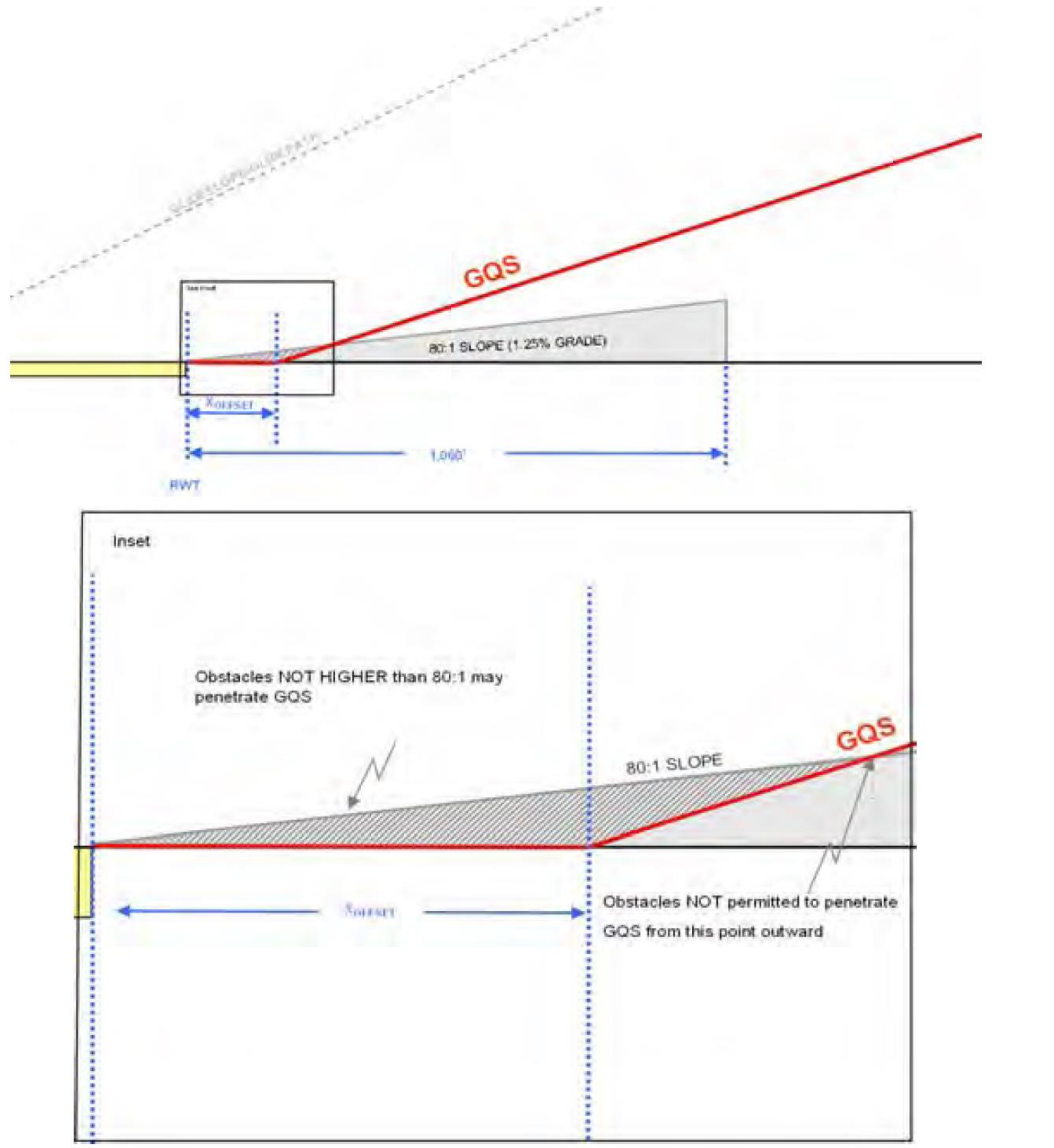
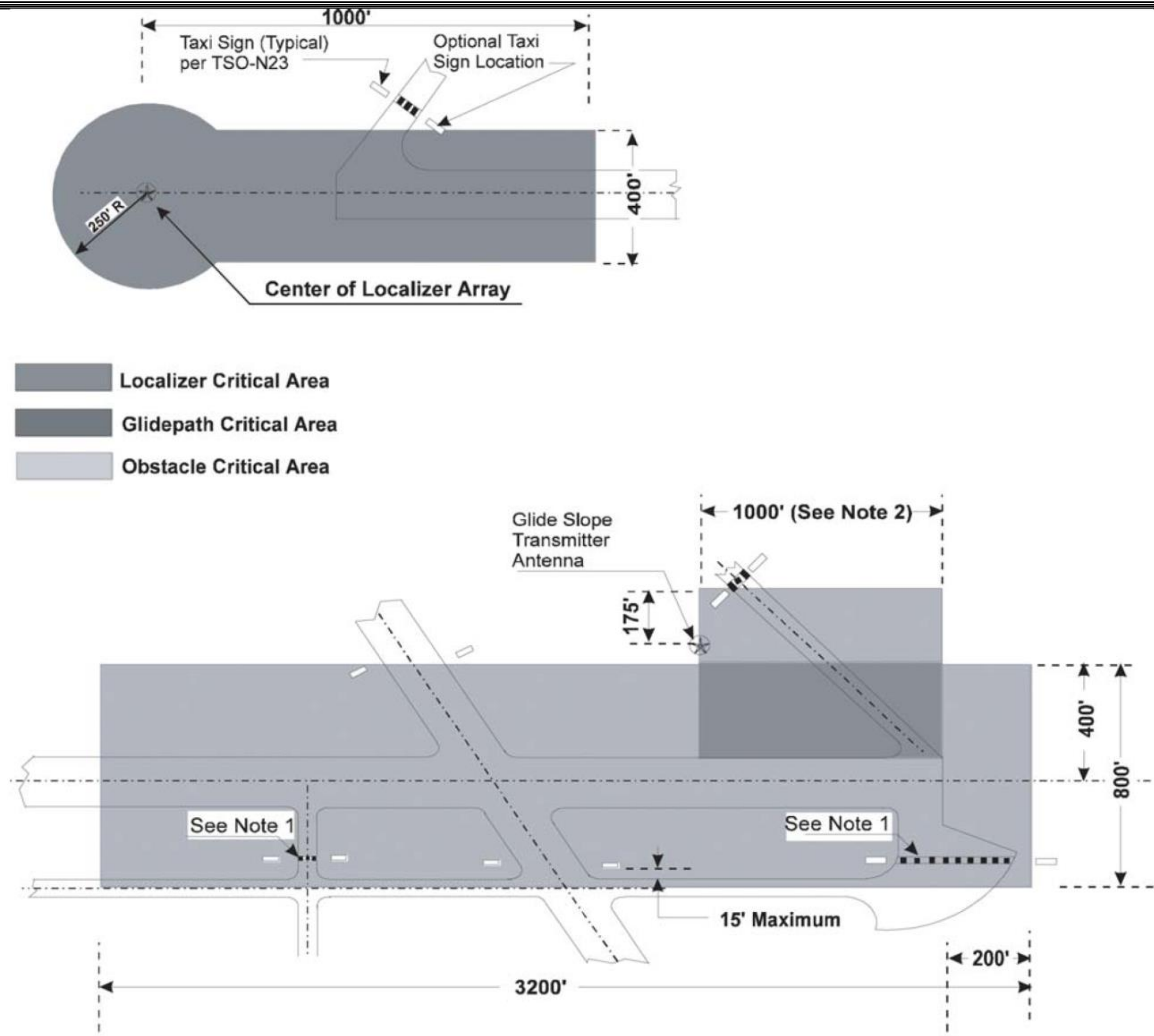


Figure 2-5G. Allowable GQS Penetrations.



NOTES: 1. Location of hold lines when operations are permitted on a 400-foot parallel taxiway.
2. Or to the end of the runway, whichever is greater.

Figure 2-6: Category II Critical Areas.

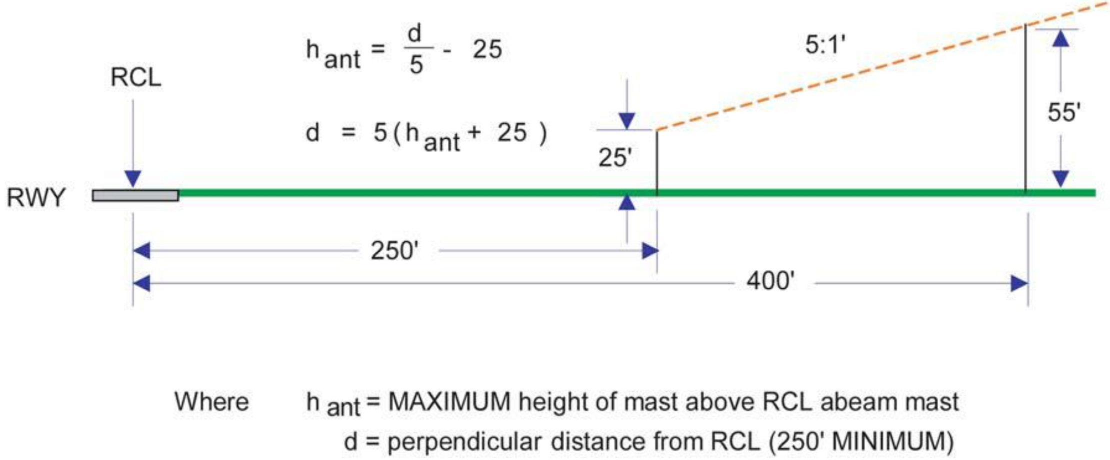


Figure 2-7: ILS Antenna Mast Limitations. Para 2.12.

Formula 2-0. ILS Antenna Mast Height Limitations	
Math Notation	$h_{ant} = \frac{d}{5} - 25$, AND $d = 5(h_{ant} + 25)$
Standard Text	HANT=D/5-25 D = 5(HANT+25)
Given values: hant = max height of mast above RCL abeam mast (ft) d = perpendicular dist from RCL (250' MINIMUM)	

Formula 2-1. Sloping OCS Origin X_{OFFSET} (TCH<40).	
Math Notation	$X_{offset} = \dfrac{40 - TCH}{tan\left(\theta \dfrac{\pi}{180}\right)}$
Standard Text	(40 - TCH)/tan(θ * π /180)
Given values: TCH = Threshold Crossing Height tan = tangent θ = Glidepath Angle	

Formula 2-2a. GQS Half-Width at DA.	
Math Notation	$E = 0.036D + 392.8$
Standard Text	0.036*D+392.8
Given values: D = RWT to DA point dist (ft) measured along RCL extended	

Formula 2-2b. GQS Half-Width at RWT.	
Math Notation	$k = \frac{RWY_{width}}{2} + 100$
Standard Text	RWYwidth/2+100
Given values: RWY_{width} = Runway width (ft)	

Formula 2-2c. GQS Half-Width, any distance (d).	
Math Notation	$w = \left(\frac{E-k}{D}d\right) + k$
Standard Text	((E - k)/D*d)+k
Given values: D = RWT coordinates to DA point dist.(ft) d = desired distance(ft)from RWT coordinates E = Formula 2 - 2a output k = Formula 2 - 2b output	

Formula 2-2d. GQS Offset Side Width, any distance (d).	
Math Notation	$W_{OFFSET} = d\left(\frac{cos\left(\theta * \frac{\pi}{180}\right)\left[sin\left(\theta * \frac{\pi}{180}\right)(D-i)+E\right]-k}{D - sin\left(\theta * \frac{\pi}{180}\right)\left[sin\left(\theta * \frac{\pi}{180}\right)(D-i)+E\right]}\right) + k$
Standard Text	d*((cos(θ * π /180)*(sin(θ * π /180)*(D - i)+E) - k)/ (D - sin(θ * π /180)*(sin(θ * π /180)*(D - i)+E)))+k
Given values: d = desired distance (ft) from RWT coordinates cos = Cosine sin= Sine θ = FAC offset (degrees) D = RWT coordinates to Point “B” distance (ft) i = RWT coordinates to FAC intersect. dist.(ft) E = Formula 2 - 2a output k = Formula 2 - 2b output	

Formula 2-3a. GQS Elevation ILS/GLS/MLS/TLS or LPV.	
Math Notation	$Z_{ILS} = \frac{(r + F + V_{OFFSET})cos\left(\frac{2\theta}{3} \cdot \frac{\pi}{180}\right)}{cos\left(\frac{d - X_{OFFSET}}{r} + \frac{2\theta}{3} \cdot \frac{\pi}{180}\right)} - r$
Standard Text	((r+F+VOFFSET)*cos(2*θ/3*π/180))/ (cos((d - XOFFSET)/r+2* θ /3* π /180)) - r
Given values: r = mean earth radius (ft) F = THRe or LTP elevation V_{OFFSET} = per paragraph 2.11.1a, otherwise 0 cos = cosine d = desired distance (ft) from RWT coordinates X_{OFFSET} = per paragraph 2.11.1a, otherwise 0 θ = GPA	

Formula 2-3b. RESERVED

Formula 2-4. EC Adjusted Obstacle MSL Elevation.	
Math Notation	$O_{EE} = OBS_{MSL} - (r + F) * \left(\frac{1}{\cos\left(\frac{OBS_Y}{r}\right)} - 1\right)$
Standard Text	OBSMSL - (r+F)*(1/cos(OBSY/r) - 1)
Given values: OBS_{MSL} = obstacle MSL elevation r = mean earth radius (ft) F = THRe or LTP elevation cos = cosine OBS_Y = perpendicular dist.(ft)from Rwy centerline to obstacle	

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CHAPTER 3. PRECISION FINAL AND MISSED APPROACH SEGMENTS

3.0 Final Segment

The area originates 200 feet from LTP or FTP and ends at the PFAF (see Figure 3-1). The primary area consists of the W and X OCS, and the secondary area consists of the Y OCS.

3.1 Alignment

The final course is normally aligned with the runway centreline extended (± 0.03°) through the LTP/RWT (± 5 feet). Where a unique operational requirement indicates a need for an offset course, it may be approved provided the offset does not exceed 3°. Where the course is not aligned with the RCL, the MINIMUM HAT is 250 feet, and MINIMUM RVR is 2,600 feet. Additionally, the course must intersect the runway centreline at a point 1,100 to 1,200 feet toward the LTP/RWT from the DA point (see Figure 3-2).

3.2 OCS Slopes

In this document, slopes are expressed as rise over run; e.g., 1:34. Determine the OCS slope associated with a specific GPA using the following formula:

$$\mathrm{S} = \frac{102}{\mathrm{GPA}} \qquad \mathrm{Example} = \frac{102}{3} = 34$$

3.2.1 Origin

The OCS begins at 200 feet from LTP or FTP, measured along course centreline and extends to the PFAF. The rising slope normally begins at the OCS origin. However, when the GPI to RWT distance is less than 954 feet, the slope is zero from its origin to distance ‘d’ from the origin. The slope associated with the glidepath begins at this point (see Figure 3-3). Use the following formula to determine distance ‘d’:

Where d = 954 – GPI
GPI = 801.41 ft

Example: d = 954 – 801.41 = 152.59 ft

3.2.2 Revising GPA for OCS Penetrations

Raising the glidepath angle may eliminate OCS penetrations. To determine the revised minimum glidepath angle, use the following formula:

$$Revised\ Angle = \frac{102\left(\frac{D-(200+d)}{S}+p\right)}{D-(200+d)} = \frac{102\left(\frac{2200-(200+0)}{34}+2.18\right)}{2200-(200+0)} = 3.12°$$

Where D = distance (ft) from RWT

d = d from para 3.2.1 for GPI less than 954’, 0 for GPI 954’ or greater

S = W surface slope

p = penetration in feet

*Actual answer is 3.1118°. Always round to the next higher hundredth (0.01) degree. This prevents rounding errors in amount of penetration causing miniscule penetration values using the revised angle.

3.3 Precision Obstacle Free Zone (POFZ)

3.3.1 Application

A POFZ is required for a Precision Runway when;

a. a vertically guided approach is provided to the runway;
b. the reported ceiling is below 250 feet and/or visibility conditions less than RVR4000 (¾ SM); and,
c. an aircraft is on its final approach within 2 NM of the runway threshold.

3.3.2 Characteristics

The POFZ ;

a. extends 200 feet before the threshold of a Precision Runway;
b. has a width of 400 feet on each side of the extended runway centreline; and
c. extends upward from the surface

See Figure 3.4 for depiction of the Precision Obstacle Free Zone

When the operational conditions for maintaining a POFZ are met, the area is kept free of all:

a. fixed objects except for visual aids required to be there by function; and

b. mobile objects including aircraft, except for the wing of an aircraft holding on a taxiway waiting for runway clearance, however, neither the fuselage nor the tail may infringe the POFZ.

3.3.3 Notes

a. Runway with displaced thresholds or with taxiways prior to the threshold may be operationally impacted by the requirements of the Precision Obstacle Free Zone (POFZ).

b. The protection of the POFZ requires the involvement of ATC if there is to be a primary hold position within the area of the POFZ, or if taxiing aircraft will infringe into the POFZ.

3.4 W OCS

See Figure 3-5.

3.4.1 Width

The width is 400 feet either side of course at the beginning (edge of POFZ), and expands uniformly to 2,200 feet either side of course 50,200 feet from LTP or FTP, as defined by the formula:

$$D_W = 0.036\ (D - 200) + 400$$

Where D = the distance in feet from LTP or FTP

D_W = Perpendicular distance in feet from course centerline to W surface outer boundary

3.4.2 Height

The height (Z_W) of the W OCS above ASBL is defined by the formula:

$$Z_W = \frac{D - (200 + d)}{S}$$

Where D = the distance in feet from RWT

d = d from para 3.2.1 for GPI less than 954', 0 for GPI 954' or greater

S = W surface slope

3.4.3 W OCS Penetrations

Lowest minimums are achieved when the "W" surface is clear. If the surface is penetrated by an existing obstacle, adjust obstruction height, raise the GPA (see paragraph 3.2.2), or displace the RWT to eliminate the penetration. If the penetration cannot be eliminated, adjust the DA (see paragraph 3.8).

3.5 X OCS

See Figure 3-6.

3.5.1 Width

The perpendicular distance (D_X) from the course to the outer boundary of the X OCS is defined by the formula:

$$D_X = 0.10752\,(D - 200) + 700$$

Where D = distance (ft) from LTP or FTP

3.5.2 Height

The X OCS begins at the height of the W surface at distance D from LTP or FTP, and rises at a slope of 1:4 in a direction perpendicular to the final approach course. Determine the height (Z_X) above ASBL for a specific location of the X OCS using the following formula:

$$Z_X = \underbrace{\frac{D - (200 + d)}{S}}_{\text{Height of W Sfc}} + \underbrace{\frac{D_O - D_W}{4}}_{\text{Rise of X Sfc}}$$

Where D = the distance in feet from LTP or FTP

d = d from para 3.2.1 for GPI less than 954’, 0 for GPI 954’ or greater

D_O = the perpendicular distance in feet between course centreline and a specific point in the X surface

D_W = the perpendicular distance in feet between course centreline and the W surface boundary

S = the slope associated with GPA $\left(\frac{102}{GPA}\right)$

3.5.3 X OCS Penetrations

Lowest minimums can be achieved when the X OCS is clear. To eliminate, avoid, or mitigate a penetration, take one of the following actions listed in the order of preference.

- **a.** Remove or adjust the obstruction location and/or height.
- **b.** Displace the RWT.
- **c.** Raise the GPA (see Para 3.2.2) within the limits of table 2-2A.
- **d.** Adjust DA (for existing obstacles only) (see Para 3.8).

3.6 Y OCS

See Figure 3-7.

3.6.1 Width

The perpendicular distance (D_Y) from the runway centreline extended to the outer boundary of the Y OCS is defined by the formula:

$$D_Y = 0.15152\,(D - 200) + 1000$$

Where D = distance (ft) from LTP or FTP

3.6.2 Height

The Y OCS begins at the height of the X surface at distance D from LTP or FTP, and rises at a slope of 1:7 in a direction perpendicular to the final approach course. The height (Z_Y) of the Y surface above ASBL is defined by the formula:

$$Z_Y = \underbrace{\frac{D - (200 + d)}{S}}_{\text{Height of W Sfc}} + \underbrace{\frac{D_X - D_W}{4}}_{\text{Rise of X Sfc}} + \underbrace{\frac{D_O - D_X}{7}}_{\text{Rise of Y Sfc}}$$

Where
- D = the distance in feet from LTP or FTP
- d = d from Para 3.2.1 for GPI less than 954’, 0 for GPI 954’ or greater
- D_X = the perpendicular distance in feet between course centreline and the X surface outer boundary
- D_O = the perpendicular distance in feet between course centreline and an obstruction in the Y surface
- D_w = the perpendicular distance in feet between course centreline and the W boundary.
- S = the slope associated with GPA (102/GPA)

3.6.3 Y OCS Penetrations

Lowest minimums can be achieved when the Y OCS is clear. When the OCS is penetrated, remove the obstruction or reduce its height to clear the OCS. If this is not possible, a subjective evaluation is necessary. Consider the obstruction's physical nature, the amount of penetration, obstruction location with respect to the X surface boundary, and density of the obstruction environment to determine if the procedure requires adjustment. If an adjustment is required, take the appropriate actions from the following list:

a. Adjust DA for existing obstacles (see Para 3.8).

b. Displace threshold.

c. Offset final course.

d. Raise GPA (see Para 3.2.2).

e. If an adjustment is not required, CHART the obstruction.

3.7 Decision Altitude (DA) And Height Above Touchdown Zone (HAT)

The DA value may be derived from the HAT. The MINIMUM HAT for Category I operations is 200 feet. Calculate the DA using the formula:

DA = HAT + TDZE

3.8 Adjustment Of DA For Final Approach OCS Penetrations

See Figure 3-8.

The distance from GPI to the DA may be increased to ensure DA occurs at a height above ASBL providing sufficient obstruction clearance. This adjustment is available for existing obstacles only. Proposed obstructions shall not penetrate the OCS.

3.8.1 DA DISTANCE FROM LTP/FTP

Determine the distance from LTP to the adjusted DA point using the formula:

$$D_{adjusted} = \frac{102h}{GPA} + (200 + d)$$

Where $D_{adjusted}$ = adjusted distance (ft) from LTP to DA
d = d from Para 3.2.1 for GPI < 954’, 0 for GPI ≥ 954’
h = obstacle height (ft) above ASBL
GPA = glide path angle

Note: If obstacle is in the X surface, subtract X surface rise from h.
If obstacle is in the Y surface, subtract X and Y surface rise from h.

3.8.2 Calculate The Adjusted DA and HAT

Calculate the adjusted DA and HAT using the formula:

$$DA = \tan\left(\left[\frac{102h}{GPA} + (200 + d)\right] + \frac{TCH}{\tan(GPA)}\right) + LTP_{elevation}, \quad \mathrm{HAT = DA - TDZE}$$

Where d = D from para 3.2.1 for GPI < 954’, 0 for GPI ≥ 954’
TCH = threshold crossing height (ft)
$LTP_{elevation}$ = landing threshold point elevation (ft)

3.8.3 Calculate The Revised Minimum HAT/ Maximum ROC

Calculate the revised minimum HAT and maximum ROC using the formula:

$$MinHat\ and\ Max\ ROC = \frac{GPA}{3} * 250$$

3.8.4 Compare HAT and Minimum HAT

Compare the HAT and the minimum HAT and publish the higher of the two values.

3.8.5 Mark And Light

Initiate action to mark and light obstructions that would require DA adjustment when they are located between the DA and the LTP/FTP. These obstacles shall also be noted and identified on the IAP chart.

3.9 Missed Approach

The missed approach segment begins at DA and ends at the clearance limit. It is comprised of Section 1 (initial climb) and Section 2 (from end of Section 1 to the clearance limit). Section 2 beginning width is ± 0.5 NM. The 40:1 OCS begins at the elevation of Section 1b at centreline.

Note: If an RNAV transition is required for the missed approach, apply the LPV criteria for all segments of the ILS procedure as per Volume 2, Chapter 1 (PBN).

3.9.1 Sections 1 and 2

Section 1 is aligned with the final approach course. It is comprised of 3 subsections, beginning at DA and extending 9860.69 feet.

a. Section 1a.

(1) Area. Section 1a begins at the DA point and overlies the final approach primary (W and X surfaces) OCS, extending 1,460 feet in the direction of the missed approach. This section is always aligned with the final approach course (see Figures 3-9B and 3-9C).

(2) OCS. The height of the Section 1a surface is equal to the underlying W or X surface as appropriate. If this section is penetrated, adjust DA per Figure 3-9C to mediate the penetration.

b. Section 1b.

(1) Area. Section 1b begins at the end of section 1a, extends to a point 9860.69 feet from DA, and splays along the extended final course to a total width of 1 NM. This section is always aligned with the final approach course (see Figures 3-9A, 3-9D).

(2) OCS. Section 1b OCS is a 1:28.5 inclined plane rising in the direction of the missed approach. The height of the beginning of section 1b is equal to the height of the W OCS at the end of Section 1a (see Figure 3-9D). Evaluate obstructions using the shortest distance of the obstruction from the end of Section 1a. Adjust DA per Figure 3-9E to mediate penetrations in this section.

c. Section 1c (see Figure 3-9F).

(1) Area. These are 1:7 secondary areas that begin at the DA point. These sections splay to a point on the edge and at the end of Section 1b.

(2) OCS. An inclined plane starting at the DA point and sloping 1:7, perpendicular to the MA course. The inner boundaries originate at the elevation of the outer edges of the W surface at the beginning of Section 1b. The outer boundaries originate at the elevation of the outer edges of the X surfaces at the DA point. These inner and outer boundaries converge at the end of Section 1b (9860.69 feet from the DA point). Obstacles in Section 1c, adjacent to the X surfaces, are evaluated with a 1:7 slope from the elevation of the outer boundaries of the X surfaces. Obstacles in Section 1c, adjacent to Section 1b, are evaluated using the 1:7 slope, beginning at the elevation at the outer edge of Section 1b (see Figures 3-9A and 3-9F). Reduce the obstruction height by the amount of 1:7 surface rise from the edge of Section 1a or 1b (measured perpendicular to Section 1 course). Then evaluate the obstruction as if it were in Section 1a or 1b.

d. Section 2.

(1) Straight-Ahead (15° or less of final course heading). Section 2 is a 40:1 OCS that starts at the end of Section 1 and is centered on the missed approach course. The width increases uniformly from 1 NM at the beginning to 12 NM at a point 13.377 NM from the beginning. A secondary area for reduction of obstacle clearance is identified within Section 2. The secondary area begins at zero miles wide and increases uniformly to 2 NM wide at the end of Section 2. PCG is required to reduce obstacle clearance in the secondary areas (see Figure 3-11A). Use TP308/GPH209, Volume 1, Chapter 18, to determine if a climb-in-holding evaluation is required.

(2) Turning Missed Approach. Where turns of MORE than 15° are required, design the procedure to begin the turn at an altitude at least 400 feet above the elevation of the TDZ. Assume the aircraft will be 200 feet above DA at the end of section 1b. Extend section 1b 30.39 feet for each additional foot of altitude necessary before a turn can commence. This point is where section 2 40:1 OCS begins. Specify the "climb to" altitude in the published missed approach procedure. The flight track and outer boundary radii used shall be as specified in volume 1, para 275 and in Table 2-5. The inner boundary line shall commence at the edge of section 1 opposite the MAP. The outer and inner boundary lines shall expand to the width of the initial approach area 13.377 miles from the beginning of section 2. Secondary areas for reduction of obstacle clearance are identified within section 2. The secondary areas begin after completion of the turn (see figure 3-11B). They begin at zero miles wide and increase uniformly to 2 miles wide at the end of section 2. PCG is required to reduce obstacle clearance in the secondary area.

Supplementary Notes:

1): Obstacles are measured along the shortest distance from the obstacle to a line that runs from "b" to "a" and along the section 1c outer boundary line. The starting elevation of this line is equal to the elevation of the section 1b surface at the end of section 1b.

2): Section 2 secondary slope is a 12:1 OCS.

(3) Combination Straight-Turning Missed Approach Procedures. Use TP308/GPH209 Volume 1, Paras 277d and f to establish the charted missed approach altitude. Use TP308/GPH209 Volume 1, Para 277e to determine if a climb-in-holding evaluation is required.

3.9.2 Reserved

3.9.3 Missed Approach ROC Rationale

The obstacle clearance concept applied to the departure and missed approach climb manoeuvre in instrument procedures design is to enable the aircraft to gain sufficient altitude to supply at least the minimum ROC for the subsequent level surface segments of the procedure. The obstacle evaluation method for a climb manoeuvre is the application of a rising OCS below the minimum climbing flight path. The vertical distance between the climbing flight path and the OCS is ROC. The ROC and OCS slope values are dependent on a minimum aircraft climb performance of 200 ft/NM (see Figure 3-12). Whether the climb is for departure or missed approach is immaterial. The standard for determining OCS slope is that 76% $\left(\frac{19}{25}\right)$ of the altitude gained defines the OCS slope; 24% $\left(\frac{6}{25}\right)$ of the altitude gained defines the ROC value.

The amount of ROC increases as the aircraft climbs until the point en route or initial segment ROC (1,000/1,500/2,000 feet as appropriate) is realized. After this point, application of a sloping surface for obstacle clearance purposes is not required. Where an obstacle penetrates the OCS, a greater than normal climb gradient (greater than 200 ft/NM) is required to provide adequate ROC. Since the climb gradient will be greater than 200 ft/NM, the ROC requirement will be greater than 48 ft/NM ($\mathbf{0.24} * [\boldsymbol{Y} > 200] = [Z > 48]$).

The ROC expressed in ft/NM can be calculated using the formula:

$$\frac{0.24h}{0.76d}\,or\,\frac{6h}{19d}$$

Where h = the height of the obstacle in feet above the altitude from which the climb is initiated

d = the distance in NM from the initiation of climb to the obstacle

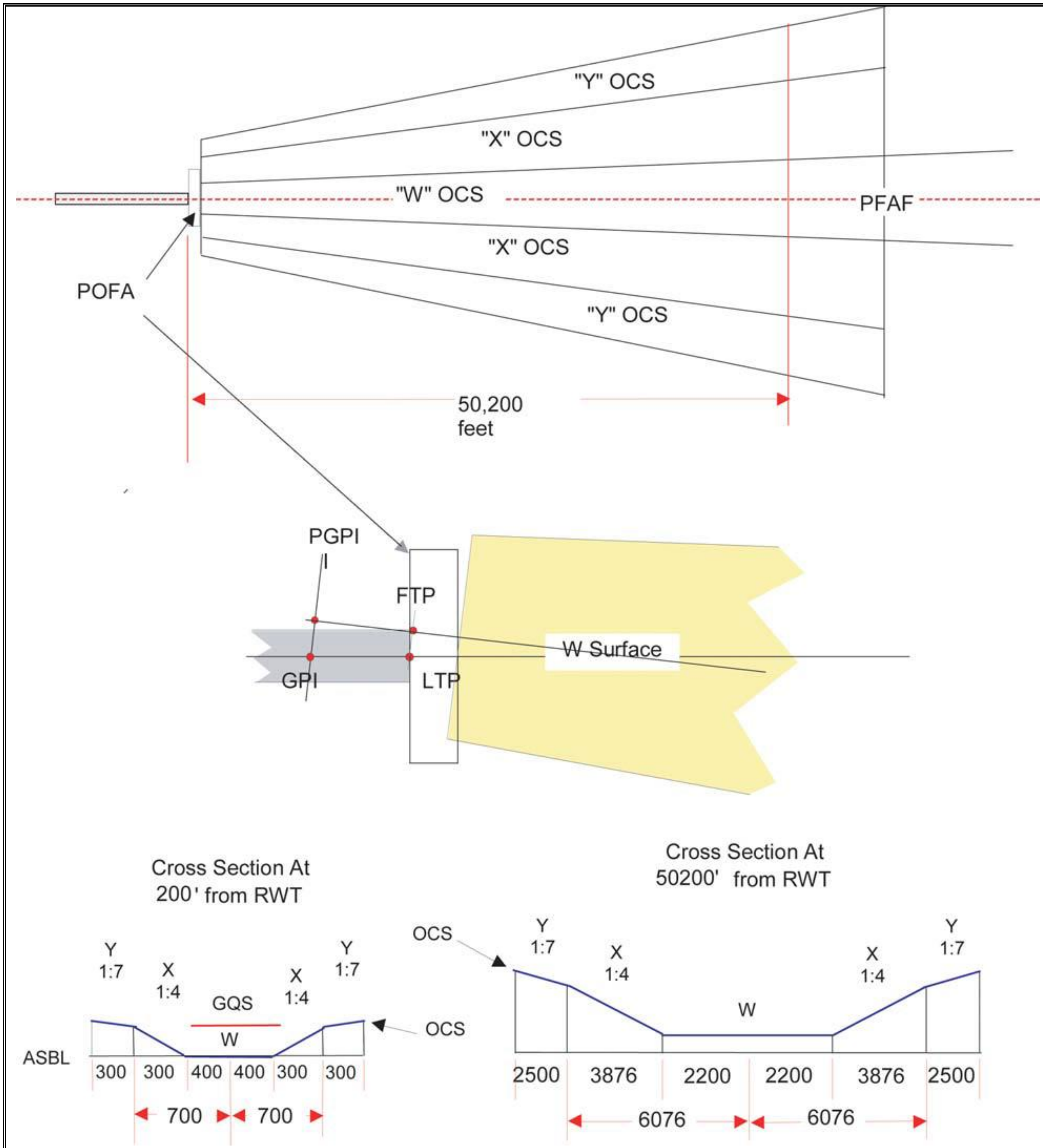


Figure 3-1. Precision Obstacle Clearance Area. Para 3.0.

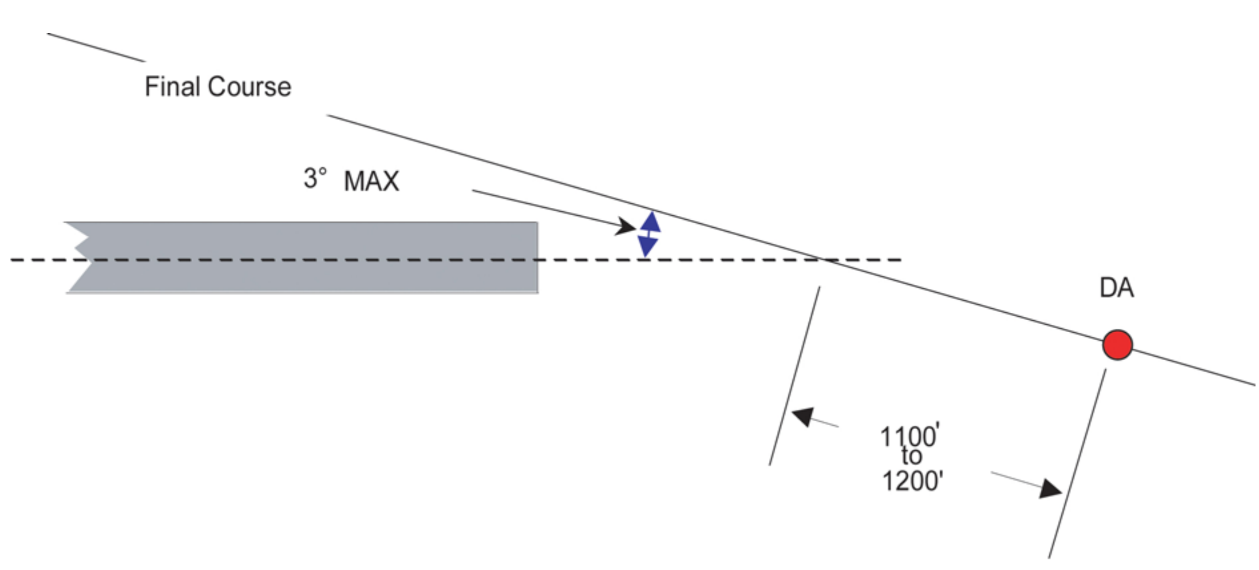


Figure 3-2: Offset Final. Para 3.1.

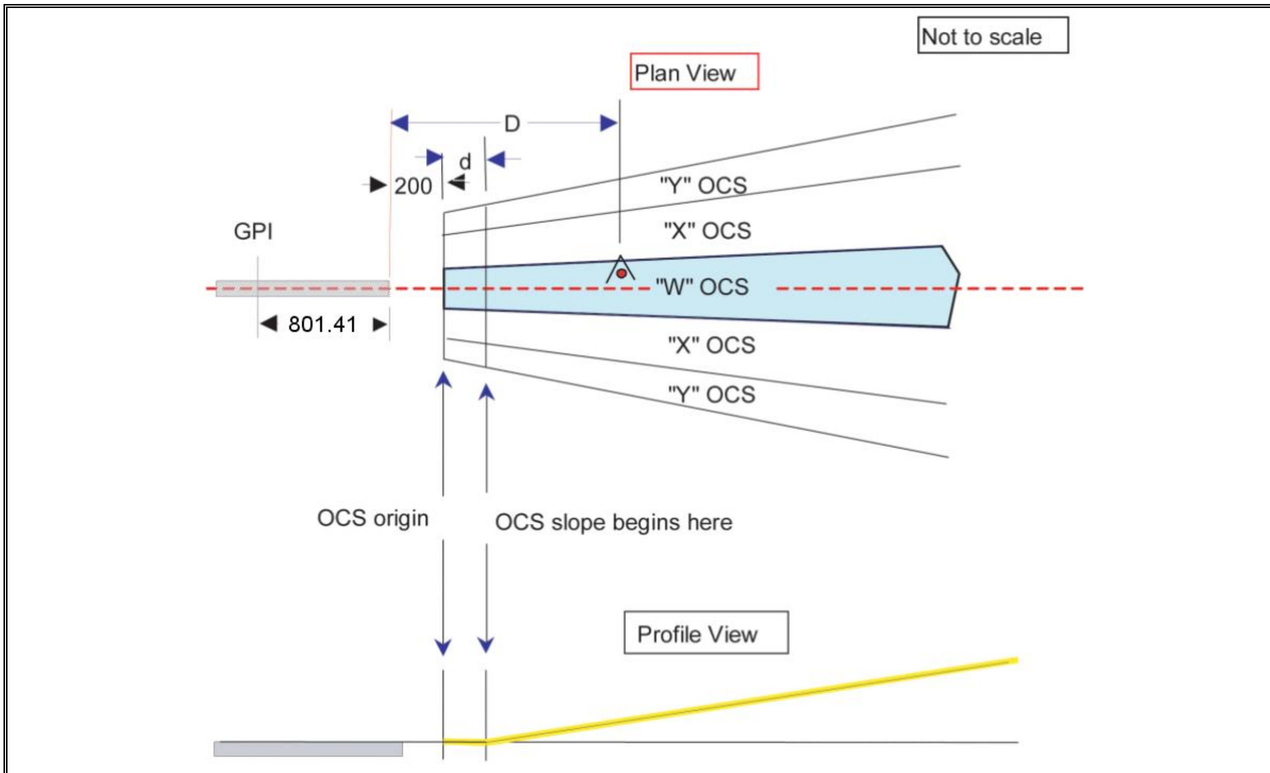


Figure 3-3: OCS Slope When GPI <954'. Para 3.2.

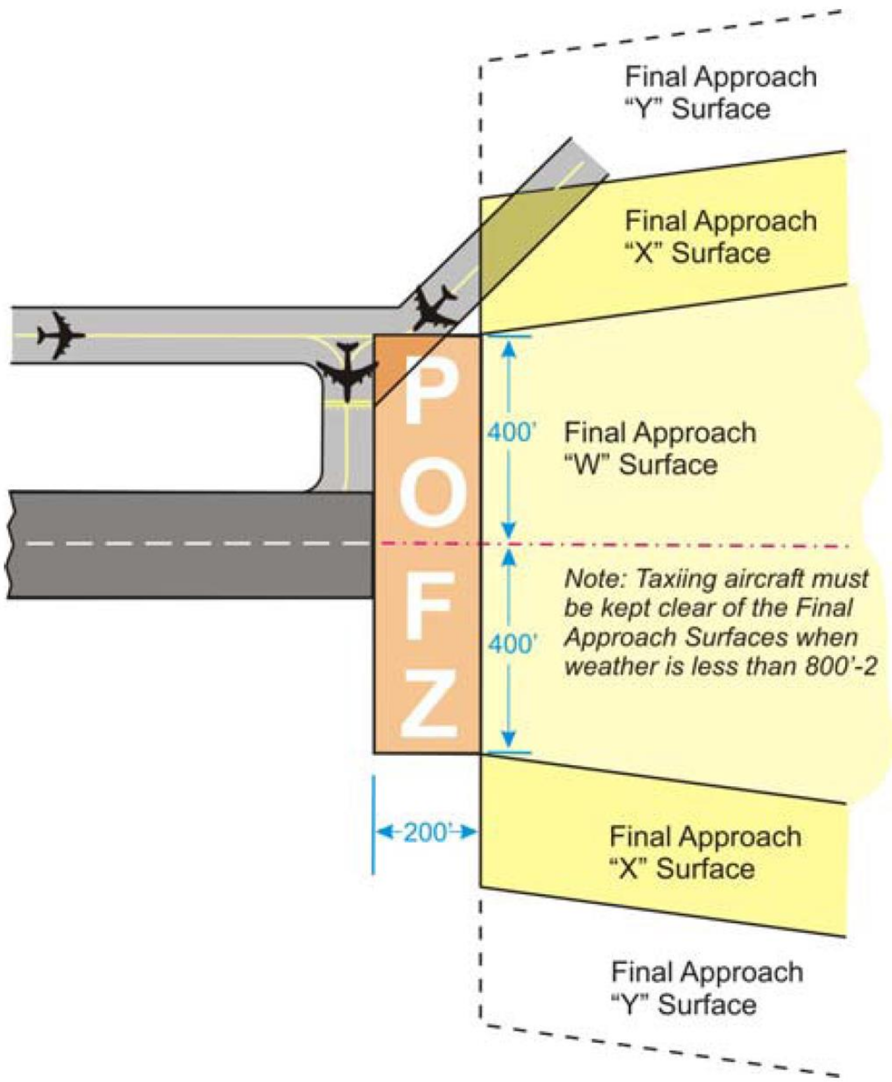


Figure 3-4: POFZ. Para 3.3.

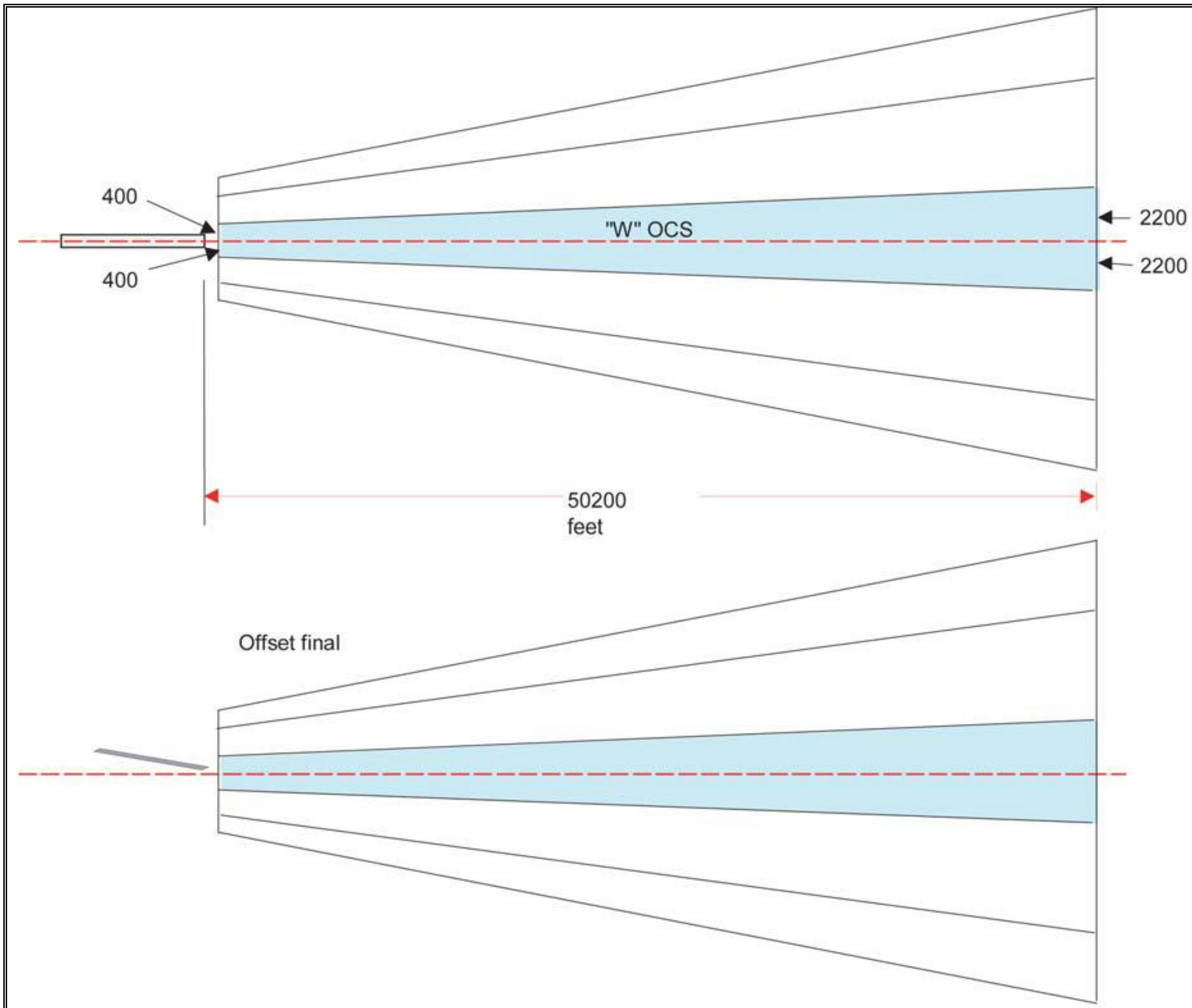


Figure 3-5: W OCS. Para 3.4.

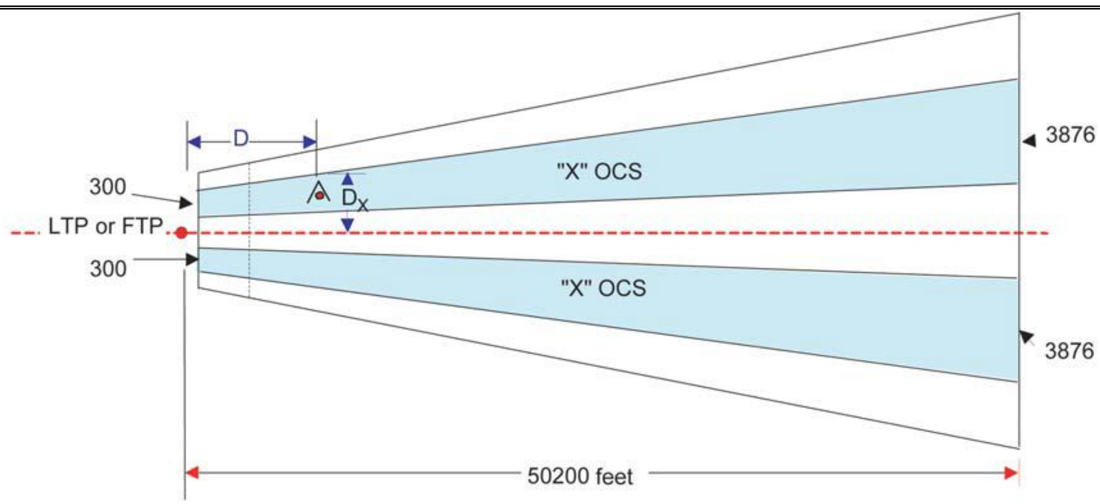


Figure 3-6: X OCS. Para 3.5.

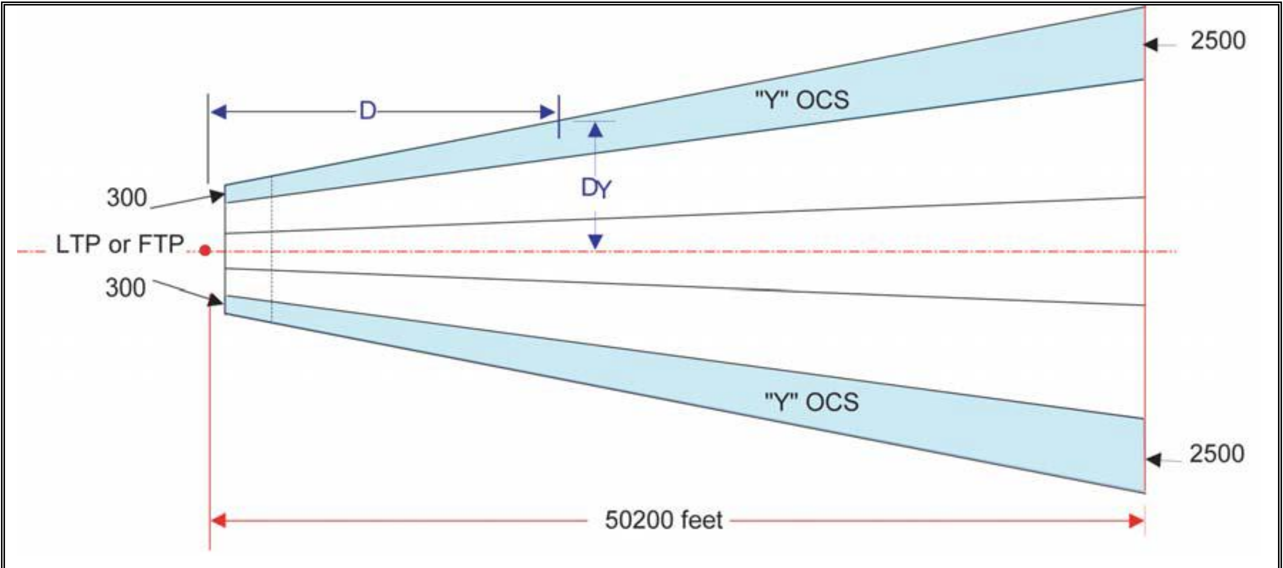


Figure 3-7: Y OCS. Para 3.6.

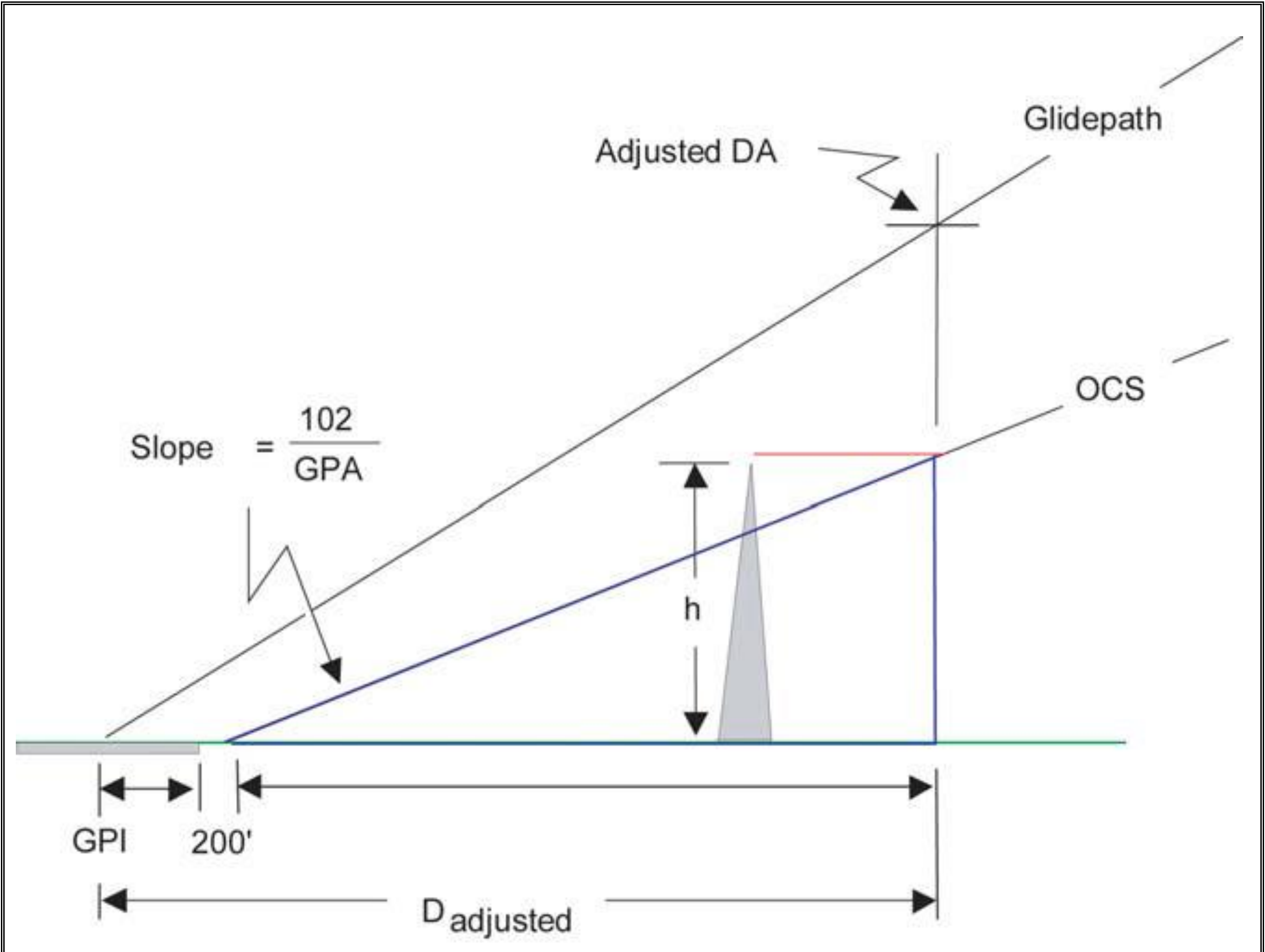


Figure 3-8: DA Adjustment. Para 3.8.1.

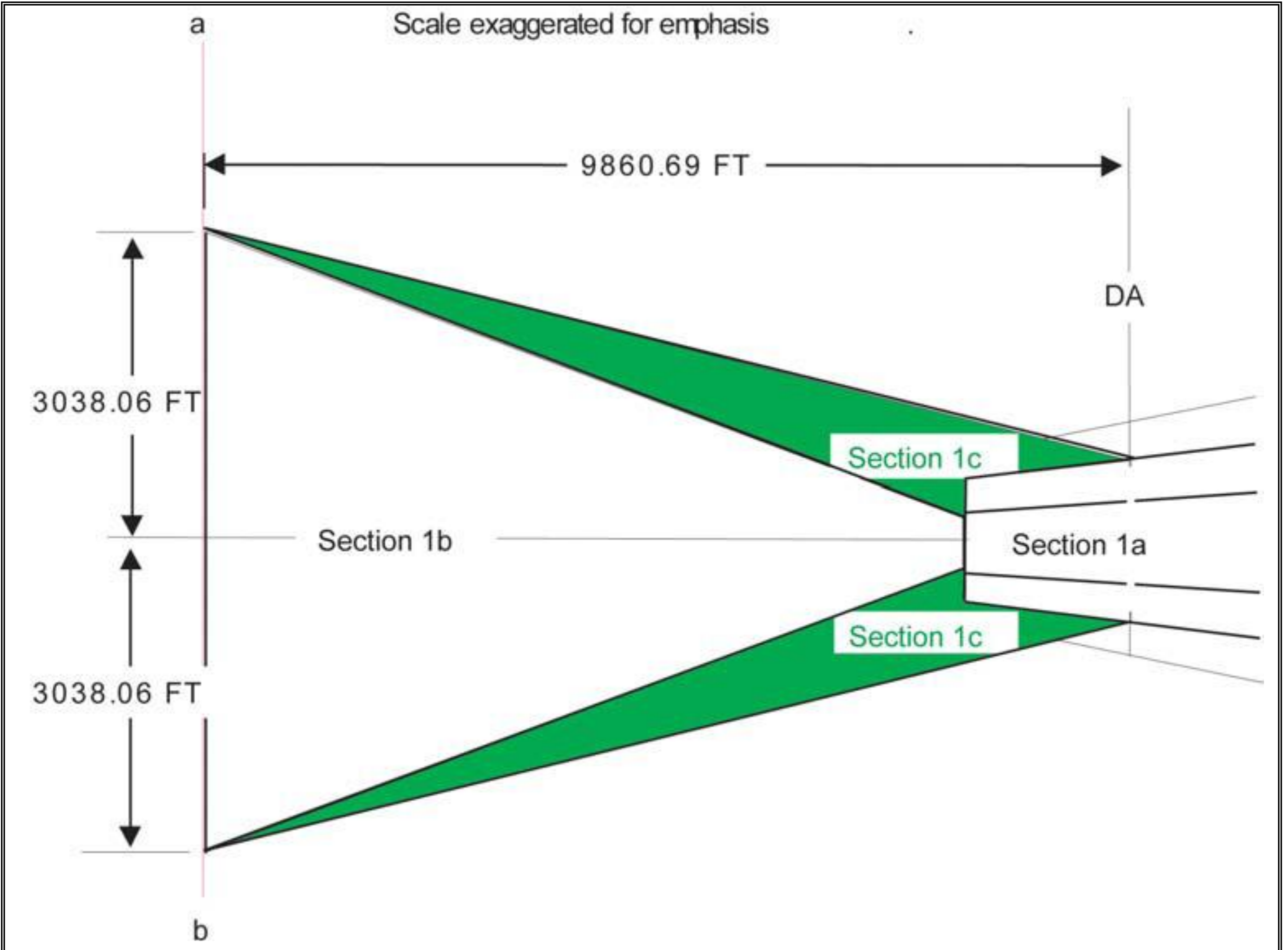


Figure 3-9a: Section 1a, 1b, 1c. Para 3.9.1.

Figure 3-9B . Section 1a

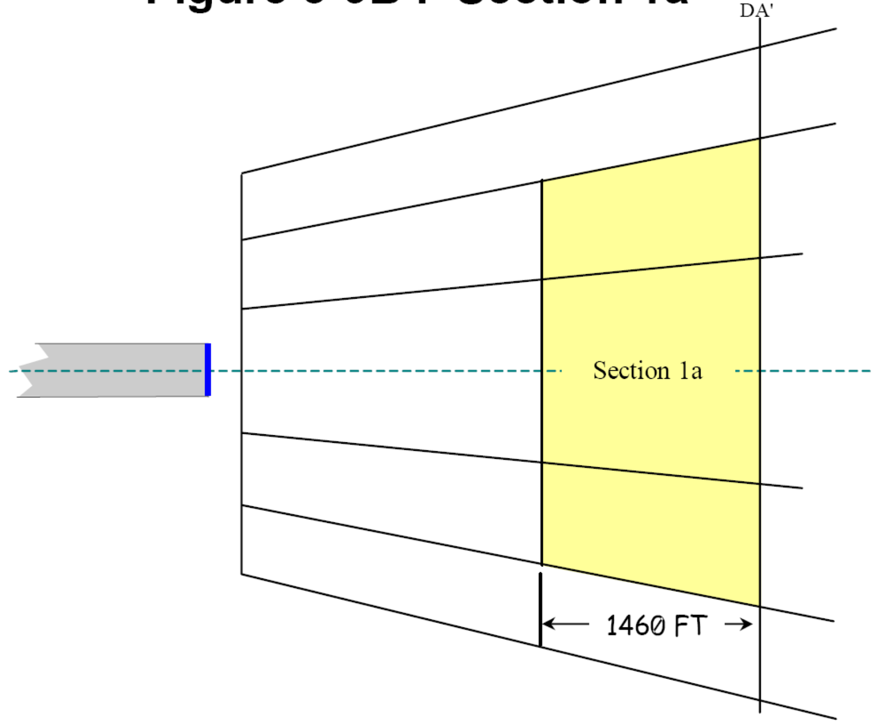
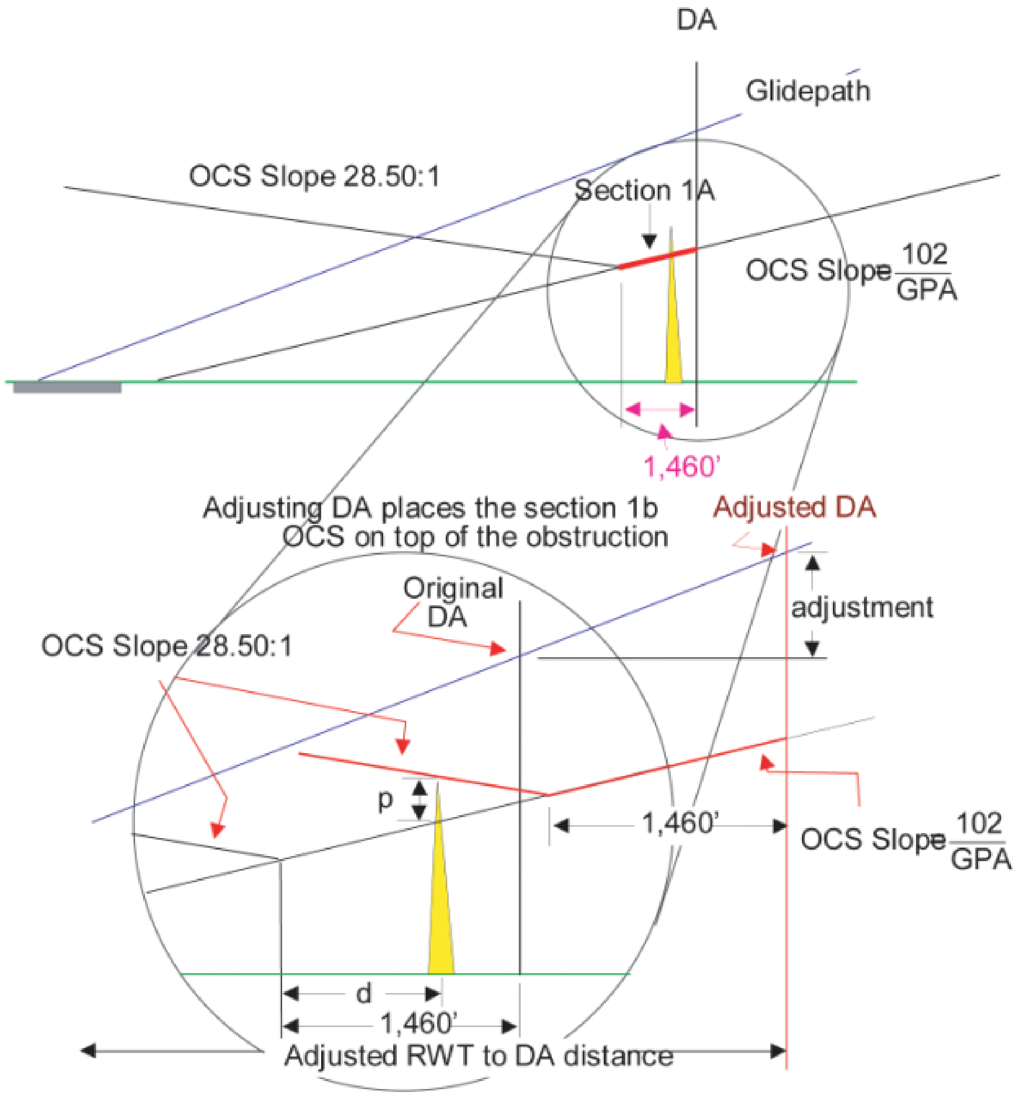


Figure 3-9B: Section 1a. Para 3.9.1.



d= X_O – (RWT to DA Distance – 1,460)

$$adjustment = Tan(GPA)\left[\left(\frac{p}{\frac{1}{28.50}+\frac{GPA}{102}}\right)+d\right]$$

adjusted DA (MSL) = original DA + adjustment

adjusted RWT to DA Dist = $\dfrac{\text{adjusted DA (MSL) – (RWT MSL elevation + TCH)}}{\text{tan (GPA)}}$

Where
p = penetration (ft)
GPA = glide path angle
X_O = distance from RWT to obstruction (ft)
d = distance (ft) from obstruction to point where the 28.5:1 OCS originates

Figure 3-9C: Penetration Of Section 1a OCS. Para 3.9.1.

Figure 3-9D. Section 1b

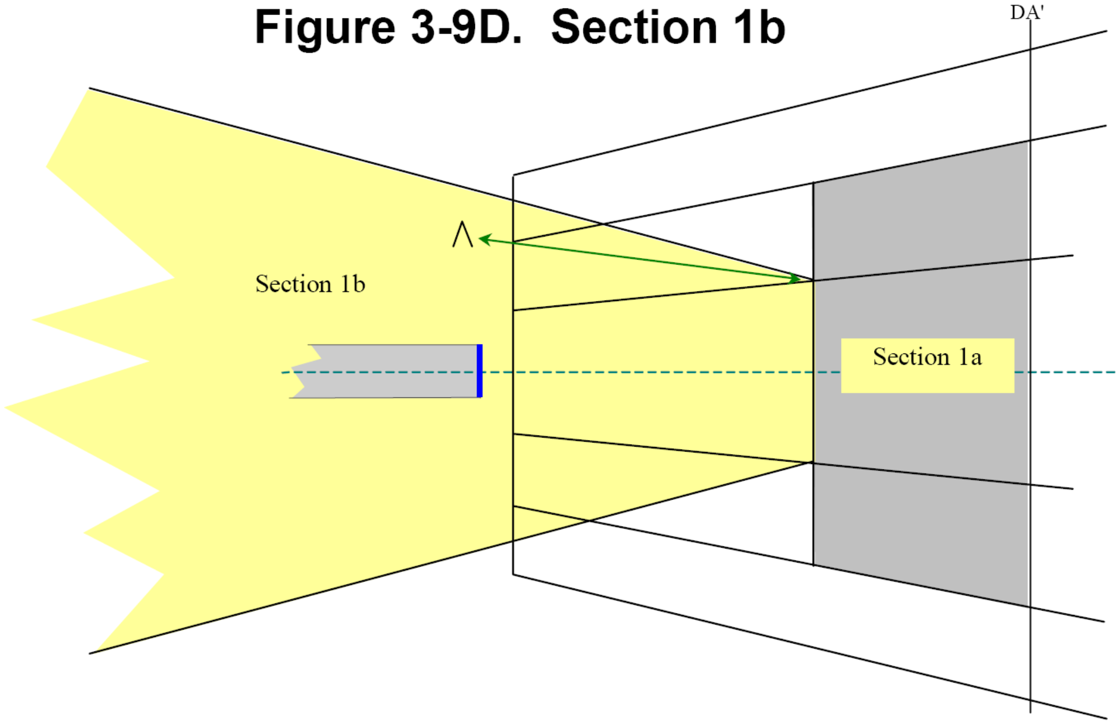
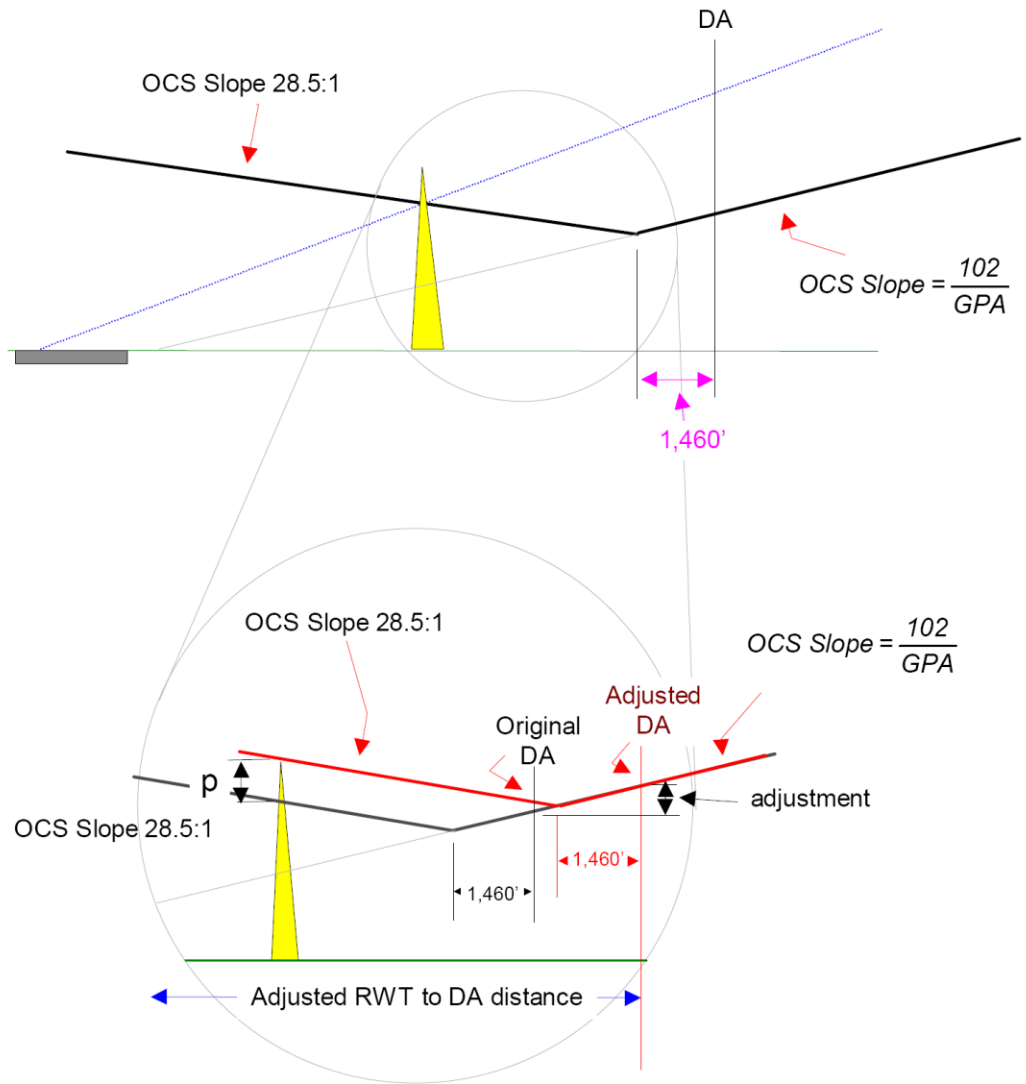


Figure 3-9D: Section 1b. Para 3.9.1.b.



$$adjustment = Tan(GPA)\left(\frac{p}{\frac{1}{28.50}+\frac{GPA}{102}}\right)$$

adjusted DA (MSL) = original DA + adjustment

$$\text{adjusted RWT to DA Dist} = \frac{\text{adjusted DA (MSL)} - \text{(RWT MSL elevation + TCH)}}{\tan(GPA)}$$

Where p = penetration (ft)
GPA = glide path angle
X_O = distance from RWT to obstruction (ft)
d = distance (ft) from obstruction to point where the 28.5:1 OCS originates

Figure 3-9E: Penetration Of Section 1b OCS.

Figure 3-9F. Section 1c

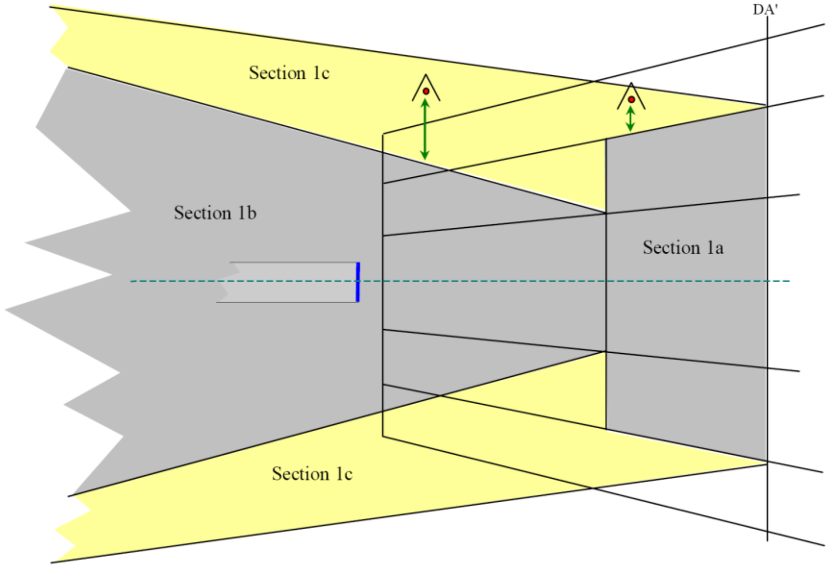


Figure 3-9F. Section 1c

Figure 3-10A: RESERVED

Figure 3-10B: RESERVED

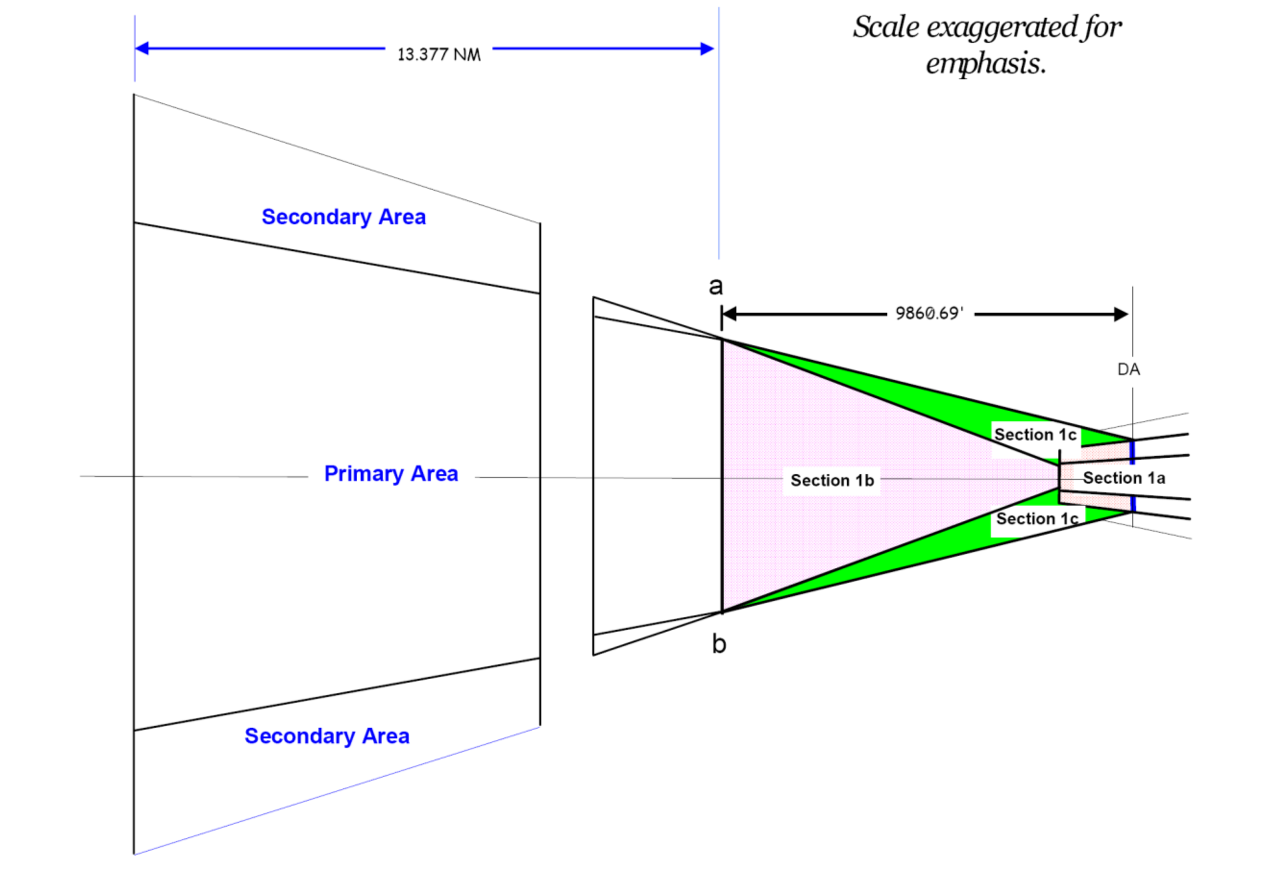


Figure 3-11A: Straight Missed Approach. Para 3.9.1.d.(1).

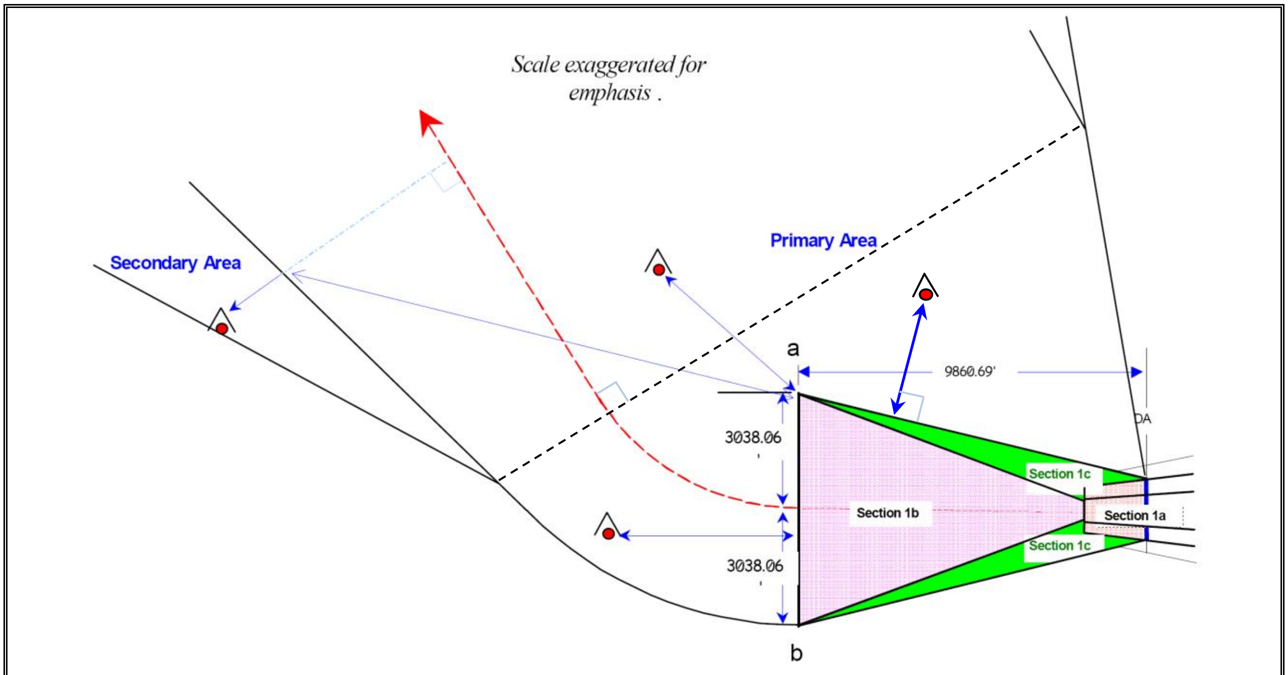


Figure 3-11B: Turning Missed Approach. Para 3.9.1.d.(2).

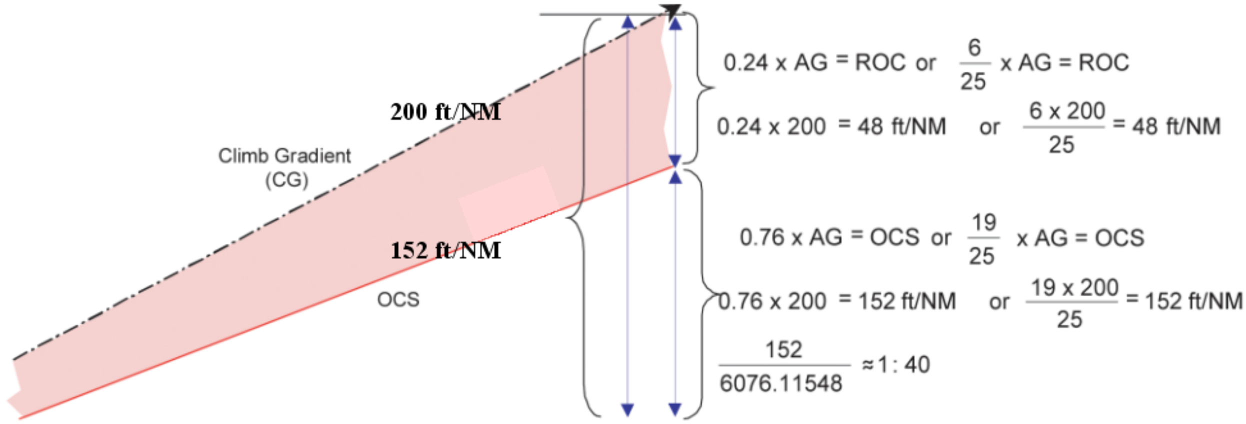


Figure 3-12: ROC and OCS Slope Values. Para 3.9.3.

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APPENDIX 1. VERTICALLY-GUIDED APPROACH OBSTACLE ASSESSMENT AND CATEGORY II/III ILS REQUIREMENTS

1.0 GENERAL

General vertically-guided obstacle clearance criteria are contained in Volume 3, and Volume 2 for Area Navigation (RNAV) and apply unless otherwise specified by this standard. Airport and facility requirements to support approval of Category (CAT) I, II, and III precision operations are contained in the latest editions of the following directives:

- AC 120-29, Criteria for Approval of Category I and Category II Weather Minima for Approach.
- AC 120-28, Criteria for Approval of Category III Weather Minima for Takeoff, Landing, and Rollout.
- Order 6750.24, Instrument Landing System (ILS) and Ancillary Electronic Component Configuration and Performance Requirements.
- Order 8400.8 , Procedures For The Approval Of Facilities For FAR Part 121 And Part 135 Cat IIII Operations
- Order 8400.13, Procedures for the Evaluation and Approval of Facilities for Special Authorization Category I Operations and all Category II and III Operations.

2.0 ACCEPTABLE OBSTACLES.

Existing equipment essential to flight operations may penetrate the OFZ and/or specified TERPS surfaces without impacting the TERPS procedure. An obstacle may be considered acceptable when its type is permitted to be excluded in the specific area/surface where it is physically located, and it meets the prerequisites for exclusion described in the following paragraphs and in Table 1. Surface penetrations by acceptable obstructions require no adjustment of approach minima, and the procedure may be considered “unrestricted”. Any object “fixed by function” on a runway crossing or adjacent to a CAT II or III runway must also conform to the specified conditions. This criteria is limited to TERPS evaluation and does not provide relief from compliance from airport design or equipment siting standards.

2.1 ALL VISUAL AIDS ON FRANGIBLE MOUNTS.

Visual aids (to include visual glide slope indicator (VGSI), taxiway signage, runway distance remaining markers, etc.) installed in accordance with (IAW) the latest editions of FAA Order 6850.2, Visual Guidance Lighting Systems, and US Advisory Circular 150/5340-18, Standards for Airport Sign Systems, are acceptable obstacles excluded from TERPS consideration.

2.2 NAVIGATIONAL AID (NAVAID) AND AUTOMATED SURFACE OBSERVING SYSTEM (ASOS) COMPONENTS.

The minimum siting distance for glide slope shelter, precision approach radar (PAR), runway visual range (RVR), and ASOS components (except wind sensor towers) is specified in US AC 150/5300-13, Airport Design and Order 6560.10, Runway Visual Range. In order for one of these components to be considered acceptable for TP308/GPH209, it must be located at least 400 ft from runway centerline and must not exceed a height of 15 ft above the elevation of the point on the runway centerline abeam them. ASOS wind sensors exceeding 15 ft above the runway centerline elevation but sited in accordance with the Federal Standard for Siting Meteorological Sensors at Airports are also considered acceptable obstacles. Obstacles more than 15 ft above the runway centerline elevation may be permitted if the minimum distance from the runway centerline is increased 10 ft for each foot the structure exceeds 15 ft. Frangible PAR reflectors are not considered obstacles.

2.2.1 Glide Slope Antennas.

End-Fire Glideslopes (EFGS) sited in accordance with Order 6750.16D Siting Criteria for Instrument Landing Systems and other applicable standards are exempt from the clear area and OFZ requirements of this standard, Order 8260.3B, volume 3, and Order 8260.54A. Other glide slope antennas for CAT I procedures are not excluded from TERPS evaluation, and must remain clear of OFZs in accordance with AC 150/5300-13. For CAT II/III TERPS evaluations, glide slope antennas meeting the following standards are considered acceptable obstacles (see paragraph 2.0). Antenna location is referenced by measurement from the runway threshold along runway centerline (X), perpendicular distance from runway centerline (Y), and height above the runway centerline elevation abeam the antenna (Z). The minimum "Y" value (Ymin) is 250 feet for antenna masts with a "Z" value of 45 feet. For antennas/masts with a "Z" value > 45 feet, the Ymin distance from runway centerline is increased 10 feet laterally for each foot the antenna height exceeds 45 feet. Calculate Ymin using the formula below.

$$Y_{MIN} = 10(Z) - 200$$

Simplified from

$$Y_{MIN} = 250 + 10\,(Z - 45)$$

Antennas that penetrate a 10:1 rising surface originating 250 feet from runway centerline at a "Z" value of 45 feet require a frangible mast and approval from Transport Canada or Department of National Defense (DND) [as appropriate] to exclude from TERPS consideration (see Figure 1).

Obstacle type	Location	Prerequisite for Exclusion
Visual Navigation Aids • VGSI (PAPI, PVASI, VASI, etc.) • Approach light Systems • REILS • Airport Beacon • Visual Landing Aids (Wind Cone, etc.) • Airport Signage	○ Final primary (e.g. precision/LPV W, X) ○ Inner Approach OFZ ○ Missed Section 1 A,B,C,D A1	only when installed IAW applicable siting standard (i.e., Order 6850.2, AC 150/5340-30, or military equivalent, etc.)
Electronic NAVAIDs/Components • ILS Glideslope Shelter • PAR components • Radar reflectors on frangible mounts • End-fire Glideslope antenna Glideslope Antenna Localizer Antenna serving opposite runway	○ Final primary (e.g. precision/LPV W, X) ○ Inner Approach OFZ ○ Missed Section 1 A,B,C,D, A1	only when installed IAW applicable siting standards, AC 150/5300-13 or military equivalent only when meets par 2.2.1 only when meets par 4.0
Meteorological Equipment • Cloud height sensors • Visibility sensors • Wind sensors • Temperature/dew point sensors • Lightning Detection sensor • Precipitation sensors • Pressure sensors • AWOS/ASOS components • Runway Visual Range components	○ Final primary (e.g. precision/LPV W, X) ○ Inner Approach OFZ ○ Missed Section 1 A,B,C,D, A1	only when installed IAW Federal Standard for Siting Meteorological Equipment at Airports, other applicable standards or military equivalents
Taxiing/ holding/ Parked Aircraft/ Ground Vehicles	○ Final OCS (e.g. precision/LPV W,X,Y) ○ POFZ ○ CAT II/III Missed section 1, B, C, D, A1	only when meets paragraph 2.3

Table 1. Acceptable Obstructions.

2.3 AIRCRAFT/GROUND VEHICLE CONSIDERATION AS OBSTACLES.

Taxiing, holding, parked aircraft and ground vehicles are considered obstacles for instrument procedure obstacle clearance. When evaluating aircraft as obstacles, consider the location of the taxiway/ramp and consider the highest aircraft surface that falls within the area (see table 2 for design group tail heights). For ground vehicles consider the road/taxiway/ramp with routine vehicle traffic and apply the appropriate height from Volume 1, Chapter 2, Paragraph 216. In order to achieve the lowest landing minimums, aircraft/vehicles must not penetrate the obstacle free zone (OFZ), final, or missed approach obstacle clearance surfaces (OCS), visual segment OCS, or the precision obstacle free zone (POFZ), except as permitted below. Table 2 lists the aircraft design group standards applicable to this document.

2.3.1 Precision Final Segment Obstacle Clearance Surfaces.

Taxiing, holding, and parked aircraft/ground vehicles are considered obstacles in the final segment (e.g. precision/LPV W, X, and Y OCS surfaces) (see figure 2) unless positive controls have been established to keep the surfaces clear when aircraft on approach to the same runway are within 2 nautical miles (NM) of the landing threshold when the reported weather is less than 800 ft ceiling and/or the prevailing visibility is less than 2 statute miles (SM). Positive controls include proper placement of hold markings/signage as specified by FAA Airports Engineering Division and/or establishment of Air Traffic Control (ATC) operating procedures. Private/airport access roads that traverse one or more final segment OCS are considered acceptable when positive controls are established to either keep the surface clear when the reported weather is less than 800 - 2, or controls are in place to restrict access to vehicles necessary for the maintenance of the airport/navigation facilities of less than 10 ft in height. Controls must also prevent vehicles that penetrate the OCS from parking in the surface without being in direct contact with ATC.

2.3.2 CAT II/III Missed Approach Section 1.

Aircraft/ground vehicles that penetrate the CAT II/III missed approach surface may be eliminated from TERPS consideration when the taxiway is compliant with the runway/parallel taxiway standards from AC 150/5300-13, Airport Design.

2.3.3 Precision Obstacle Free Zone (POFZ).

See volume 3, Chapter 3, Para 3.3.

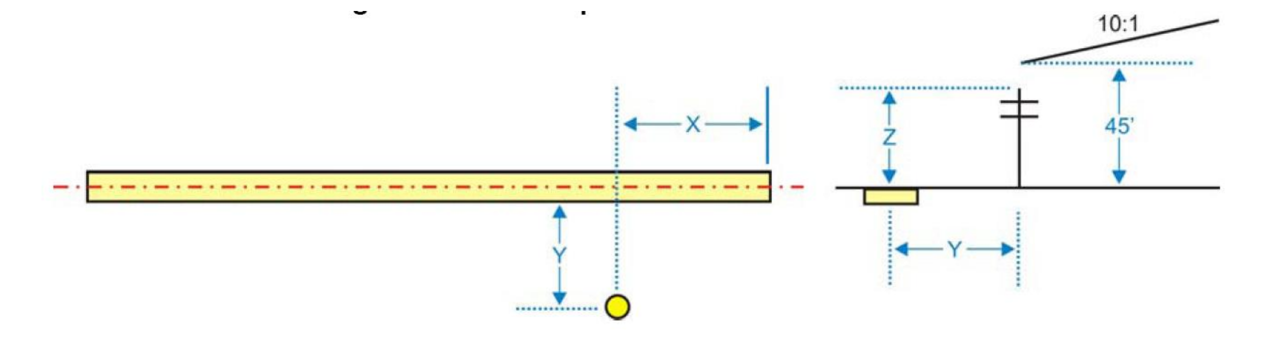

Figure 1: Glide Slope Antenna Placement.

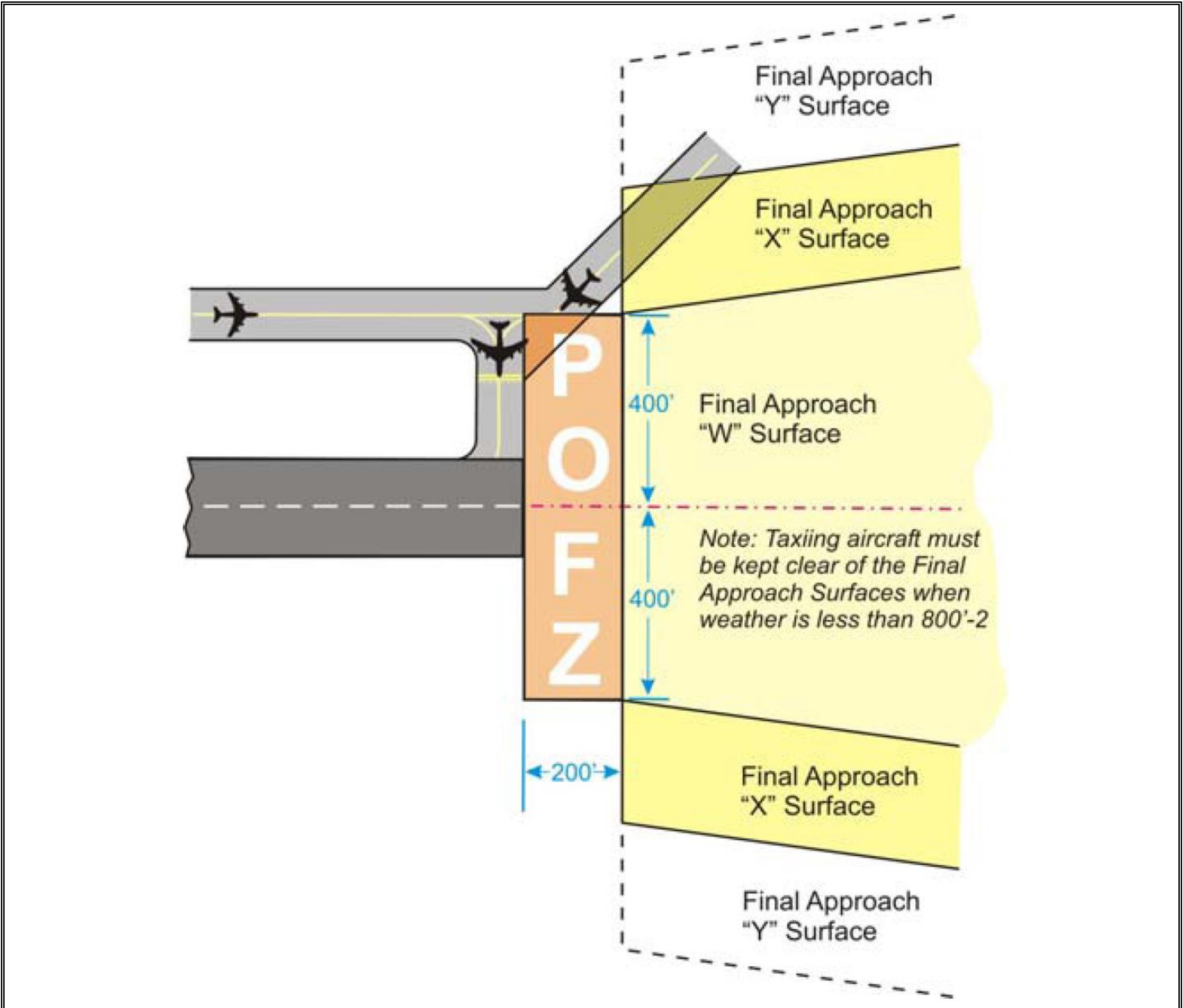

Figure 2: POFZ/Final Segment Obstacle Clearance Surfaces.

GROUP #	TAIL HEIGHT (FT)	WINGSPAN (FT)
I	< 20	< 49
II	20 - < 30	49 - < 79
III	30 - < 45	79 - < 118
IV	45 - < 57	118 - < 171
V	57 - < 66	171 - < 214
VI	66 - < 80	214 - < 262

Table 2. Aircraft Design Groups (ADG)

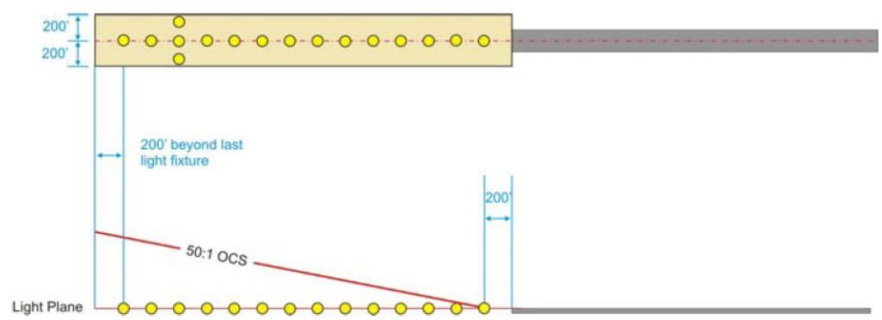

Figure 3: Inner Approach OFZ and Approach Light Area Plane.

2.4 FAILURE TO MEET STANDARDS AS AN ACCEPTABLE OBSTACLE.

Where the above standards cannot be met, consider the following actions to eliminate, limit, or mitigate a breach of the standards under paragraph 2.3.

2.4.1 Remove the obstacle.

2.4.2 Increase the HATh/visibility.

2.4.3 Modify aircraft taxi routes, limit access to private roads, or establish positive controls to keep the applicable surfaces clear.

2.4.4 Increase the Hold Line distance.

3.0 INSTRUMENT LANDING SYSTEM/MICROWAVE LANDING SYSTEM (ILS/MLS) CRITICAL AREA.

Precision approach system critical areas are described in Orders 6750.16, Siting Criteria for Instrument Landing Systems, and 6830.5, Criteria for Siting Microwave Landing Systems. CAT II/III ILS glide slope, localizer, and obstacle critical areas will be marked and lighted to ensure that ground traffic does not violate these areas during CAT II or III operations (except as allowed in Order 7110.65, Air Traffic Control).

4.0 APPROACH LIGHT AREA.

Airports operators are responsible for maintaining obstruction requirements associated with airport visual aids. Obstructions must not penetrate the approach light plane (see figure 3) or the inner-approach OFZ in accordance with AC 150/5300-13 and other applicable directives (Order 6850.2, AC 150/5340-30). For approach light plane clearance purposes, consider all roads, highways, vehicle parking areas, and railroads as vertical solid objects. Make the clearance required above interstate highways 17 feet, for railroads 23 feet, and for all other roads, highways, and vehicle parking areas 15 feet. Measure the clearance for roads and highways from the crown and edges of the road and make measurements for railroads from the top of rails. Make measurements for vehicle parking areas' clearances from the grade in the vicinity of the highest point. Airport service roads, where vehicular traffic is controlled in any manner that would preclude blocking the view of the approach lights by landing aircraft, are not considered as obstructions in determining the approach light plane.

> **Note:** *The OFZ clearing standard precludes taxiing and parked airplanes and object penetrations, except for frangible visual NAVAIDs that need to be located in the OFZ because of their function. A localizer antenna serving the opposite runway end may penetrate the approach light plane if it does not obscure the approach lights or penetrate the inner-approach OFZ.

5.0 REQUIREMENTS FOR CAT I PRECISION OPERATIONS.

5.1 OBSTACLE FREE ZONE (OFZ) REQUIREMENTS.

The OFZ requirements contained in AC 150/5300-13 appropriate for precision runways must be met to enable CAT I landing operations.

5.2 LIGHTING REQUIREMENTS.

See Volume 1, Chapter 3.

5.3 MINIMUMS.

See Volume 1,Chapter 3

5.4 FINAL AND MISSED APPROACH EVALUATIONS.

See Volume 3, chapters 1-3.

6.0 REQUIREMENTS FOR CAT II PRECISION OPERATIONS.

The CAT I requirements of paragraph 5 apply. In addition, the following criteria apply.

6.1 OFZ REQUIREMENTS.

Apply the OFZ standards described in AC 150/5300-13.

6.2 LIGHTING REQUIREMENTS

(DND: apply appropriate military directives).

CAT II required lighting includes the following:

6.2.1 Standard ALSF-1 or ALSF-2 approach lights;

6.2.2 Standard touchdown zone lights;

6.2.3 Standard runway centerline lights; and

6.2.4 Standard high intensity runway lights.

> **Note:** Exceptions to lighting criteria may be authorized only if an equivalent level of safety can be demonstrated by an alternate means. Examples of exceptions are: substitution for required approach lighting components due to an approved specific aircraft system providing equivalent information or performance (such as an autoland system, head up display (HUD) with inertial augmented flight path vector display), or availability of redundant, high integrity, computed or sensor based runway information (e.g., high resolution radar or approved enhanced flight vision systems (EFVS)), suitably displayed to a pilot.

6.3 SURFACE MOVEMENT GUIDANCE AND CONTROL SYSTEM (SMGCS).

Approved SMGCS operation per AC 120-57, Surface Movement Guidance and Control System, as required.

6.4 MARKING AND SIGNS.

Develop CAT II procedures only when the airport/runway meets applicable standards for taxiway markings and airport surface signs for CAT II precision operations (or ICAO equivalent at Non-United States airports). Runway markings and CAT II hold lines should be marked in accordance with applicable standards to authorize the lowest possible minimums. Other guidance, such as Order 6750.24, Instrument Landing System and Ancillary Electronic Component Configuration and Performance Requirements, OpSpecs, and an approved SMGCS plan, may permit operational contingencies or exceptions. Examples of these actions are: snow removal, rubber deposit removal on runway touchdown zone markings or centerline markings, critical area hold line or runway centerline marking repainting, runway hold line sign snow removal, etc.

6.5 AN UNRESTRICTED CAT I PROCEDURE.

The CAT I final approach segment obstacle evaluation applies to the CAT II approach authorization. The CAT I procedure must support a 200-ft HAT and lowest possible visibility (no restrictions incurred by lack of infrastructure or obstacle surface penetrations).

Note:

1. The final course alignment must be coincident with the runway centerline.
2: Existing CAT II procedures that require adjustment for small missed approach penetrations as a result of conversion from HAT to HATh are NOT considered restrictions when the amended DA does not exceed the height of the original DA.

6.6 OPERATIONAL AIR TRAFFIC CONTROL TOWER (ATCT).

An operating on-airport ATCT must support CAT II ground and flight operations. If the ATCT does not provide continuous service, publish a note on the chart indicating the procedure is not authorized when the tower is closed.

6.7 APPROACH MINIMUMS.

CAT II procedures require special authorization from the Transport Canada. AC 120-29 contains equipment and flight crew qualifications. Operators desiring lower than CAT I minimums require OpSpecs authorization for air carrier operations or a Letter of Authorization (LOA) for Part 91 operations. Table 3 lists lowest authorized minimums. Higher minimums may be necessary based on environmental factors in the vicinity of the airport or other requirements. Class II/T/2 is the minimum class of performance authorized for CAT II operations. For public Part 97 procedures, the lowest CAT II HATh/RVR values in feet are 100/1200. Table 3 lists RVR values for HATh values greater than 100.

6.7.1 Calculation of Radio Altimeter (RA) Height.

To determine RA height, determine the distance (d) from landing threshold point (LTP) to the point decision altitude (DA) occurs. Obtain the terrain elevation on final approach course at distance (d) feet from LTP. Subtract the terrain elevation from the DA to calculate the RA (see figure 4).

HATh (ft)	RVR (ft)
101-140 (01 - 40 adjustment)	1200
141-180 (41 - 80 adjustment)	1600
181-199 (81 - 99 adjustment)	1800
Note: *Chart only one set of minimums indicating the lowest authorized CAT II HATh.	

Table 3. Lowest Public CAT II Minimums*

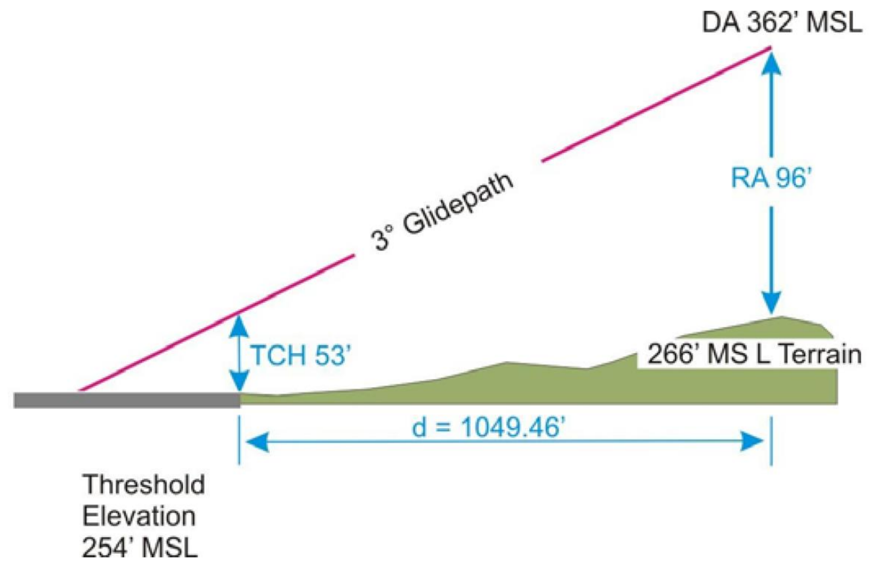

Figure 4: Calculating RA.

$$d = \frac{DA - (Threshold\_Elev + TCH)}{\tan(GPA)} = \frac{362 - (254 + 53)}{\tan(3)} = 1049.46 \text{ from LTP}$$

$$RA = DA - terrain\_elevation = 362 - 266 = 96 \text{ ft}$$

6.8 ADJUSTMENT OF CAT II MINIMUMS.

The HATh is measured in feet from the highest elevation, and visibility in RVR reported in hundreds of feet. The lowest attainable values are a HATh of 100 ft and RVR of 1,200 ft. Application of CAT II obstacle clearance criteria may identify objects that exceed the allowable height in surface “A” (see paragraph 6.9.1) or penetrate the approach light surface (except allowable localizer antenna, see paragraph 4.0 Note). In such cases, adjustment to the HATh must be made as follows:

NOTE: If the adjusted HATh is greater than or equal to 200, revert to CAT I criteria.

6.8.1 Penetrations of the Final Approach Surface.

6.8.2 Penetrations of the primary (W, X) surfaces are not authorized.

Taxiing, holding, and parked aircraft are obstacles in the final segment analysis. Apply volume 3, paragraph 3.6.3 to obstacle penetrations in the “Y” surface, except paragraph 3.6.3c is not applicable (see paragraph 6.5 Note).

6.8.3 Inner-Approach OFZ and Missed Approach Surface "A, B, C, or D."

For penetrations of the inner-approach OFZ or missed approach surface A, when an obstacle is not considered acceptable, adjust the HATh upward one foot for each foot of surface penetration and adjust the RVR, as specified in table 3. For obstacle penetrations of the missed approach surface B, C, or D, increase the RVR, as specified in table 3, as if the HATh was adjusted, but do not raise the HATh.

6.9 MISSED APPROACH SEGMENT.

6.9.1 Section 1.

The area begins at the end of the final OCS trapezoid and is aligned with a continuation of the final approach course, continuing in the direction of landing for a distance of 9,200 excluding extensions. It is comprised of 5 surfaces: surface A, surface B, surface C, surface D, and surface A1 (see figure 5). Surface A, B, C, or D must not be penetrated unless the obstacle is either deemed acceptable IAW paragraph 2.0 or the minima is adjusted (see paragraph 6.8). Surface A1 must not be penetrated, unless the obstacle is either deemed acceptable IAW paragraph 2.0. Surface A1 extended must not be penetrated, unless the obstacle is either deemed acceptable IAW paragraph 2.0 or the procedure is published as a Special and mitigated with a climb gradient greater than standard (see paragraph 6.9.2c). Use the following formulas to calculate the MSL height of the OCS at any given distance (X) from threshold and (Y) from runway centerline:

h = MSL height of OCS

X = distance (ft) from runway threshold measured parallel to runway centerline

Y = perpendicular distance (ft) from runway centerline

e = MSL elevation of the runway centerline at distance X

f = MSL elevation of the runway centerline 3,000 ft from threshold

k = increase in surface width due to altitude:

If airport elevation ≤1000 MSL then k = 0 or

if airport elevation >1000 MSL then k = 0.01*(airportelev – 1000)

CASE 1. Where X ≤ 3000' and:

Y < (200+k):	$h = e$	A Surface
Y ≥ (200+k):	$h = \frac{11(Y - (200 + k))}{40} + e$	B Surface
Y > (400+k):	$h = \frac{7(Y - (400 + k))}{40} + 55 + e$	C Surface
Y > (600+k):	$h = \frac{Y - (600 + k)}{10} + 90 + e$	D Surface

CASE 2. Where X > 3000' and:

(Calculate h using the following formulas, select highest value of the 2 results)

Y > (200+k):	$h = \frac{11(Y - (200 + k))}{40} + f$ **(B surface)**	$h = \frac{X - 3,000}{40} + f$ **(A1 Surface)**
Y > (400+k):	$h = \frac{7(Y - (400 + k))}{40} + 55 + f$ **(C surface)**	$h = \frac{X - 3,000}{40} + f$ **(A1 Surface)**
Y > (600+k):	$h = \frac{(Y - (600 + k))}{10} + 90 + f$ **(D surface)**	$h = \frac{X - 3,000}{40} + f$ **(A1 Surface)**

6.9.2 Section 2.

See figure 6.

a. Straight-Ahead Missed Approach Area (applies to turns 15 degrees or less). This area starts at the end of the A1 surface and is centered on the specified missed approach course. The width increases uniformly from +/- (1200 + k) feet at the beginning to en route width at a point 15 miles from the runway threshold. When positive course guidance is provided for the missed approach procedure, secondary reduction areas that are zero miles wide at the point of beginning and increase uniformly to initial secondary width may be added to section 2 (see figure 6).

b. Turning Missed Approach Area. (Applies to turns of more than 15°). See figures 7, 8, and 9. Missed approach section 1 obstacle clearance surface is based on the assumption that aircraft will be 200 ft above the runway elevation at the end of the A1 surface. However, the design of the turning missed approach area must consider that aircraft executing a missed approach will climb straight ahead until reaching a height of at least 400 ft above the threshold elevation (TDZE). The A1 surface area must be extended longitudinally using the following formula:

$d = (T_{MSL} - (A_{MSL} + 200)) * Slope$
d = A1 surface extension distance in feet
A_{MSL} = Runway elevation at end of A surface
T_{MSL}= Turn height (as a minimum, TDZE + 400)
Slope = 6076.11548/CG.

Note: For special procedures requiring a climb gradient A1 surface extended may be shortened (see figure 10).

The A1 surface extended OCS will continue to slope at 40:1 and the area will splay at 15 degrees from the nominal end of A1 surface width until reaching the turn altitude/point. Apply the applicable turning flight track/outer boundary radius (see Volume 1, chapter 2, table 5) both originating on the line marking the end of A1 surface extended. Unless a fix/facility identifies the turn point, the inner boundary line must commence at the inside turn edge of the D surface opposite the end of the touchdown area (A surface). When the turn point is marked by a fix/facility, the inside tieback may be constructed relative to the end of the A1 surface extended (Volume 1, paragraph 277). When the point on the inside turn side of section 2 area abeam the clearance limit is past an imaginary line extended perpendicular to the edge of section 1 abeam the end of the touchdown zone on inside turn side, the inner boundary line commences on the outside turn edge of the D surface opposite the end of the touchdown area (A surface). See figure 9. The outer and inner boundary lines extend to points each side at flight track at the clearance limit at a rate that achieves initial segment width 15 miles from the runway threshold. Where secondary areas are required, they must commence after completion of the turn at the point where PCG is achieved.

c. Section 2, Obstacle Clearance.

Section 2 OCS is a 40:1 inclined plane originating at the end of section 1. Beginning height is equivalent to the end of the A1 surface height on centerline. When the A1 surface is extended for turning missed approach, section 2 originates at the end of the A1 surface extended and the beginning height is equivalent to the A1 extended surface height on centerline. Obstacles in section 2 are measured to the nearest edge of section 1 (or to the A1 surface extended). Section 3 is necessary for turns more than 90° as described in Volume 1, paragraph 276b, except point “B” is defined as the point of the inside of turn edge of section 1 abeam the end of the A surface regardless of the location of the inside tieback point (see paragraph 6.9.2b). When an object penetrates the 40:1 surface in the A1 surface extended or section 2, a public procedure is not authorized. A special procedure (see Order 8260.19 chapter 4, section 4) with a missed approach climb gradient > 200 ft/NM may be constructed consistent with Volume 3, paragraph 3.9.3. The missed approach procedure will contain a note specifying the minimum rate of climb required to clear the obstruction by the number of feet determined by the following formula:

$$c = \frac{h-e}{0.76d} \qquad \text{Example } c = \frac{619-162}{0.76x2} = 300.66 \, ft/NM \text{ round to } 301 \, ft/NM$$

Where: c = climb gradient (ft/NM)

h = obstruction MSL elevation - elevation of runway at end of A surface

e = centerline height at nominal end of A1 surface

d = in A1 surface extended, shortest distance in NM to line marking nominal end of A1 surface. In section 2/3, distance in NM from nominal end of A1 surface to A1 surface extended + distance to nearest edge of section 1 (to include A1 surface extended).

The climb gradient is effective until reaching the hundred-foot (3100; 1600; etc.) altitude equal to the height of the obstacle + ROC. Do not publish climb gradients less than 200 ft per NM.

Example:

Chart plan view note: “Missed approach obstructions require a minimum climb gradient of (number) ft/NM to (altitude).”

7.0 REQUIREMENTS FOR CAT III PRECISION.

AC 120-28 refers to use of ICAO Annex 10 criteria, Order 6750.24, and the applicable NAVAID classification for CAT III operations. NAVAID use is predicated on applicable ILS, MLS, or GLS performance classifications; e.g., ILS III/E/3, GLS II/D/3, or equivalent classification at non-U.S. facilities. For GLS, an appropriate equivalent performance classification to ILS, as specified by FAA or the ICAO, may also be used; e.g., Performance Level/Coverage/Integrity as in “II/T/2.” Threshold crossing height (TCH) requirements contained in Volume 3, paragraph 2.6 applies. Except as noted below, the above criteria for CAT II precision applies.

7.1 REQUIREMENTS FOR LOWER THAN CAT II (RVR 1200) OPERATIONS.

7.1.1 Lighting Requirements.

Lead on/off lights are required to approve operations below RVR 600.

7.1.2 Surface Movement Guidance and Control System (SMGCS).

Approved SMGCS operation per AC 120-57, as required.

7.2 MINIMUMS.

Publish the lowest authorized CAT III RVR when the runway supports unrestricted CAT II operations. When CAT II operations for a runway are restricted, CAT III minimums for the runway must be determined by collision risk analysis. The following minimum RVR standards are applicable to published Part 97 CAT III Standard Instrument Approach Procedures (SIAP) based on equipment performance class (see Order 6750.24):

7.2.1 Class III/D/3 - RVR ≥ 700.

> **Note:** CAT III procedures with facility class III/D/3 performance require the notation “Localizer not suitable for Electronic Rollout Guidance.”

7.2.2 Class III/E/3 - RVR ≥ 600.

7.2.3 Class III/E/4 - RVR < 600.

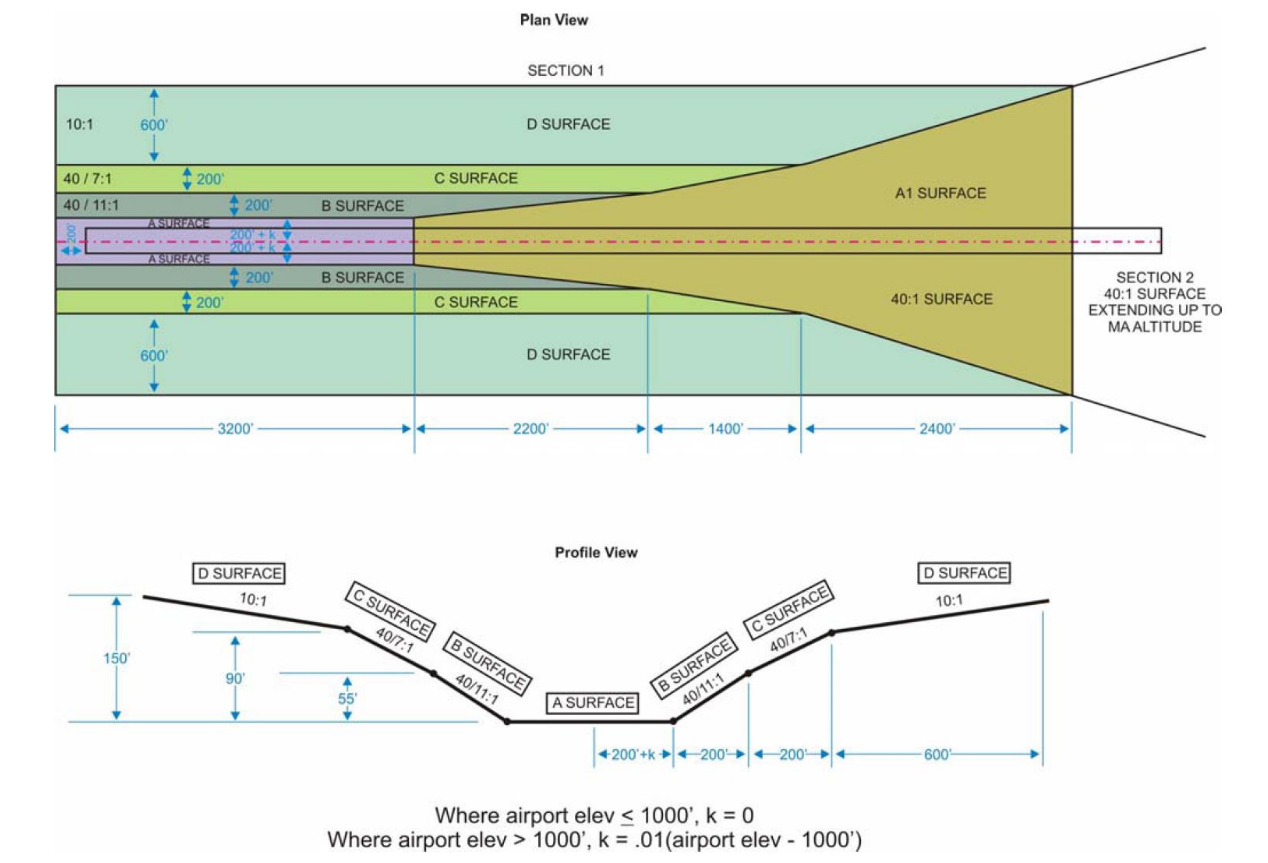

Figure 5: CAT II/III Missed Approach Section 1

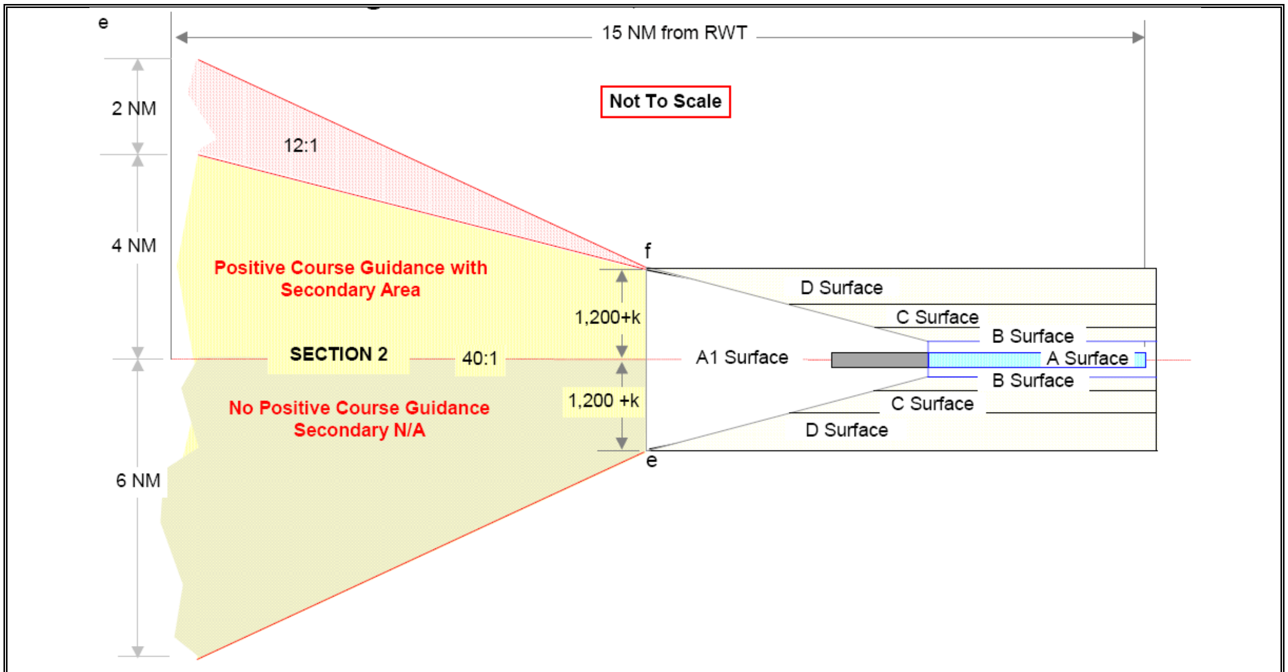

Figure 6: Section 2, Non-RNAV DTA.

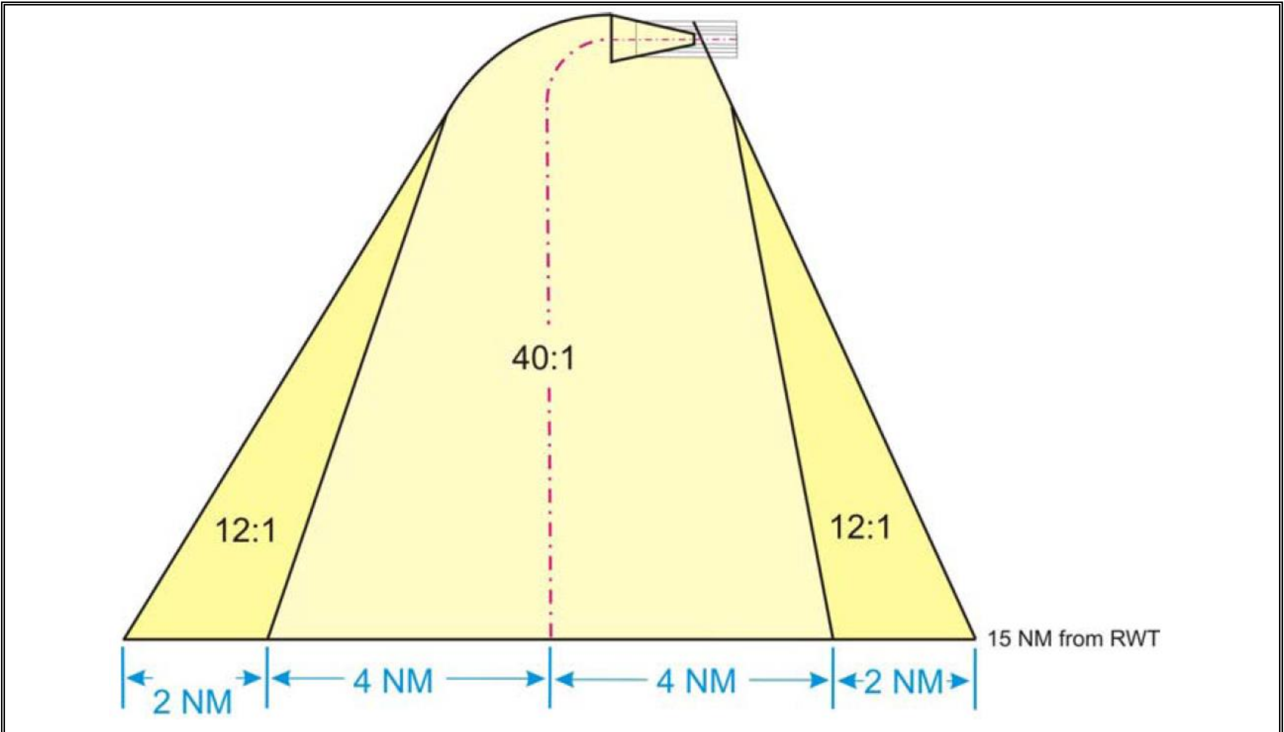

Figure 7: Turning Missed Approach Detail.

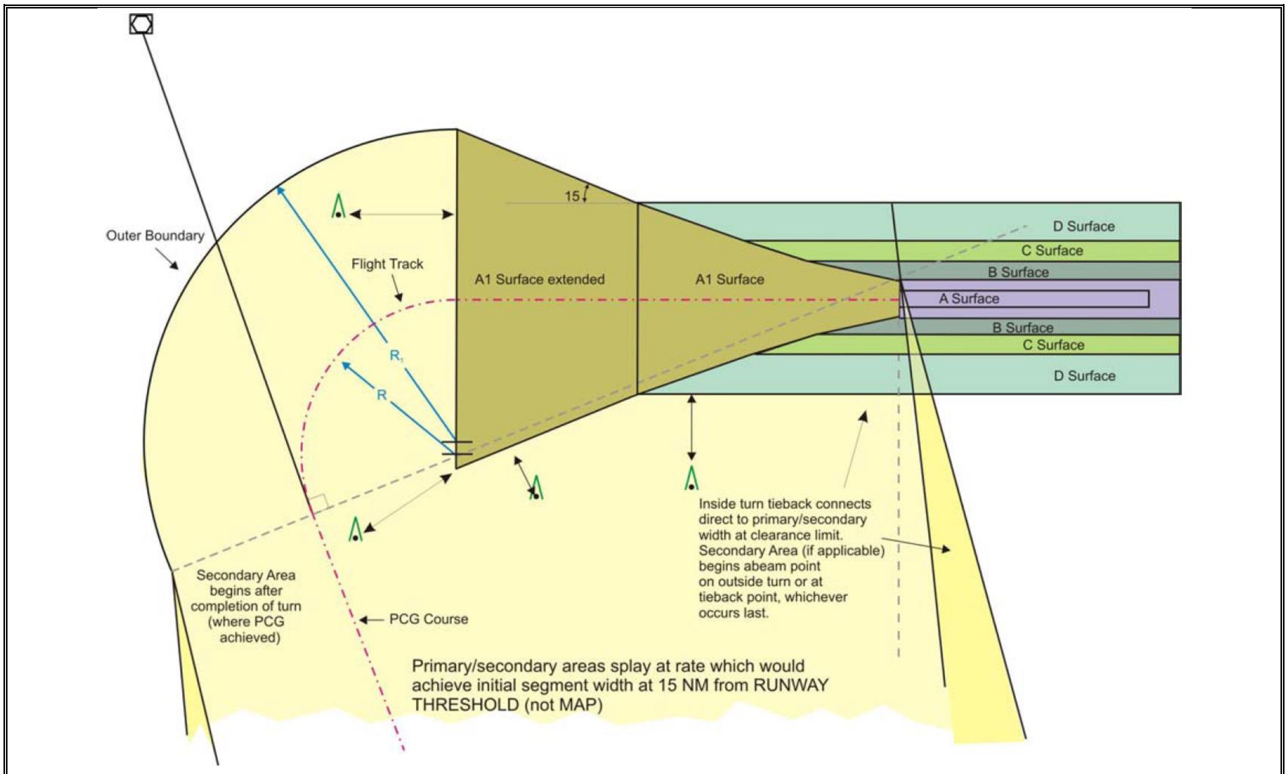

Figure 8: Turning Missed Approach (Section 1 Extended).

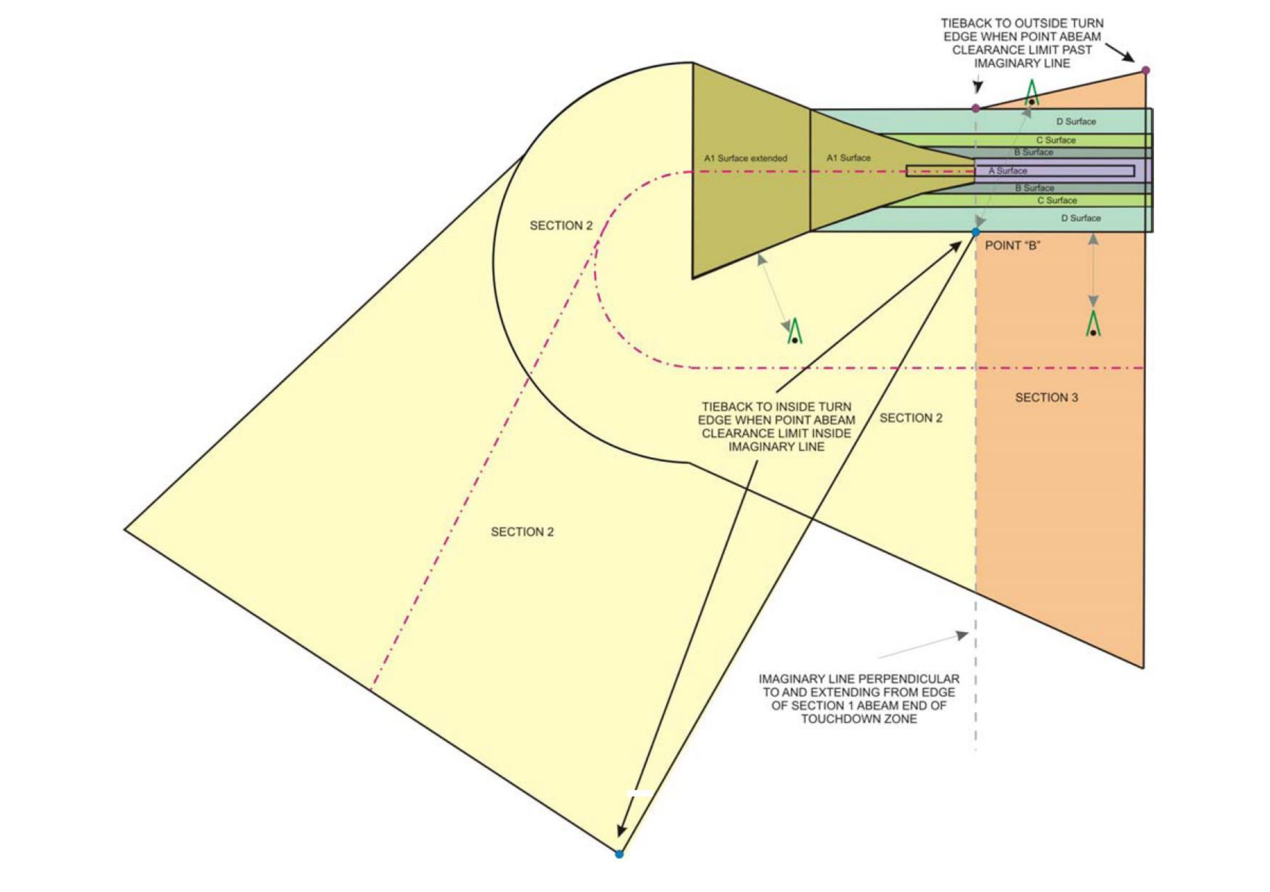

Figure 9: Turning Missed Approach Detail – Continued.

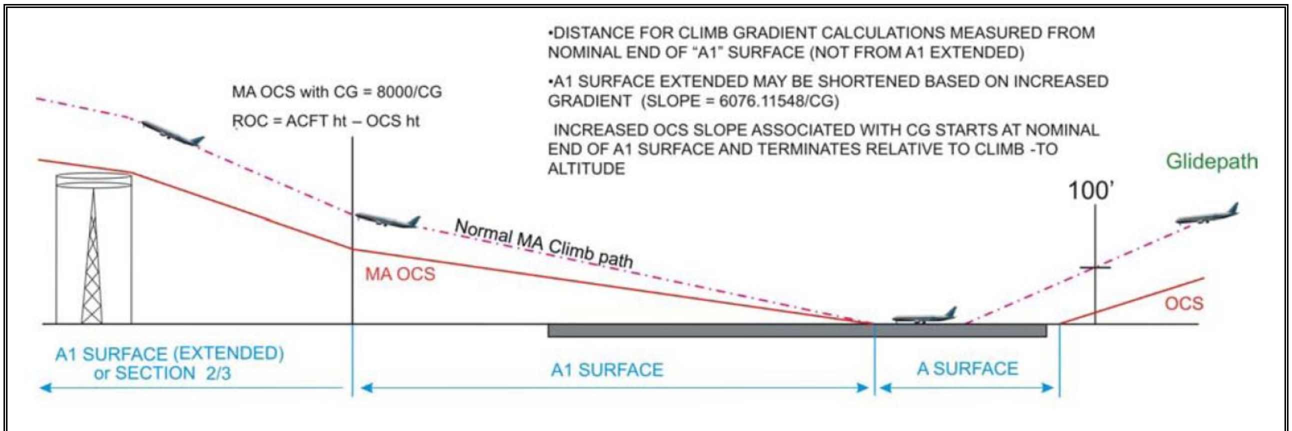

Figure 10: Missed Approach Climb Gradient (Special Procedures).

PPENDIX 2. SIMULTANEOUS INDEPENDENT PARALLEL INSTRUMENT APPROACHES [SIPIA] – WIDELY SPACED RUNWAYS

1.0 General

Simultaneous dual and triple ILS approach procedures using ILS installations with parallel courses may be authorized when the minimum standards in this appendix and chapter 2 of this Volume are met.

2.0 System Components

Simultaneous ILS approach procedures require the following basic components:

2.1. An ILS Is Specified In Chapter 2 Of This Volume For Each Runway

Adjacent markers of the separate systems shall be separated sufficiently to preclude interference at altitudes intended for use.

2.2 ATC Approved RADAR For Monitoring Simultaneous Operations

3.0 Inoperative Components

When any component specified in Para 2.0 becomes inoperative, simultaneous ILS approaches are not authorized on that runway.

4.0 Feeder Routes And Initial Approach Segment

The criteria for feeder routes and the initial approach segment are contained in TP308/GPH209 Volume 1, chapter 2, Para 2.3. The initial approach shall be made from a facility or satisfactory radio fix by radar vector. Procedure and penetration turns shall not be authorized.

4.1 Altitude Selection

In addition to obstacle clearance requirements, the altitudes established for initial approach shall provide the following vertical separation between glide slope intercept altitudes:

4.1.1 Dual

Simultaneous dual ILS approaches shall require at least 1,000 feet vertical separation between glide slope intercept altitudes for the two systems (see Figure A2-1).

4.1.2 Triple

Simultaneous triple ILS approaches shall require at least 1,000 feet vertical separation between GS intercept altitudes for any combination of runways. No two runways share the same GS intercept altitude (see Figure A2-2).

4.2 Localizer Intercept Point

The localizer intercept point shall be established UNDER chapter 2, Para 2.3 of this volume. Intercept angles may not exceed 30°; 20° is optimum.

5.0 Intermediate Approach Segment

Criteria for the intermediate segment are contained in TP308/GPH209 Volume 1, Paras 241 and 242, except that simultaneous ILS procedures shall be constructed with a straight intermediate segment aligned with the final approach course (FAC), and the minimum length shall be established in accordance with chapter 2, Para 2.3.1 of this volume. The intermediate segment begins at the point where the initial approach intercepts the FAC. It extends along the inbound course to the GLIDE SLOPE intercept point.

6.0 Final Approach Segment

Criteria for the final approach segment are contained in chapter 3 of this Volume.

7.0 Final Approach Course (FAC) Standards

The FACs for simultaneous ILS approaches require the following:

7.1. Dual Approaches

The MINIMUM distance between parallel FACs is 4,300 feet.

7.2. Triple Approaches

The MINIMUM distance between parallel FACs is 5,000 feet. For triple parallel approach operations at airport elevations above 1,000 feet MSL, ASR with high-resolution final monitor aids or high update radar with associated final monitor aids is required.

7.3. No Transgression Zone (NTZ)

The NTZ shall be 2,000 feet wide equidistant between FACs.

7.4. Normal Operating Zone (NOZ)

The area between the FAC and the NTZ is half of the NOZ.

7.4.1 NOZ For Dual Simultaneous ILS Approaches

The NOZ for dual simultaneous ILS approaches shall not be less than 1,150 feet in width each side of the FAC (see Figure A2-3).

7.4.2 NOZ For Triple Simultaneous Ils Approaches

The NOZ for triple simultaneous ILS approaches shall not be less than 1,500 feet in width each side of the FAC (see Figure A2-4).

8.0 Missed Approach Segment

Except as stated in this paragraph, the criteria for missed approach are contained in chapter 3 of this Volume. A missed approach shall be established for each of the simultaneous systems. The minimum altitude specified for commencing a turn on a climb straight ahead for a missed approach shall not be less than 400 feet above the TDZE.

8.1 Dual

Missed approach courses shall diverge a minimum of 45°.

8.2 Triple

The missed approach for the centre runway should continue straight ahead. A minimum of 45° of divergence shall be provided between adjacent missed approach headings. At least one outside parallel shall have a turn height specified that is not greater than 500 feet above the TDZE for that runway.

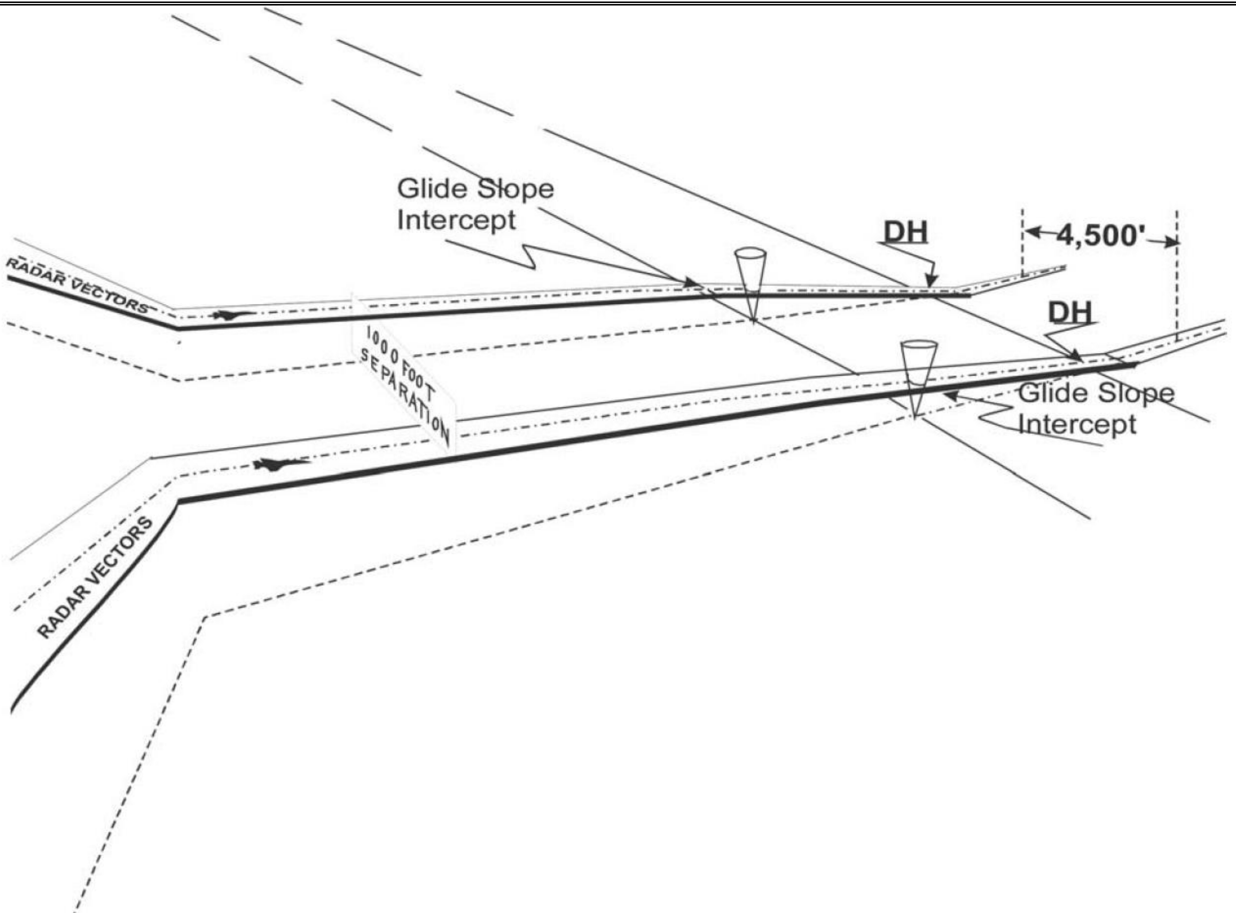

Figure A2-1: Initial Approach Segment, Simultaneous ILS. App 2, Para 4.1.1.

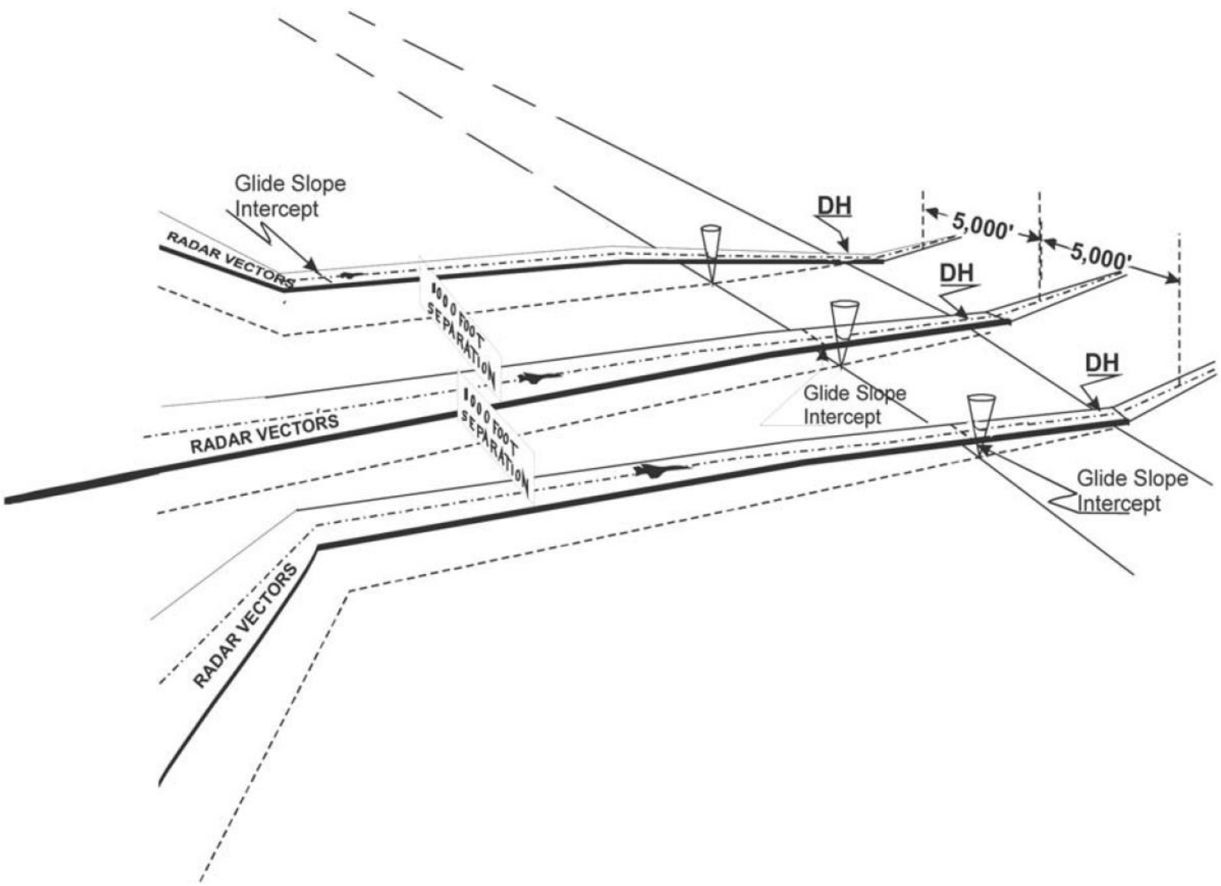

Figure A2-2: Initial Approach Segment For Triple Simultaneous ILS. Appendix 2, Para 4.1.2.

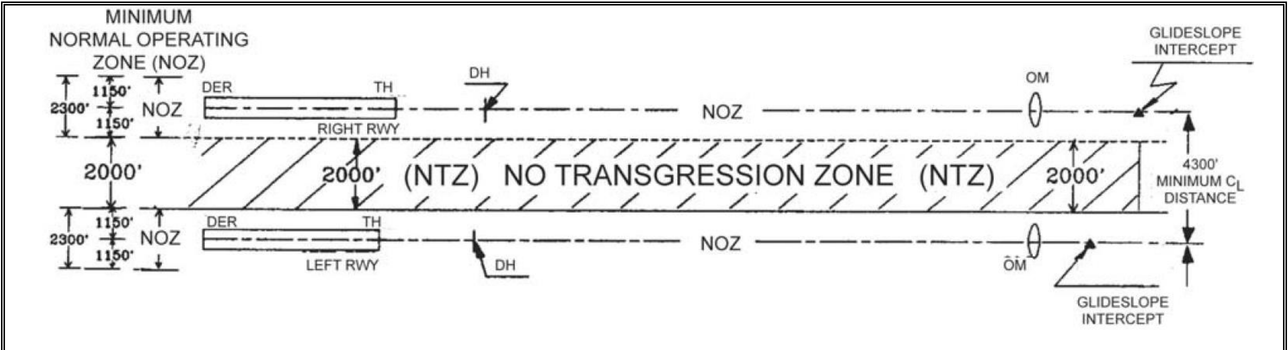

Figure A2-3: Dual Simultaneous ILS, "No Transgression And Normal Operating Zones." Appendix 2, Para 7.4.1.

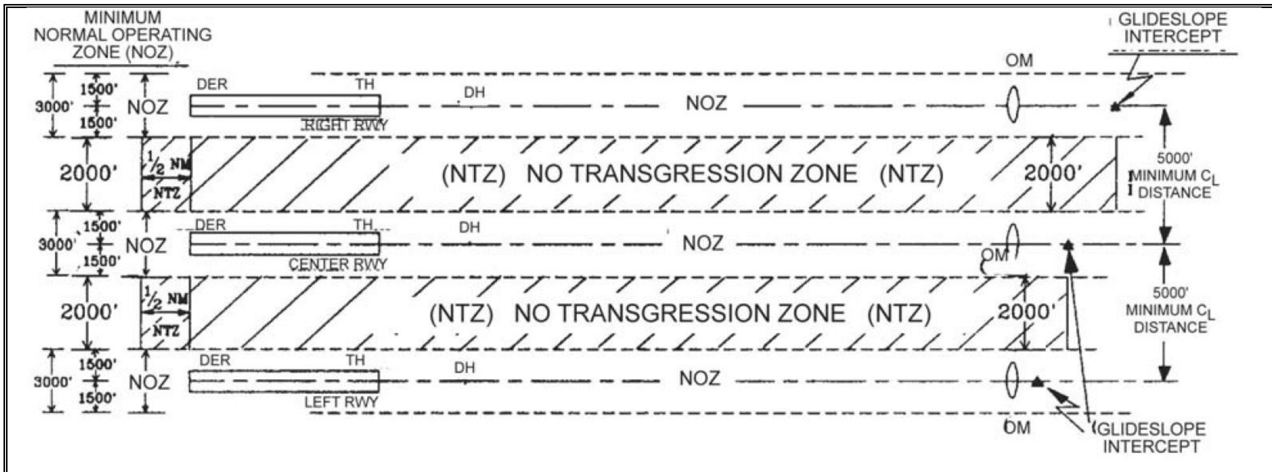

Figure A2-4: Triple Simultaneous ILS, "No Transgression And Normal Operating Zones." Appendix 2, Para 7.4.2.

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APPENDIX 3. CLOSE PARALLEL ILS/MLS APPROACHES

1.0 Background

Extensive tests have disclosed that under certain conditions, capacity at the nation's busiest airports may be significantly increased with independent simultaneous parallel approaches to runways that are more closely spaced than the minimum of 4,300 feet. Tests have shown that a reduction in minimum separation between parallel runways may be achieved by use of high update radar with high-resolution displays and automated blunder alerts.

2.0 Terminology

Automated Alert. A feature of the PRM that provides visual and/or audible alerts to the monitor controller, when an aircraft is projected to enter, or has entered the NTZ. Para 3.1.2 defines the precision runway monitor (PRM) systems alerts.

Breakout. A technique to direct aircraft out of the approach stream. In the context of close parallel operations, a breakout is used to direct threatened aircraft away from a deviating aircraft.

Close Parallels. Two parallel runways whose extended centrelines are separated by at least 3,400 feet, but less than 4,300 feet, having a precision runway monitoring system that permits simultaneous independent ILS/MLS approaches. Runways are separated by less than 3,400 to 3,000 feet with a localizer offset of not more than 3.0°.

E-Scan Radar. An electronically scanned phased array radar antenna that is cylindrical and stationary. It consists of interrogators and a surveillance processor providing an azimuth accuracy of at least 1 milliradian (0.057°) remote monitoring subsystem (RMS) and an update interval of not more than 1.0 second.

Localizer/Azimuth Offset. An angular offset of the localizer/azimuth from the runway extended centreline in a direction away from the no transgression zone (NTZ) that increases the normal operating zone (NOZ) width.

Monitor Zone. The monitor zone is the volume of airspace within which the final monitor controllers are monitoring close parallel approaches and PRM system automated alerts are active.

No Transgression Zone (NTZ). The NTZ is a 2,000-foot wide zone, located equidistant between parallel runway final approach courses in which flight is not allowed (see Figure A3-1).

Normal Operating Zone (NOZ). The NOZ is the operating zone within which aircraft flight remains during normal independent simultaneous parallel approaches (see Figure A3-1.)

Precision Runway Monitor (PRM). A specialized ATC radar system providing continuous surveillance throughout the monitoring control zone. It includes a high accuracy, high update rate sensor system, and for each runway, a high-resolution colour FMA with automated alerts. The PRM system provides each monitor controller with a clear, precise presentation of aircraft conducting approaches.

3.0 General

Criteria contained in this appendix are designed for independent simultaneous precision ILS or MLS operations to dual parallel runways with centrelines separated by at least 3,000 feet, but less than 4,300 feet. Simultaneous close parallel operations at airport elevations above 1,000 feet MSL and deviations from these criteria or glidepath angles above the U.S. civil standard of 3.0° shall not be established without approval from the Flight Standards Service, FAA, Washington, DC. When runway spacing is less than 3,400 feet, but not less than 3,000 feet, the localizers/azimuth stations in the close runway pair must be aligned at least 2-1/2° divergent from each other, but not more than 3.0°, and an electronically scanned (E-Scan) radar with an update interval of 1.0 second must be employed. All close parallel ILS/MLS operations require final approach radar monitoring, accurate to within 1.0 milliradian, an update interval of 1.0 second, and a final monitor aid (a high resolution display with automated blunder alerts). In these criteria, ILS “glide slope/localizer” terms are synonymous to and may be used interchangeably with MLS “elevation/azimuth” terms. Independent simultaneous close parallel approaches without altitude separation should not be authorized at distances greater than 10 NM from threshold. If Air Traffic Control (ATC) systems and procedures are established which assure minimal NTZ intrusions, this distance may be extended up to 12.5 NM. A separate instrument approach chart described as a special close parallel ILS/MLS procedure shall be published for each runway in the close parallel pair of runways. This special close parallel ILS/MLS procedure is to be identified in accordance with Para 3.1. A standard ILS/MLS procedure may also exist or be published for each of the runways. During close parallel ILS/MLS operations, the close parallel ILS/MLS may overlay the existing standard ILS/MLS procedure, provided that spacing localizer/azimuth alignment is less than 3,400 feet and the missed approaches diverge. A breakout obstacle assessment specified in TP308/GPH209 Volume 3, appendix 4, Obstacle Assessment Surface Evaluation for Simultaneous Parallel Precision Operations, shall be completed as part of the initial evaluation for parallel operations.

3.1 System Components

Simultaneous close parallel approach procedures are not authorized if any component of the PRM system is inoperative. System requirements for simultaneous close parallel approach procedures are:

3.1.1 ILS/MLS

There must be a full ILS or MLS on each runway.

3.1.2 PRM

A PRM system includes the following:

- **a. Radar**. Phased array electronically scanned (E-Scan) antenna; update intervals of 1.0 second.
- **b. Final Monitor Aid** (FMA). Large (not less than 20” x 20”), high resolution (100 pixels/inch minimum), colour monitors with associated visual and audible alerts.
  - (1) Caution Alert. A caution alert when the system predicts that an aircraft will enter the NTZ within 10 seconds (e.g., the target symbol and data block change from green to yellow and a voice alert sounds).
  - (2) Warning Alert. A warning alert when the aircraft has penetrated the NTZ (e.g., the target symbol and data block change to red).

(3) A Surveillance Alert. A surveillance alert when the track for a monitored aircraft inside the monitor zone has been in a coast state for more than three consecutive updates (e.g., the target symbol and data block change to red).

3.2 Procedure Charting

Volume 1, Para 161, applies, except where a separate procedure is published. In this case, "ILS/MLS PRM" should precede the approach title identification; e.g., "ILS PRM, RWY 27R" (simultaneous close parallel). Notes for approach charts for use in the close parallel operation shall be published in bold and caps as follows: "SIMULTANEOUS CLOSE PARALLEL APPROACHES AUTHORIZED WITH RUNWAYS (NUMBER) L/R" and "LOCALIZER ONLY NOT AUTHORIZED DURING CLOSE-PARALLEL OPERATIONS." The following shall also be noted: "DUAL VHF COMM REQUIRED," "MONITOR PRM CONTROLLER (FREQ) ON RWY ( ) L, (FREQ) ON RWY ( ) R," and "SEE ADDITIONAL REQUIREMENTS ON ADJACENT INFORMATION PAGE."

4.0 Feeder Routes And Initial Approach Segment

TP308/GPH209 Volume 3, chapter 2, Para 2.3 applies, except as stated in this order. The initial approach shall be made from a NAVAID, fix, or radar vector. Procedure turns and high altitude penetration procedures shall not be authorized.

4.1 Altitude Selection

Altitudes selected shall provide obstacle clearance requirements and a minimum of 1,000 feet vertical separation between aircraft on the two parallel final approach courses in the interval from localizer intercept to glide slope capture.

4.2 Localizer Intercept Point

Apply chapter 2 of this Volume, except optimum localizer intercept angles are 20° or less and the maximum intercept angle shall not exceed 30°.

4.3 NTZ

An NTZ is established and depicted on the FMA as a protected zone 2,000 feet wide, equidistant between parallel runway centrelines, beginning from the point where adjacent inbound aircraft first lose 1,000 feet of vertical separation, and extends to 0.5 NM beyond the farthest departure end of runway (DER), or the point where a combined 45° divergence occurs, whichever is farthest. The beginning of the NTZ for the final segment should begin at the most distant PFAF (see Figure A3-1). Where an offset localizer is determined to provide operational advantage, the NTZ shall be established for the final segment equidistant between adjacent final approach courses beginning and ending as stated above.

4.4 NOZ

An NOZ is established so that the NOZ for each close parallel runway is not less than 700 feet wide on each side of the approach course at any point. The width of the NOZ is equal on each side of the final approach course centreline, and the half-width is defined by the distance from the nearest edge of the NTZ to the final approach course centreline. The length of the NOZ equals the length of the NTZ. Each parallel runway provides an NOZ for the final and missed approach segments that equal the length of the NTZ (see Figure A3-1).

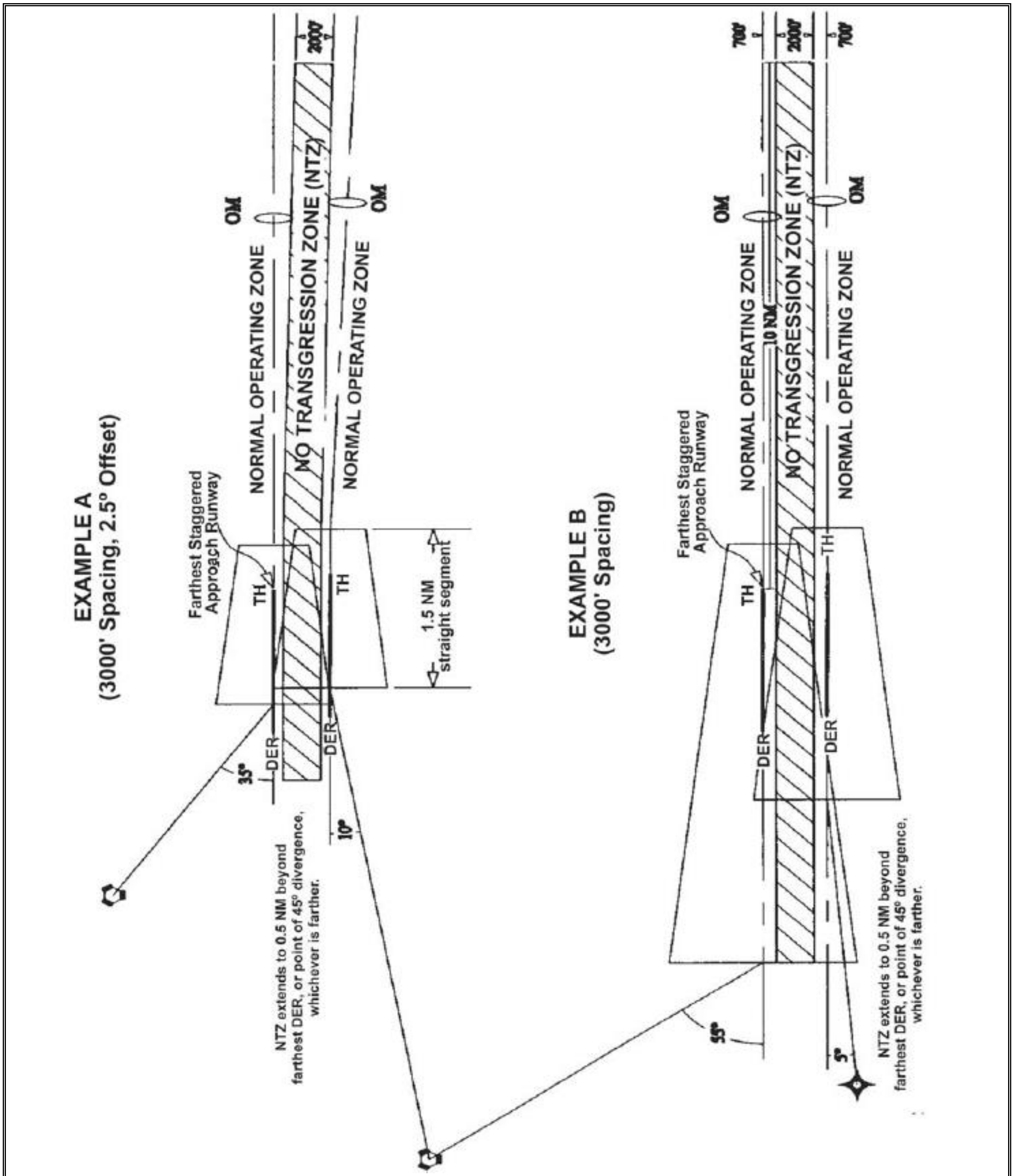


Figure A3-1: Examples Of Close Parallel Finals And Missed Approach Segments, Runway Spacing 3,000' And 3,400', Appendix 3. Para 4.2 and 4.4.

5.0 Intermediate Approach Segment

Chapter 2, Para 2.3, of this Volume applies, except where close parallel procedures have a straight intermediate segment aligned with the final approach course. Where an existing ILS/MLS procedure is published with a transition intercept angle greater than 30° which cannot be reduced, a separate close parallel procedure shall be established with intercept angles of less than 30°.

6.0 Final Approach Segment

Volume 3, Chap 3 applies. In addition to these criteria, independent simultaneous approaches to close parallels runways require the following:

6.1 Close Parallel Approach Runway Separation

Approaches shall have a minimum of 3,400-foot separation between the parallel final approach courses.

6.2 PRM

A PRM system must be in operation and providing service in accordance with Para 3.1.2.

6.3 NTZ

An appropriate NTZ shall be established between close parallel final approach courses as described in Para 4.3 (see Figure A3-1).

6.4 NOZ

Appropriate NOZ's shall be established for each parallel final approach segment as described in Para 4.4 (see Figure A3-1).

6.5 Staggered Runway Thresholds

Where thresholds are staggered, the glide slope intercept point from the most distant runway approach threshold should not be more than 10 NM. It is recommended that the approach with the higher intercept altitude be the runway having the most distant approach threshold from the point of view of an aircraft on approach.

6.6 Localizer/ Azimuth Offset

Where an offset localizer is utilized, apply chapter 3 of this Volume. Where approach thresholds are staggered, the offset localizer course should be to the runway having the nearest approach threshold (from the point of view of an aircraft on approach). An offset requires a 50-foot increase in decision height (DH) and is not authorized for Category II and III approaches. (Autopilots with autoland are programmed for localizers to be on runway centreline only.) The NTZ shall be established equidistant between final approach courses.

6.7 Monitor Zone

This zone is a radar-monitored volume of airspace within which the PRM system automated alerts are active. The extent of the monitor zone is as described in the following three subsections.

6.7.1 Monitor Zone Length

The PRM monitor zone begins where aircraft conducting simultaneous parallel approaches reach less than 1,000-foot vertical separation during final approach (typically at glide slope intercept for the higher altitude localizer intercept) and extends to 0.5 NM beyond the farthest DER, or the point where a 45° divergence occurs, whichever generates the greatest length for the monitor zone.

6.7.2 Monitor Zone Width

The PRM monitor zone (automated alerts) includes all of the area between the final approach courses and extends 0.5 NM outboard of each final approach course centreline.

6.7.3 Monitor Zone Height

The PRM monitor zone height may be defined in as many as five separate segments, each having an independent maximum height. Each segment covers the entire monitor zone width, and a portion of the monitor zone length. Within each segment, the monitor zone height extends from 50 feet above ground level to a minimum of 1,000 feet above the highest point within that segment of the glide slope, the runway surface, or the missed approach course, whichever attains the highest altitude.

7.0 Minimums

For close parallel procedures, only straight-in precision minimums apply.

8.0 Missed Approach Segment

Volume 3 chapter 3 applies, except as stated in this appendix. Missed approach procedures for close parallels shall specify a turn as soon as possible after reaching a minimum of 400 feet above the touchdown zone, and diverge at a minimum of 45°. The turn points specified for the two parallel procedures should be established at the end of the straight segment minimum of 1.5 NM. A 45° divergence shall be established by 0.5 NM past the most distant DER. Where an offset localizer is used, the first missed approach turn point shall be established so that the applicable flight track radius (table 5 in Volume 1, chapter 2), constructed in accordance with Volume 1, chapter 2, Section 7, for the fastest category aircraft expected to utilize the offset course, shall not be less than 700 feet from the NTZ.

8.1 NTZ

The NTZ shall be continued into the missed approach segment, as defined in Para 4.3 of this appendix (see Figure A3-1).

8.2 NOZ

The NOZ shall be continued into the missed approach segment, as defined in Para 4.4 of this appendix (see Figure A3-1).

APPENDIX 4. OBSTACLE ASSESSMENT SURFACE EVALUATION FOR SIMULTANEOUS PARALLEL PRECISION OPERATIONS

1.0 Background

One of the major aviation issues is the steady increase in the number and duration of flight delays. Airports have not been able to expand to keep pace with traffic growth. The federal aviation administration (FAA) has taken a variety of measures to increase airport capacity. These include revisions to air traffic control procedures; addition of landing systems, taxiways and runways; and application of new technology. The precision radar monitor (PRM) program is one of these new initiatives. PRM is an advanced radar monitoring system intended to increase the use of multiple, closely-spaced parallel runways in instrument meteorological conditions (IMC) weather by use of high resolution displays with alert algorithms and higher aircraft position update rate. Monitor controllers are required for both standard and closely spaced runway separations. The primary purpose of radar monitoring during simultaneous, independent approach operations is to ensure safe separation of aircraft on the parallel approach courses. This separation may be compromised if an aircraft blunders off course toward an aircraft on the adjacent approach. For close parallel operations (3,400 feet but less than 4,300 feet) and for standard parallel operations (4,300 feet and above), the radar monitoring allows controllers to direct either aircraft off the approach course to avoid a possible collision. Resolution of a blunder is a sequence of events: the monitor alerts and displays the blunder, the controllers intervene, and the pilots comply with controller instructions; thus, increasing the operational safety, flyability, and airport capacity.

2.0 Definitions

2.1 Course Width (CW).

The angular course deviation required to produce a full scale (±) course deviation indication of the airborne navigation instrument. This width is normally tailored to a parameter of not greater than ±3°. For precision runways longer than 4,000 feet, a linear sector width parameter of ±350 feet each side of centreline at RWT applies. Few category I localizers operate with a course sector width less than 3° (±1½°). Tailored width may be determined by the formula:

$$W = \text{ArcTan}\left(\frac{350}{D}\right) \quad \text{Total Course Width at RWT} = 2 \times W$$

Where W = the half width in degrees at RWT

D = the distance in feet from the localizer antenna to RWT

2.2 Parallel Approach Obstruction Assessment (PAOA).

An examination of obstruction identification surfaces, in addition to the ILS TP308/GPH209 surfaces in the direction away from the NTZ and adjacent parallel ILS runway, into which an aircraft on an early ILS breakout could fly.

2.3 Parallel Approach Obstruction Assessment Surfaces (PAOAs).

PAOA assessment surfaces for identifying obstacles that may impact simultaneous precision operations.

2.4 Parallel Approach Obstruction Assessment Surface Penetration.

One or more obstructions that penetrate the PAOAs.

2.5 Parallel Approach Obstruction Assessment Controlling Obstruction (PAOACO).

The obstruction within the boundaries of the PAOAs, which constitutes the maximum penetration of that surface.

2.6 No Transgression Zone (NTZ).

See TP308/GPH209 Volume 3, appendix 3, Para 4.3.

2.7 Normal Operational Zone (NOZ).

See TP308/GPH209 Volume 3, appendix 3, Para 4.4.

3.0 General

This appendices characterizes criteria used during the interim test phase of evaluating close parallel operations where early turnout obstacle assessments were accomplished by contractual means using terrestrial photometric techniques combined with survey methods of surface evaluation. This assessment technique is recommended for future evaluations of all independent simultaneous parallel approach operations. Facility information (glidepath angle (GPA), threshold crossing heights (TCH), touchdown zone elevation (TDZE), threshold elevations, etc.) may be obtained from air traffic planning and automation, flight procedures offices, and/or the systems management organizations for the regions in which independent simultaneous parallel operations are planned.

3.1 Parallel Runway Simultaneous ILS Approaches

The procedures for airports with multiple parallel runways must ensure that an aircraft approach on one runway is safely separated from those approaching the adjacent parallel runway. An example of such procedures is depicted in Figure A4-1. Aircraft are directed to the two intermediate segments at altitudes, which differ, by at least 1,000 feet. Vertical separation is required when lateral separation becomes less than 3 NM, as aircraft fly to intercept and stabilize on their respective localizers (LOC). This 1,000-foot vertical separation is maintained until aircraft begin descent on the glidepath.

3.1.1 Lateral RADAR Separation Is Less Than The 3nm and The 1,000 foot Altitude Buffer Is Lost

When lateral radar separation is less than the 3 NM and the 1,000-foot altitude buffer is lost, the aircraft must be monitored on radar. The controllers, on separate and discrete frequencies, will observe the parallel approaches, and if an aircraft blunders from the NOZ into a 2,000-foot NTZ, the monitor controller can intervene so that threatened aircraft on the adjacent approach are turned away in time to prevent a possible encounter. This manoeuvre, on the part of the threatened aircraft, is termed a "breakout" because the aircraft is directed out of the approach stream to avoid the transgressor aircraft. A controller for each runway is necessary so that one can turn the transgressing aircraft back to its course centreline while the other directs the breakout (see Figure A4-1).

3.1.2 Flanking The 2000-Foot NTZ By Two Equal Normal Operational Zones

The 2,000-foot NTZ, flanked by two equal NOZs, provides strong guidance to the monitor controller and manoeuvring room for the aircraft to recover before entering the adjoining NOZ. Aircraft are required to operate on or near the approach course within the limits of the NOZ. If an aircraft strays into the NTZ or turns to a heading that will take it into the NTZ, it is deemed a threat to an aircraft on the adjacent course and appropriate corrective action or breakout instructions are issued (see Figure A4-2).

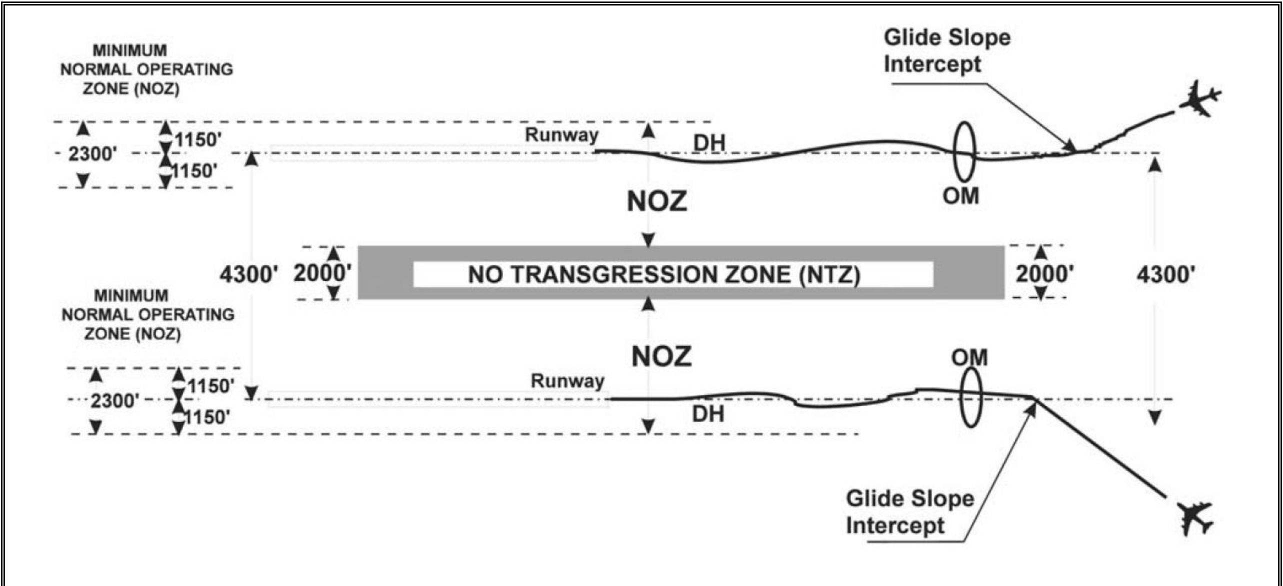


Figure A4-1: Simultaneous Precision Parallel Runway Approach Zones. Appendix 4, Para 3.1.

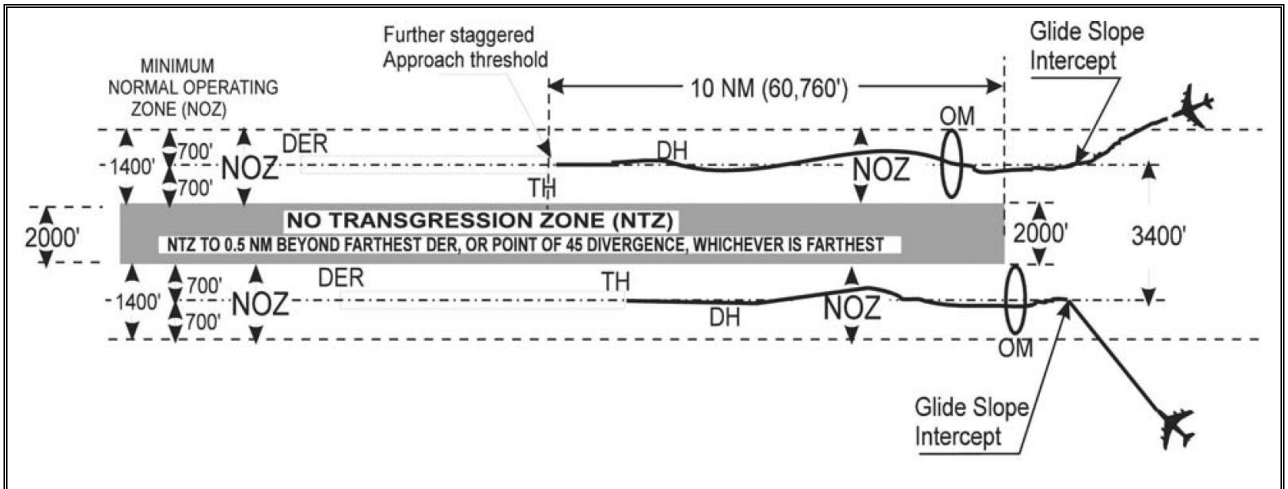


Figure A4-2: Simultaneous ILS No Transgression Zone And Normal Operating Zone. Appendix 4, Paras 3.1.2 and 4.1.2

4.0 PAOA Evaluation

The PAOA evaluation shall be conducted to identify penetrating obstacles as part of a coordinated assessment for all independent simultaneous approach operations to parallel ILS/MLS runways. In these criteria, ILS glidepath/localizer terms are synonymous to and may be used interchangeably with MLS elevation glidepath/azimuth (GP/AZ) terms. The surface dimensions for the obstacle assessment evaluation are defined as follows:

4.1 Surface 1

A final approach course descent surface which is coincident with the glide slope/glidepath (GS/GP) beginning at runway threshold with the width point abeam the threshold 350 feet from runway centreline opposite the NTZ, with lateral boundaries at the outer edge of the LOC/AZ CW, and ending at the farthest GS/GP intercept (see Figure A4-3).

4.1.1 Length

Surface 1 begins over the runway threshold at a height equal to the TCH for the runway, and continues outward and upward at a slope that is coincident with the GS/GP, to its ending at the GS/GP intercept point.

4.1.2 Width

Surface 1 has a width equal to the lateral dimensions of the LOC/AZ course width. The surface 1 half-width (see Figure A4-2) is calculated using the following formula:

$$\frac{1}{2}\ W = A \text{ x } \tan\left(\frac{B}{2}\right) + 350$$

Where W = the width of surface 1 in feet
A = the distance from RWT measured parallel to course in feet
B = the course width beam angle in feet

OR

$$\frac{1}{2}\ W = L \text{ x } \tan\left(\frac{B}{2}\right)$$

Where W = the width of surface 1 in feet
L = the distance in feet from azimuth antenna in feet
B = the course width beam angle in feet

4.1.3 Height

Surface height at any given centreline distance (d), may be determined in respect to threshold elevation, by adding the TCH to the product of centreline distance in feet from threshold times the tangent of the GS/GP angle.

$$h1 = (d \text{ x } \tan(GPA)) + TCH$$

Where h1 = the surface 1 height above ASBL in feet

4.2 Surface 2

4.2.1 Length

Same as Para 4.1.1.

4.2.2 Width And Height

Surface 2 shares a common boundary with the outer edge of surface 1 on the side opposite the NTZ, and slopes upward and outward from the edge of the descent surface 1 at a slope of 11:1, measured perpendicular to the LOC/AZ extended course centreline. Further application is not required when the 11:1 surface reaches a height of 1,000 feet below the MVA, MSA, or MOCA, whichever is lowest (see Figure A4-4).

4.3 Surface 3 (Category I)

4.3.1 Length

For category I operations, surface 3 begins at the point where surface 1 reaches a height of 200 feet above the TDZE and extends to the point the 40:1 and 11:1 slopes reach a height of 1,000 feet below the MVA, MSA, or MOCA, whichever is lowest.

4.3.2 Width

From the beginning point, the edge of surface 3 area splays at a 15° angle from a line parallel to the runway centreline.

4.3.3 Height

Surface 3 begins at a height of 100 feet above TDZE (100 feet lower than surface 1). The surface rises longitudinally at a 40:1 slope along the 15° splay line CD while continuing laterally outward and upward at an 11:1 slope (line CE is perpendicular to the 15° splay line CD). Further application is not required when the 40:1 and 11:1 slopes reach a height of 1,000 feet below the MVA, MSA, or MOCA, whichever is lowest (see Figure A4-5).

4.4 Surface 4 (Category II)

4.4.1 Length

Surface 4 begins at the point where surface 1 reaches a height of 100 feet above the runway TDZE and extends to the point 40:1 and 11:1 slopes reach a height of 1,000 feet below the MVA, MSA, or MOCA, whichever is lowest.

4.4.2 Width

From the point of beginning, the edge of surface 4 area splays at a 15° angle from a line parallel to the runway centreline.

4.4.3 Height

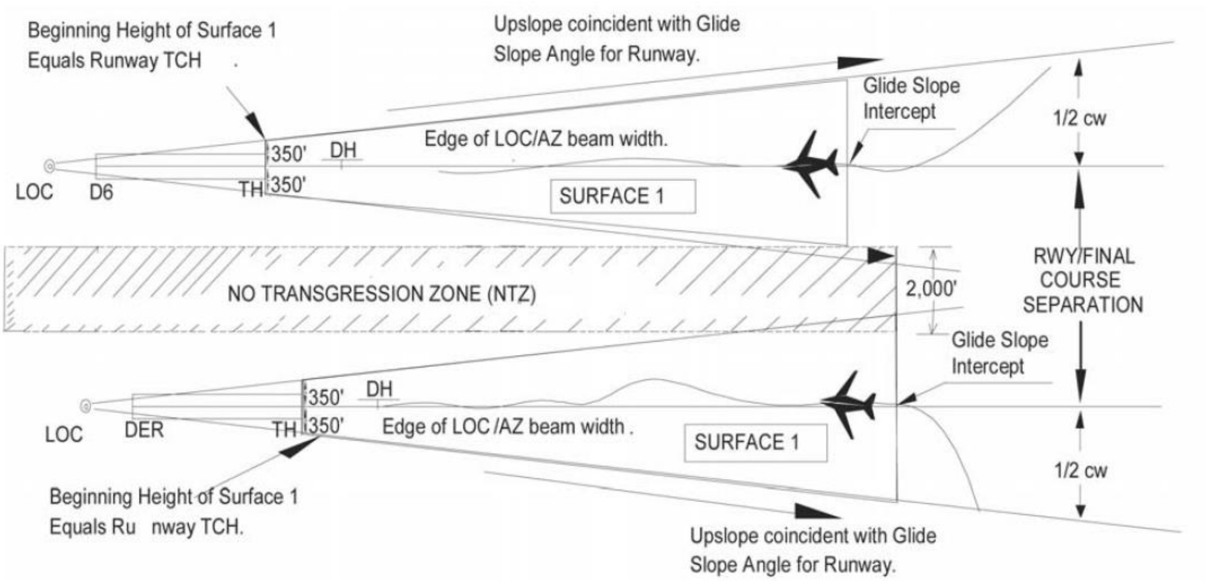
Surface 4 begins at the point where surface 1 reaches a height of 100 feet above the runway TDZE and rises longitudinally at a 40:1 slope along the 15° splay line CD, while continuing laterally outward and upward at an 11:1 slope (line CE is perpendicular to the 15° splay line CD). Further application is not required when the 40:1 and 11:1 slopes reach a height of 1,000 feet below the MVA, MSA, or MOCA, whichever is lowest (see Figure A4-6).

4.5 Latitude-Longitude List

Establish a latitude-longitude list for all obstacles penetrating the PAOA surfaces 2, 3, and 4. Identify locations of surface penetration within the surface areas (see Figures A4-3, A4-4, and A4-5).

4.6 Parallel Operations Application Requirements

PAOA obstacle penetrations shall be identified and, through coordinated actions of those affected, considered for electronic mapping on controller radar displays. If possible, penetrations should be removed by facilities considering independent simultaneous approach operations to parallel precision runways. Where obstacle removal is not feasible, air traffic operational rules shall be established to avoid obstacles. If a significant number of penetrations occur, a risk assessment study shall be required to provide guidance as to whether independent simultaneous ILS/MLS operations to parallel runways should be approved or denied.



1/2 CW = Perpendicular distance from runway/extended C_L to edge of course beam width.

1/2 CW = Distance from Threshold in feet along C_L X TAN (1/2 Course Beam Angle) + 350'.

OR

1/2 CW = Distance from LOC/AZ Antenna in feet along C_L X TAN $\left(\frac{\text{LOC/AZ Beam Angle}}{2}\right)$.

Surface 1 Height - Distance from TH in feet along CL X TAN of the GS/GP angle + TCH.

Figure A4-3: Final Descent Surface 1. Appendix 4, Paras 4.1 and 4.5

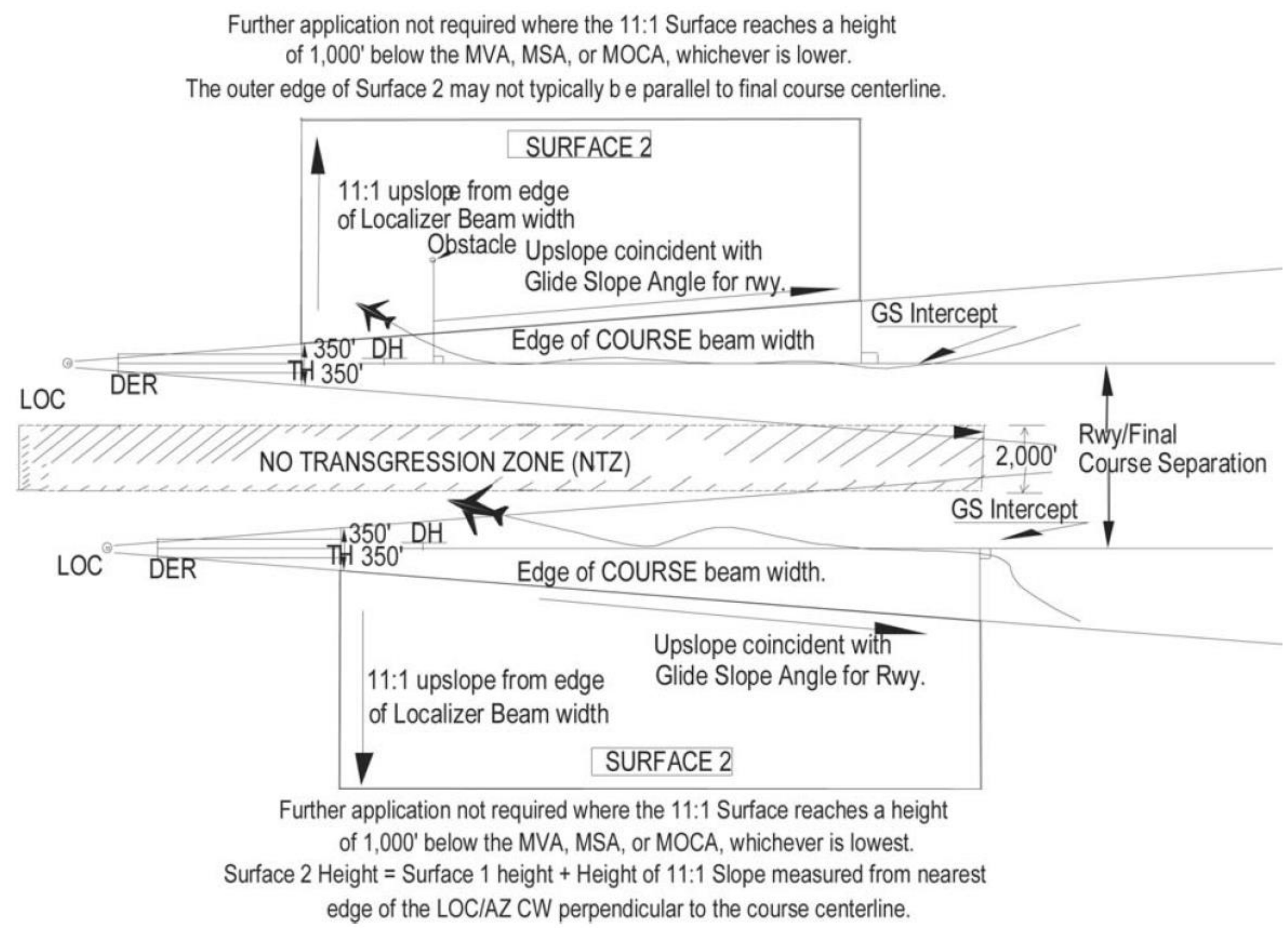


Figure A4-4: Parallel Approach Obstacle Assessment Surface 2. Appendix 4, Para 4.2.2 and 4.5

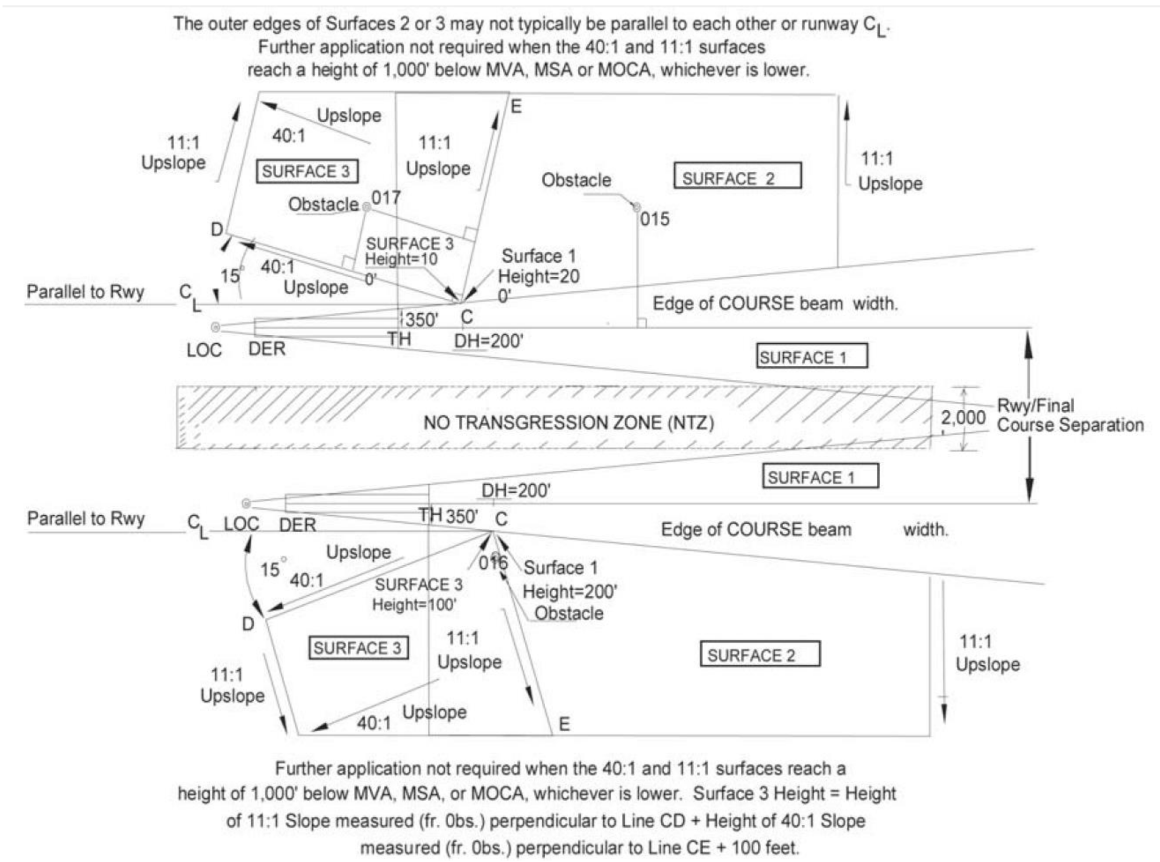


Figure A4-5: CAT 1 Missed Approach Early Breakout Parallel Approach Obstacle Assessment Surface 3. Appendix 4, Para 4.3.3 and 4.5

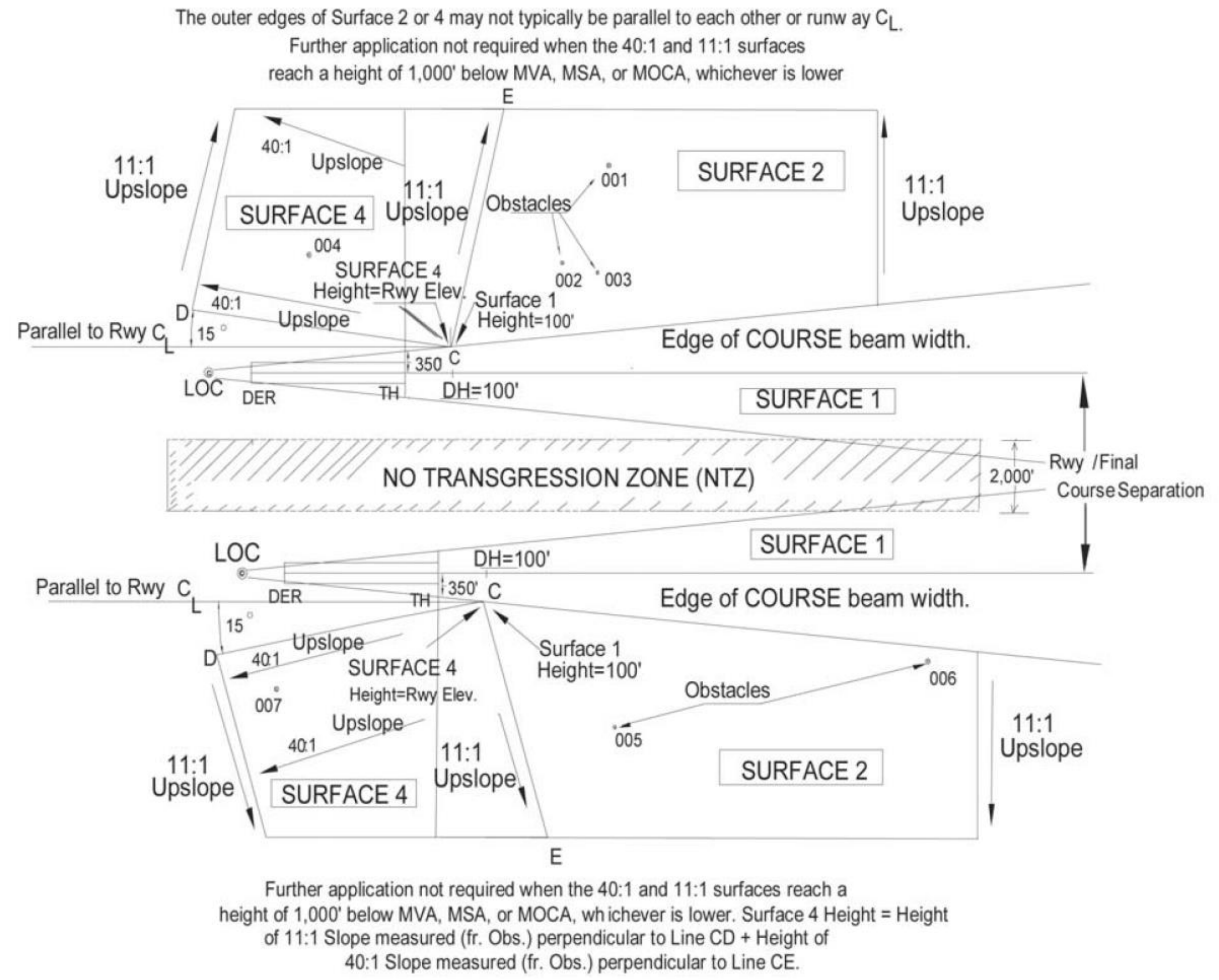


Figure A4-6 CAT II Missed Approach Early Breakout Parallel Approach Obstacle Assessment Surface 4. Appendix 4, Para 4.4.3

APPENDIX 5. THRESHOLD CROSSING HEIGHT (TCH), GROUND POINT OF INTERCEPT (GPI), AND RUNWAY POINT OF INTERCEPT (RPI) CALCULATION

1.0 General

The images in this appendix present examples of the calculation worksheets. These spreadsheets may be used to calculate the applicable values, by filling in the appropriate variables in the blue area of each sheet. The spreadsheets can be found on the Internet on the Transport Canada website.

1.1 Non-RADAR Precision TCH/GPI/RPI Worksheet

1,016.00	A=Distance (ft) from GS antenna to RWT
100.00	a=RWT elevation (MSL)
98.00	c=Elevation (MSL) of runway crown at RPI/TDP
90.00	h=ILS antenna base elevation (MSL)
107.20	p=Phase center (MSL) of elevation antenna
3.00	e=Glidepath angle

STEP 1: CALCULATE OR SPECIFIY TCH

51.25	**ILS** (smooth terrain)	$\tan(e) \times A - (a - c)$
43.25	**ILS** (rapidly dropping terrain)	$\tan(e) \times A - (a - h)$
60.45	**MLS**	$\tan(e) \times A + (p - a)$
50.00	**LAAS/WAAS**	Specify TCH

STEP 2: CALCULATE GPI

977.84	**ILS** (smooth terrain)	
825.19	**ILS** (rapidly dropping terrain)	$\frac{TCH}{\tan(e)}$
1,153.38	**MLS**	
954.06	**LAAS/WAAS**	

STEP 3: CALCULATE RPI

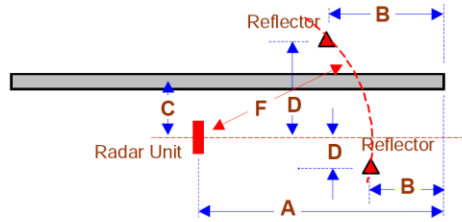
1,016.00	**ILS** (smooth terrain)	
863.35	**ILS** (rapidly dropping terrain)	$\frac{TCH + (a - c)}{\tan(e)}$
1,191.55	**MLS**	
992.22	**LAAS/WAAS**	

Figure A5-1: Non RADAR Precision TCH/GPI/RPI Worksheet

1.2 Precision Approach RADAR (PAR) (Scanning RADAR) Worksheet

Figure A5-2.
Precision Approach Radar (PAR)
(Scanning Radar)

Version 1.0

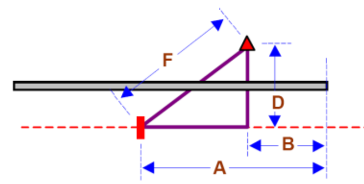


ELEVATIONS (MSL):		DISTANCES (FT):	
Threshold [a]:	100	AZ antenna to threshold [A]:	4500
Touchdown Reflector [b]:	105	TD reflector to threshold [B]:	750
RWY Crown in TDZE [c]:	100.7	AZ antenna to centerline [C]:	450
RPI (if known) [d]:	100.5	TD reflector to CLA line [D]:	475
Glidepath Angle [e]:	3	RWY gradient (if required) [E]:	0.00023333

STEP 1: Determine distance from AZ antenna to TD reflector [F].

3,779.96

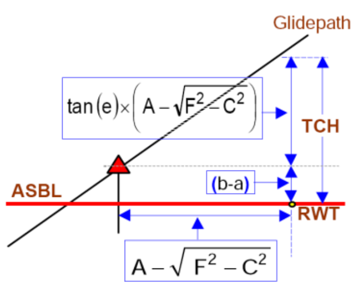
$$F = \sqrt{(A - B)^2 + D^2}$$

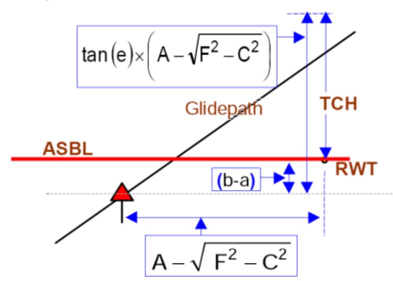


STEP 2: Determine threshold crossing height [TCH].

44.14

$$TCH = \tan(e) \times \left(A - \sqrt{F^2 - C^2} \right) + (b - a)$$





STEP 3: Determine ground point of intercept [GPI].

842.32

$$GPI = \frac{TCH}{\tan(e)}$$

STEP 4: Determine runway point of intercept [RPI].

[d] known

832.78

$$RPI = \frac{TCH - (d - a)}{\tan(e)}$$

[d] unknown

838.59

$$RPI = \frac{TCH}{\tan(e) + E} \quad \text{for up sloping runway}$$

[d] unknown

846.09

$$RPI = \frac{TCH}{\tan(e) - E} \quad \text{for down sloping runway}$$

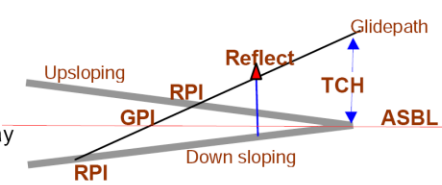


Figure A5-2: Precision Approach RADAR (PAR) (Scanning RADAR) Worksheet

1.3 Precision RADAR TCH/GPI/RPI Worksheet

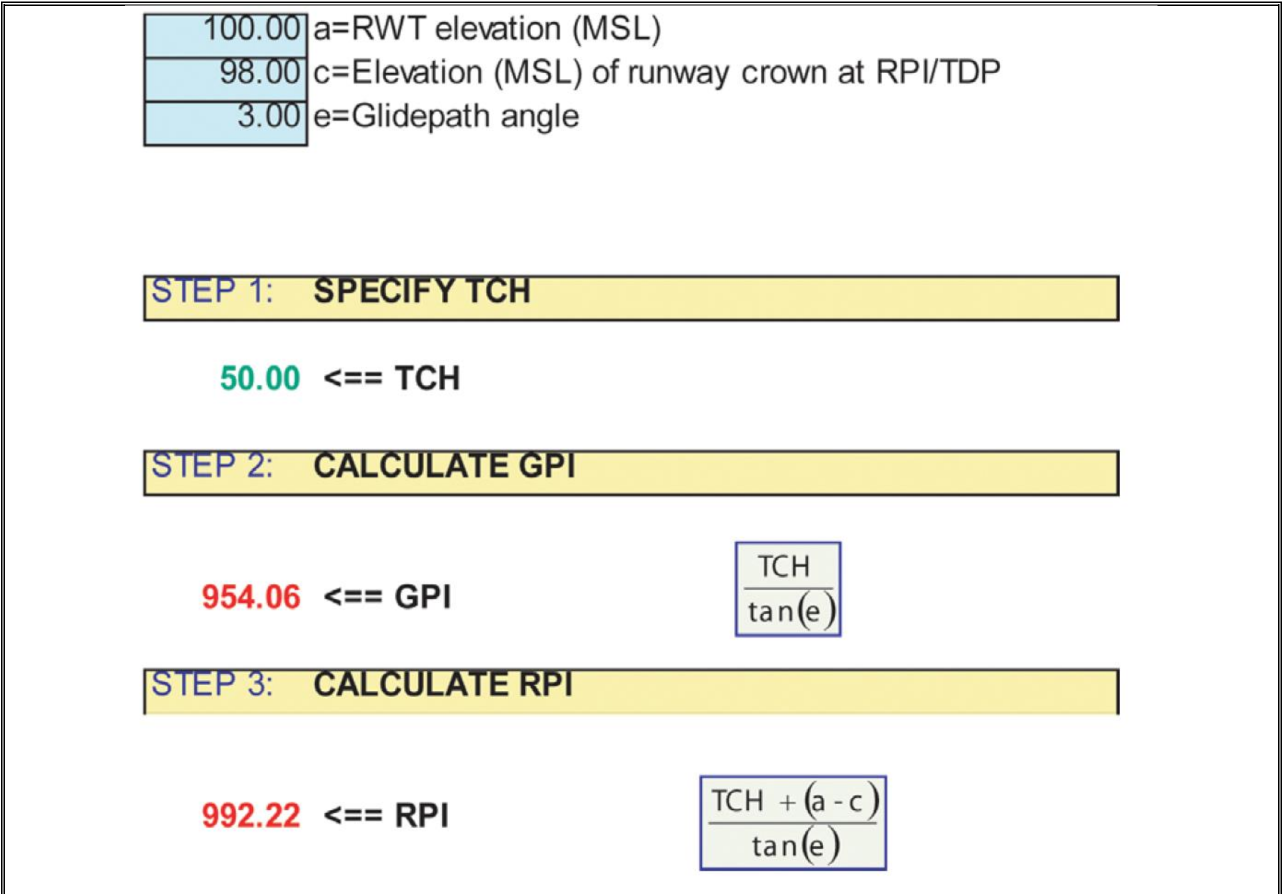


Figure A5-3: Precision RADAR Worksheet

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ALPHABETICAL INDEX

Paragraph

CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

VOLUME 4

DEPARTURE PROCEDURE CONSTRUCTION ~ RESERVED ~

TRANSPORT CANADA
NATIONAL DEFENSE

5 January 2017

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CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

VOLUME 5

HELICOPTER INSTRUMENT PROCEDURE CONSTRUCTION

TRANSPORT CANADA
NATIONAL DEFENSE

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CHAPTER 1. HELICOPTER PROCEDURES

SECTION 1. ADMINISTRATION

100. General

This chapter contains criteria for application to "helicopter only" procedures. These criteria are based on the premise that helicopters are approach Category A aircraft with special maneuvering characteristics. The intent, therefore, is to provide a relief from those portions of other chapters that are more restrictive than the criteria specified herein. However, any criteria contained elsewhere in other chapters of this document may be applied to helicopter only procedures when an operational advantage may be gained.

a. Identification of Inapplicable Criteria. Criteria contained elsewhere in TP308 applies to helicopter procedures, except as detailed in this chapter. Circling approach and high altitude penetration criteria do not apply to helicopter procedures.

b. Use of Existing Facilities. Helicopter-only procedures based on existing facilities may be developed using criteria contained in this chapter.

101. Terminology And Abbreviations

The following terms are peculiar to helicopter procedures and are defined as follows:

HAL. Height above landing area elevation.

Height Above the Surface (HAS). The height of the MDA above the highest terrain/surface within a 5,200-foot radius of the MAP in Point in Space procedures.

Supplementary note: The highest terrain/surface used to calculate HAS includes vegetation.

Landing Area. As used in helicopter operations, refers to the portion of the heliport or airport runway used, or intended to be used for the landing and take-off of helicopters.

Landing Area Boundary (LAB). The beginning of the landing area of the heliport or runway.

Point in Space Approach (PINSA). An instrument approach procedure to a point in space, identified as a Missed Approach Point, which is not associated with a specific landing area within 2,600 feet of the MAP.

Touchdown Zone (TZ). As used in helicopter procedures, is identical to the landing area.

Touchdown Zone Elevation (TDZE). As used in helicopter procedures, is the highest elevation in the landing area.

102. RESERVED

103. Type Of Procedure

HELICOPTER ONLY PROCEDURES are designed to meet low altitude straight-in requirements ONLY.

104. Facilities For Which Criteria Are Not Provided

This chapter does not include criteria for procedures predicated on VHF/UHF DF, area navigation (RNAV), airborne radar approach (ARA) or microwave landing system (MLS). Procedures utilizing VHF/UHF DF may be developed in accordance with the appropriate chapters of this document. Criteria for RNAV, ARA, and MLS with high glide path angle or selectable glide path angle capability will be developed at a later date.

105. Procedure Identification

Identify helicopter-only procedures using the term “COPTER,” the type of facility or system providing final approach course guidance, and:

- **a. For approaches to runways.** The abbreviation RWY, and the runway number; e.g., COPTER ILS or LOC RWY 17; COPTER RNAV (GPS) RWY 31.
- **b. For approaches to heliports and a point-in-space.** The magnetic final approach course value and degree symbol; e.g., COPTER ILS or LOC 014°; COPTER TACAN O97°, COPTER RNAV (GPS) 010°.
- **c. For approaches based on an ARC final.** The word ARC will be used, and will be followed by a sequential number; e.g., COPTER VOR/DME ARC 1.
- **d. For separate procedures at the same location.** Use the same type of facility and same final approach course, add an alpha suffix starting in reverse alphabetical order; COPTER ILS or LOC Z RWY 28L (first procedure), COPTER ILS or LOC Y RWY 28L (second procedure), COPTER ILS or LOC X RWY 28L (third procedure), etc.

SECTION 2. APPLICATION

106. General Criteria

These criteria are based on the unique manoeuvring capability of the helicopter at airspeeds not exceeding 90 knots.

107. Point In Space Approach

Where the centre of the landing area is not within 2,600’ of the MAP, an approach procedure to a point in space may be developed using any of the facilities for which criteria are provided in this chapter. In such procedures the point in space and the missed approach point are identical and upon arrival at this point, helicopters must proceed under visual flight rules (or special VFR in control zone as applicable) to a landing area or conduct the specified missed approach procedure. The published procedure shall be noted to this effect and also should identify available landing areas in the vicinity by noting the course and distance from the MAP to each selected landing area. Point in space approach procedures will not contain alternate minima.

108. Approach Categories

When helicopters use instrument flight procedures designed for fixed wing aircraft, approach Category “A” approach minima shall apply.

109. Procedure Construction

Volume 1, Para 214, applies except for the reference to circling approach.

110. Descent Gradient

The descent gradient criteria specified in other chapters of this document do not apply. The **OPTIMUM** descent gradient in all segments of helicopter approach procedures is 400 feet per nautical mile. Where a higher descent gradient is necessary, the recommended **MAXIMUM** is 600 feet per nautical mile. However, where an operational requirement exists a gradient of as much as 800 feet per nautical mile may be authorized provided the gradient used is depicted on approach charts. See special procedure turn criteria in Para 112.

111. Initial Approach Segments Based On Straight Courses And Arcs With Positive Course Guidance

Volume 1, Para 232, is changed as follows:

a. Alignment.

(1) Courses. The two-mile lead radial specified in Para 232.a.(1) is reduced to 1 NM (see Figure 2–3).

(2) Arcs. The MINIMUM arc radius specified in Para 232.a.(2) is reduced to 4 NM. The 2-mile lead radial may be reduced to 1 NM (see Figure 2–10).

112. Initial Approach Based On Procedure Turn

Volume 1, Para 234, applies except for all of subparagraph d. and the number 300 in subparagraph e.(1), which is changed to 600. Since helicopters operate at approach Category A speeds, the 5 NM procedure turn will normally be used (see Figure 1-105). However, the larger 10 and 15 NM areas may be used if considered necessary.

Descent Gradient. Because the actual length of the track will vary with environmental conditions and pilot technique it is not practical to specify a descent gradient solely in feet per mile for the procedure turn. Instead the descent gradient is controlled by requiring the procedure turn completion altitude to be as close as possible to the final approach fix altitude. The difference between the procedure turn completion altitude and the altitude over the final approach fix shall not be greater than those shown in Table 1–23.

113. Intermediate Approach Segment Based On Straight Courses

Volume 1, Para 242, is changed as follows:

a. Alignment. The provisions of Volume 1, Para 242.a, apply with the exception that the intermediate course shall not differ from the final approach course by more than 60 degrees.

b. Area.

(1) Length. The OPTIMUM length of the intermediate approach segment is 2 NM. The **MINIMUM** length is 1 mile and the recommended **MAXIMUM** is 5 NM. A distance greater than 5 NM should not be used unless an operational requirement justifies the greater distance. When the angle at which the initial approach course joins the intermediate course exceeds 30 degrees (see Figure 2–3), the **MINIMUM** length of the intermediate course is as shown in Table 1–24.

114. Intermediate Approach Segment Based On An Arc

Volume 1, Para 243, is changed as follows: Arcs with a radius of less than 4 NM or more than 30 NM from the navigation facility shall not be used.

a. Area.

(1) Length. The OPTIMUM length of the intermediate approach segment is 2 NM. The **MINIMUM** length is 1 NM and the recommended **MAXIMUM** is 5 NM. A distance greater than 5 NM should not be used unless an operational requirement justifies the greater distance. When the angle at which the initial approach course joins the intermediate course exceeds 30 degrees (see Figure 2–3), the **MINIMUM** length of the intermediate course is as shown in Table 1–24.

115. Intermediate Segment Within A Procedure Turn Segment

Volume 1, Para 244, is changed as follows: The normal procedure turn distance is 5 NM from the fix or from the facility. This produces an intermediate segment 5 NM long. The portion of the intermediate segment considered for obstacle clearance will always have the same length as the procedure turn distance. A distance greater than 5 NM should not be used unless an operational requirement justifies the greater distance (see Figure 2–13, Volume 1, Para 244).

116. Final Approach

Volume 1, Para 250, applies except that the word runway is understood to include landing area and the reference to circling approach does not apply. The final approach course in precision approach procedures shall be aligned as indicated in Paras 152 and 159. For non-precision procedures final approach course alignment shall be as follows:

- **a. Approaches to a Landing Area**. The final approach course should be aligned so as to pass through the landing area. Where an operational advantage can be achieved, a final approach course which does not pass through the landing area may be established, provided such a course lies within 2,600 feet of the centre of the landing area at the MAP.
- **b. Point in Space Approaches**. The final approach course should be aligned to provide for the most effective operational use of the procedure consistent with safety.

117. Missed Approach Point (MAP)

Volume 1, Para 272, is changed to state that the specified distance may not be more than the distance from the final approach fix to a point not more than 2,600 feet from the centre of the landing area. The MAP may be located more than 2,600 feet from the landing area, provided the MINIMUM visibility agrees with the increased distance; e.g., MAP 3,800 feet from the landing area, basic visibility is ¾ mile (see Figure 1-108). For point in space approaches the MAP is on the final approach course at the end of the final approach area.

118. Straight Missed Approach Area

Volume 1, Para 273, applies with the exception that the length of the primary and secondary missed approach area is reduced from 15 NM to 7.5 NM and will have the width of the appropriate airway at termination.

119. Straight Missed Approach Obstacle Clearance

Volume 1, Para 274, applies except that “TDZ or airport elevation” is changed to “landing area elevation”; the slope of the missed approach surface is changed from 40:1 to 20:1 and the secondary area slope is changed from 12:1 to 4:1.

120. Turning Missed Approach Area

The provisions of Volume 1, Para 275, apply with the exception that when applying missed approach criteria shown in Figures 2–19 through 2–24, and Table 2–5, change all flight path lengths to 7.5 NM, missed approach surface slope to 20:1, secondary slopes to 4:1, obstacle clearance radius (R_1) to 1.3 NM and flight path radius (R_1) to 4,000 feet (66 NM). The area width will expand uniformly to the appropriate airway width.

121. Turning Missed Approach Obstacle Clearance

All missed approach areas described in Volume 1, Para 276, and depicted in Figures 2–25 and 2–26 will be adjusted for helicopter operation using the values shown in Volume 1, Para 120. The area width will expand uniformly to the appropriate airway width.

122. Combination Straight And Turning Missed Approach

Volume 1, Para 277, applies except that the values shown in Volume 5, Para 120, shall be used and point B is relocated to a position abeam the MAP. The area width will expand uniformly to the appropriate airway width (see Figure 1-106).

123. Holding Alignment

The provisions of Volume 1, Para 1820.a, apply with the exception that when the final approach fix is a facility, the inbound holding course shall not differ from the final approach course by more than 90 degrees.

124. Holding Area

Volume 1, Para 1820.b, applies except that the MINIMUM size pattern is No. 1.

SECTION 3. TAKE-OFF AND LANDING MINIMA

125. Application

The minima specified in this section apply to Helicopter Only procedures.

126. Altitudes

Volume 1,Chapter 3 is used as follows for helicopter criteria:

a. In Volume 1, Para 321, reference to 40:1 is changed to 20:1.

b. Volume 1, Paras 322 and 351, do not apply.

c. Volume 1, Paras 324, 938, and 1028, apply except that a DH of 100 feet may be approved without approach lights. Table 3-1, referenced in Volume 1, Para 350, does not apply.

d. Table 1–29 in Volume 5, Para 167, governs the establishment of the DH.

127. Visibility

Volume 1, Chapter 3 is used changed as follows for helicopter criteria:

a. Volume 1, Paras 330, 331, 332, and 343, do not apply.

b. Straight-in Minima.

(1) **Non-precision Approaches** (landing area within 2,600 feet of MAP). The minimum visibility may not be less than the visibility associated with the HAL as specified in Table 1–25.

(2) **Precision Approaches.** The minimum visibility authorized ¼ mile (1400 RVR).

c. Point in Space Approaches. The minimum visibility shall be 1 SM. Table 1–25 does not apply.

128. Visibility Credit

Where visibility credit for lighting facilities is allowed for fixed wing operations, the same type credit should be considered for helicopter operations. The approving authority will grant credit on an individual case basis until such time as a standard for helicopter approach light systems is established. The minimum visibility authorized prior to applying credit for lights may be reduced ¼ mile for both precision and non-precision procedures where approved approach light systems are operative. In addition, in precision approach procedures where RVR is approved and minima have been reduced to ¼ mile, 1,400 RVR may also be authorized.

129. Take-Off Minima

Helicopter take-off minima will be in accordance with the appropriate civil or military regulations as applicable.

SECTION 4. ON-HELIPORT VOR, NO FAF

130. General

Volume 1, Para 400, does not apply. These criteria apply to procedures based on a VOR facility located within 2,600 feet of the centre of the landing area in which no final approach fix is established. These procedures must incorporate a procedure turn.

131. Initial And Intermediate Segments

These criteria are contained in Section 2 of this chapter.

132. Final Approach Segment

Volume 1, Para 413, does not apply except as noted below. The final approach begins where the procedure turn intersects the final approach course inbound.

- **a. Alignment**. Volume 1, Para 116.a, applies.
- **b. Area**. The primary area is longitudinally centred on the final approach course. The minimum length is 5 NM. This may be extended if an operational requirement exists. The primary area is 2 NM wide at the facility, and expands uniformly to 4 NM wide at 5 NM from the facility. A secondary area is on each side of the primary area. It is zero NM wide at the facility and expands uniformly to .67 NM on each side of the primary area at 5 NM from the facility (see Figure 1–107).
- **c. Obstacle Clearance**. Volume 1, Para 413.c.(1), applies.
- **d. Procedure Turn Altitude**. The procedure turn completion altitude shall be in accordance with Table 1–23.
- **e. Use of Step-down Fix**. Volume 1, Para 413.e, applies except that 4 NM is changed to 2.5 NM.
- **f. Minimum Descent Altitude**. Criteria for determining MDA are contained in Section 3 of this chapter and Chapter 3.

SECTION 5. TACAN, VOR/DME, AND VOR WITH FAF

133. Final Approach Segment

Volume 1, Para 513, does not apply except as noted below.

a. Alignment. Volume 1, Paras 116.a and b, apply.

b. Area. Volume 1, Para 513.b, applies except that portion which refers to the minimum length of the final approach segment. The minimum length of the final approach segment is shown in Table 1–26.

c. Obstacle Clearance. Volume 1, Para 513.c.(1), applies.

134. Reserved

135. Missed Approach Point

The identification of the MAP in Volume 1, Para 514, is changed as follows: The missed approach point is a point on the final approach course which is not farther that 2,600 feet from the centre of the landing area (see Figure 1–108). For point in space approaches the MAP is on the final approach course at the end of the final approach area.

136. Arc Final Approach Segment Radius

Volume 1, Para 523.b, does not apply. The final approach arc shall be a continuation of the intermediate arc. It shall be specified in NM and tenths thereof. The minimum arc radius on final approach is 4 NM.

137. Arc Final Approach Segment Alignment

Volume 1, Para 523.b.(1), does not apply. The final approach arc should be aligned so as to pass through the landing area. Where an operational advantage can be achieved, a final approach course, which does not pass through the landing area may be established provided the arc lies 2,600 feet of the landing area at the MAP.

138. Reserved

SECTION 6. ON-HELIPORT NDB, NO FAF

139. General

Volume 1, Para 600, does not apply. These criteria apply to procedures based on an NDB facility located within 2,600 feet of the centre of the landing area in which no final approach fix is established. These procedures must incorporate a procedure turn.

140. Final Approach Segment

Volume 1, Para 613, does not apply except as noted below. The final approach begins where the procedure turn intersects the final approach course inbound.

a. Alignment. Volume 1, Para 116.a, applies.

b. Area. The primary area is longitudinally centred on the final approach course. The minimum length is 5 NM. This may be extended if an operational requirement exists. The primary area is 2.5 NM wide at the facility, and expands uniformly to 4.25 NM wide at 5 NM from the facility. A secondary area is on each side of the primary area. It is zero NM wide at the facility, and expands uniformly to .67 NM wide on each side of the primary area at 5 NM from the facility. Figure 1–109 illustrates the primary and secondary areas.

c. Obstacle Clearance. Volume 1, Para 613.c.(1), applies.

d. Procedure Turn Altitude (Descent Gradient). The procedure turn completion altitude shall be in accordance with Table 1–23.

e. Use of Step-down Fix. Volume 1, Para 613.e, applies except that 4 NM is changed to 2.5 NM.

f. Minimum Descent Altitude. Criteria for determining the MDA are contained in Section 3 of this chapter and Chapter 3.

SECTION 7. NDB PROCEDURES WITH FAF

141. General

These criteria apply to procedures based on an NDB facility that incorporates a final approach fix.

142. Final Approach Segment

Volume 1, Para 713, does not apply except as noted below:

- **a. Alignment**. Volume 1, Paras 116.a and b, apply.
- **b. Area**. Volume 1, Para 713.b, applies except that portion which refers to the minimum length of the final approach segment. The minimum length is specified in Table 1–26.
- **c. Obstacle Clearance**. Volume 1, Para 713.c.(1), applies.

143. Missed Approach Point

The identification of the MAP in Volume 1, Para 714, is changed as follows: The missed approach point is a point on the final approach course which is not farther than 2,600 feet from the centre of the landing area (see Figure 1–108). For point in space approaches, the MAP is on the final approach course at the end of the final approach area.

SECTION 8. RESERVED

144—149. Reserved

SECTION 9. ILS PROCEDURES

150. General

Chapter 9 is changed as noted in this section. These criteria apply to the present design of instrument landing systems (on airport) only.

151. Intermediate Approach Segment

Volume 1, Para 922, applies with the exception that Table 1–27 specifies the minimum length of the intermediate segment based on the angle of intersection of the initial approach course with the localizer course.

152. Final Approach Segment

Volume 1, Para 930, applies except that glide slope intersection need not occur prior to the FAF normally used for fixed operations.

a. The **optimum length** of the final approach course is 3.0 NM. The minimum length is 2.0 NM. A distance in excess of 4.0 NM should not be used unless a special operational requirement exists.

b. **Final Approach Termination**. The final approach shall terminate at a landing point (runway) or at a hover point between the Decision Height and the GPI. Where required, visual hover/taxi routes will be provided to the terminal area.

153. Missed Approach Area

Normally existing missed approach criteria described in Volume 3, Para 3.9, will be utilized for helicopter operations. However, if an operational advantage can be gained, the areas described in Volume 1, Para 168 through 171, may be substituted.

154. Reserved

155. Localizer

Chapter 9 is changed as noted in this paragraph.

a. **Alignment**. Volume 1, Para 902, applies except that alignment shall be as specified in Para 116.a and b.

b. **Area**. Volume 1, Para 903, applies except that portion which refers to the minimum length of the final approach segment. The minimum length of the final approach segment is shown in Table 1–26.

c. **Missed Approach Point**. The identification of the MAP in Volume 1, Para 907, is changed as follows: The missed approach point is a point on the final approach course which is not farther than 2,600 feet from the landing area (see Figure 1–108). For point-in-space approaches, the MAP is on the final approach course at the end of the final

SECTION 10. PRECISION APPROACH RADAR (PAR)

156. Intermediate Approach Segment

Volume 1, Para 1014, applies with the exception that Volume 5, Table 1–27, specifies the MINIMUM length of the intermediate segment based on the angle of intersection of the initial approach course with the intermediate course.

157. Reserved

158. Final Approach Segment

The provisions of Volume 1, Paras 1020.b.(1) and (2), do not apply. The minimum distance from the glide slope intercept point to the GPI is 2 NM.

159. Final Approach Alignment

Volume 1, Para 1020.a, applies with the exception that a final approach course shall be aligned to a landing area. Where required, visual hover/taxi routes shall be established leading to terminal areas.

160. Final Approach Area

a. Length. The final approach area is 25,000 feet long, measured outward along the final approach course from the GPI. Where operationally required for other procedural considerations or for existing obstacles, the length may be increased or decreased symmetrically, except when glide slope usability would be impaired or restricted (see Figure 1–110).

b. Width. The final approach area is centred on the final approach course. The area has a total width of 500 feet at the GPI and expands uniformly to a total width of 8,000 feet at a point 25,000 feet outward from the GPI. The widths are further uniformly expanded or reduced where a different length is required as in Volume 1, Para 160.a above (see Figure 1-110). The width either side of the centreline at a given distance “D” from the point of beginning can be found by using the formula:

$$250 + 0.15D = \frac{1}{2} \text{ width.}$$

161. Reserved

162. Final Approach Obstacle Clearance Surface

Volume 1, Para 1021, does not apply. The final approach obstacle clearance surface is divided into two sections.

a. Section 1. This section originates at the GPI and extends for a distance of 775 feet in the direction of the FAF. It is a level plane, the elevation of which is equal to the elevation of the GPI.

b. Section 2. This section originates 775 feet outward from the GPI. It connects with Section 1 at the elevation of the GPI. The gradient of this section varies with the glide path angle used.

(1) To identify the glide slope angle and associated final approach surface gradient to clear obstacles in Section 2:

(a) Determine the distance “D” from the GPI to the controlling obstacle and the height of the controlling obstacle above the GPI.

(b) Enter these values in the formula:

$$\text{TAN ANGLE} = \frac{\text{Obstacle Height}}{\text{D - 775}}$$

(c) Using the TAN table (see Volume 1, Annex D) convert the tangent angle to a degree angle. This is the angle of the Section 2 approach surface gradient that is required to clear the obstacle, measured from the beginning of Section 2 at the height of the GPI.

The minimum glide slope angle required is found in Table 1–28.

163. Transitional Surfaces

Volume 1, Para 1022, does not apply. Transitional surfaces for PAR are inclined planes with a slope of 4:1, which extend outward and upward from the edges of the final approach surfaces. They start at the height of the applicable final approach surface, and are perpendicular to the final approach course. They extend laterally 600 feet at the GPI and expand uniformly to a width of 1,500 feet at 25,000 feet from the GPI.

Note: The distance to the outer edge of the 4:1 transitional surface from the final approach course centreline is: ½W = 0.186D + 850. To determine the width of the transitional area, subtract the final approach primary area width found in Para 160.b.

164. Obstacle Clearance

Volume 1, Para 1024, does not apply. No obstacle should penetrate the applicable final approach surface specified in Para 162 or the transitional surfaces specified in Para 163. Obstacle clearance requirements greater than 500 feet need not be applied unless required in the interest of safety due to precipitous terrain or radar system peculiarities (see Figure 1–111).

Note: Provided the surface is free of obstacles, the terrain within Section 1 and 2 may rise at a gradient of 75:1 without adverse effect on minima.. The 75:1 gradient begins at the GPI and extends until it meets the Section 2 obstacle clearance gradient (see Figure 1-111a). This is intended to allow for terrain undulations only, Any vegetation or non-frangible man-made obstructions within this area must be treated in accordance with Para 162.

165. Glide Slope Landing Area

Required obstacle clearance is specified in Para 164. In addition, consideration requirements shall be given to the following in the selection of the glide slope angle:

a. If angles less than 3 degrees are established, the obstacle clearance requirements shall be arrived at in accordance with Volume 1, Paras 1024 and 1025.

b. Angles greater than 6 degrees shall not be established without authorization of the approving authority. The angle selected should be no greater than that required to provide obstacle clearance.

c. Angles selected should be increased to the next higher tenth of a degree, e.g., 4.71 degrees becomes 4.8; 4.69 degrees becomes 4.7.

166. Relocation Of The Glide Slope

Volume 1, Para 1027, does not apply. The GPI shall normally be located at the arrival edge of the landing area. If obstacle clearance requirements cannot be satisfied, or if operational advantages will result, the GPI may be moved into the landing area provided sufficient landing area is available forward of the displaced or relocated GPI.

167. Adjustment Of DH

Volume 1, Para 1028, does not apply. An adjustment is required whenever the angle to be used exceeds 3.8 degrees (see Table 1–29). This adjustment is necessary to provide ample deceleration between the DH point and the landing area.

168. Missed Approach Obstacle Clearance

No obstacle may penetrate a 20:1 missed approach surface that overlies the missed approach areas illustrated in Figures 1–113, 1–114, and 1–115. The missed approach surface originates at the GPI. However, to gain relief from existing obstacles in the missed approach area the point at which the surface originates may be relocated as far backward from the GPI as a point on the final approach course that is directly below the MAP. In such cases the surface originates at a height below the DH as specified in Table 1–30 (see Figure 1–112).

When penetration of the 20:1 surface originating at the GPI occurs, an upward adjustment to the DH equal to the maximum penetration of the surface should be considered.

169. Straight Missed Approach Area

The straight missed approach (maximum of 15 degrees turn from final approach course) area starts at the MAP and extends to 7.5 NM.

a. Primary Area. This area is divided into three sections.

(1) Section 1A is a continuation of the final approach area. It starts at the MAP and ends at the GPI. It has the same width as the final approach area at the MAP.

(2) Section 1B is centred on the missed approach course. It begins at the GPI and extends to a point 1 mile from the MAP outward along the missed approach course. It has a beginning width the same as the final approach area at the MAP and expands uniformly to 4,000 feet at 1 mile from the MAP.

(3) Section 2 is centred on the continuation of the Section 16 course. It begins 1 mile from the MAP and ends 7.5 NM from the MAP. It has a beginning width of 4,000 feet expanding uniformly to a width equal to that of an initial approach area at 7.5 NM from the MAP.

b. Secondary Area. The secondary area begins at the MAP, where it has the same width as the final approach secondary area. In Section 1A the width remains constant from the MAP to the GPI, after which it increases uniformly to the appropriate airway width at 7.5 NM from the MAP (see Figure 1–113).

170. Turning Missed Approach Area

Where turns of more than 15 degrees are required in a missed approach procedure, they shall commence at an altitude that is at least 400 feet above the elevation of the landing area. Such turns are assumed to commence at the point where Section 2 begins. The turning flight track radius shall be 4,000 feet (0.66 NM).

a. Primary Area. The outer boundary of the Section 2 primary area shall be drawn with a 1.3 mile radius. The inner boundary shall commence at the beginning of Section 1B. The outer and inner boundary shall flare to the width of an initial approach area 7.5 NM from the MAP.

b. Secondary Area. Secondary areas for reduction of obstacle clearance are identified with Section 2. The secondary areas begin after completion of the turn. They are zero NM wide at the point of beginning and increase uniformly to the appropriate airway at the end of Section 2. Positive course guidance is required to reduce obstacle clearance in the secondary area (see Figure 1–114).

171. Combination Straight And Turning Missed Approach Area

If a straight climb to an altitude greater than 400 feet is necessary prior to commencing a missed approach turn, a combination straight and turning missed approach area must be constructed. The straight portion of this missed approach area is divided into Section 1 and 2A. The portion in which the turn is made is Section 2B.

a. Straight Portion. Sections 1 and 2A correspond respectively to Section 1 and 2 of normal straight missed approach area and are constructed as specified in Volume 1, Para 169, except that Section 2A has no secondary areas. Obstacle clearance is provided as specified in Volume 1, Para 119. The length of Section 2A is determined as shown in Figure 1–115, and relates to the need to climb to a specified altitude prior to commencing the turn. The line A^1–B^1 marks the end of Section 2A. Point C^1 is 5,300 feet from the end of Section 2A.

b. Turning Portion. Section 2B is constructed as specified in Volume 1, Para 169, except that it begins at the end of Section 2A instead of the end of Section 1. To determine the height which must be attained before commencing the missed approach turn, first identify the controlling obstacle on the side of Section 2A to which the turn is to be made. Then measure the distance from this obstacle to the nearest edge of the Section 2A area. Using this distance as illustrated in Figure 1–115, determine the height of the 20:1 slope at the edge of Section 2A. This height plus 250 feet (rounded off to the next higher 20-foot increment) is the height at which the turn should be started. Obstacle clearance requirements in Section 2B are the same as those specified in Volume 1, Para 121, except that Section 28 is expanded to start at Point C if no fix exists at the end of Section 2A or if no course guidance is provide in Section 2 (see Figure 1–115).

Note: The missed approach areas expand uniformly to the appropriate airway width.

SECTION 11. AIRPORT SURVEILLANCE RADAR (ASR)

172. Initial Approach Segment

Volume 1, Para 1041.a.(1), applies except that 90 degrees is changed to 120 degrees.

173. Intermediate Approach Segment

Volume 1, Para 1042.b, applies with the exception that the maximum angle of intercept is changed to 120 degrees and Table 1–24 is used to determine the required minimum length of the intermediate segment.

174. Final Approach Segment

Volume 1, Para 1044, applies except for subparagraphs a, c.(2) and d.

a. Alignment. Volume 1, Paras 116.a and b, apply.

175. Missed Approach Point

The identification of the MAP in Volume 1, Para 1048, is changed as follows. The missed approach point is a point on the final approach course that is not farther than 2,600 feet from the centre of the landing area (see Figure 1–108). For point in space approaches the MAP is on the final approach course at the end of the final approach area.

176—199. Reserved

Table 1-1 TO 1-22: Reserved.

Type Procedure Turn	Altitude Difference
15 NM PT from FAF	Within 6,000 ft of alt over FAF
10 NM PT from FAF	Within 4,000 ft of alt over FAF
5 NM PT from FAF	Within 2,000 ft of alt over FAF
15 NM PT, no FAF	Not Authorized
10 NM PT, no FAF	Within 4,000 ft of MDA on Final
5 NM PT, no FAF	Within 2,000 ft of MDA on Final

Table 1-23: Procedure Turn Completion Altitude Differential. Para 112.

Angle (Degrees)	Minimum Length (NM)
30	1.0
60	2.0
90	3.0
120	4.0

Note: This Table may be interpolated

Table 1-24: Minimum Intermediate Course Length (Not applicable to PAR or ILS). Para 113.

HAL	250 – 600 ft	601 – 800 ft	More than 800 ft
Visibility (SM) Minima	½ SM	¾ SM	1 SM

Table 1-25: Effect Of HAL On Visibility Minima. Para 127.b.

Magnitude of Turn Over the Facility	Minimum Length (NM)
30°	1.0
60°	2.0
90°	3.0

Note: This Table may be interpolated

Table 1-26: Minimum Length Of Final Approach Segment (NM). Para 142.b.

Angle (Degrees)	Minimum Length (NM)
30°	1.0
60°	2.0
90°	3.0
Note: This Table may be interpolated	

Table 1-27: Intermediate Segment Angle Of Intercept vs Segment Length. Para 151 & 156

Glide Slope Angle (Degrees)	Less Than 3°	3°	4°	5°	6°	7°	8°	12°
Section 2 obstacle clearance surface gradient (degrees)	*	1.65	2.51	3.37	4.23	5.09	5.95	9.39

Note: This Table may be interpolated
* See Para 165.a.

Table 1-28: Final Approach Glide Slope – Surface Slope Angles. Para 162.b.

GS Angle (Degrees)	Up to 3.80	3.81 to 5.70	Over 5.70
Minimum DH (Feet)	100	150	200

Table 1-29: Minimum DH – GS Angle Relationship. Para 167.

GS Angle (Degrees)	3	6	9
Dist. below DH point (Feet)	100	150	200

Note: This Table may be interpolated

Table 1-30: Beginning Point Of Missed Approach Surface. Para 168.

Figure 1-1 TO 1-104: Reserved

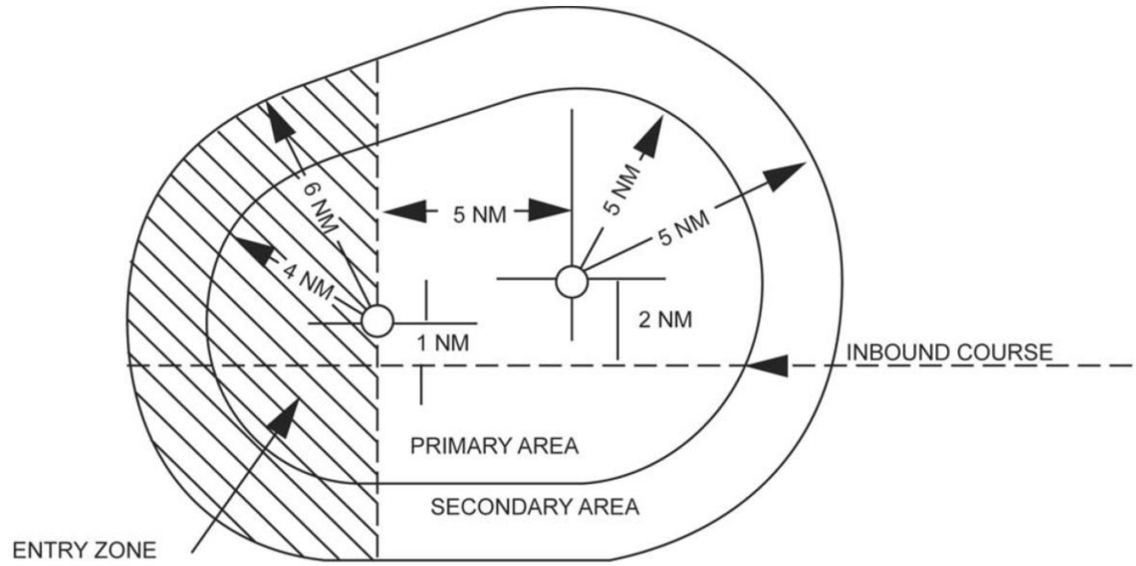
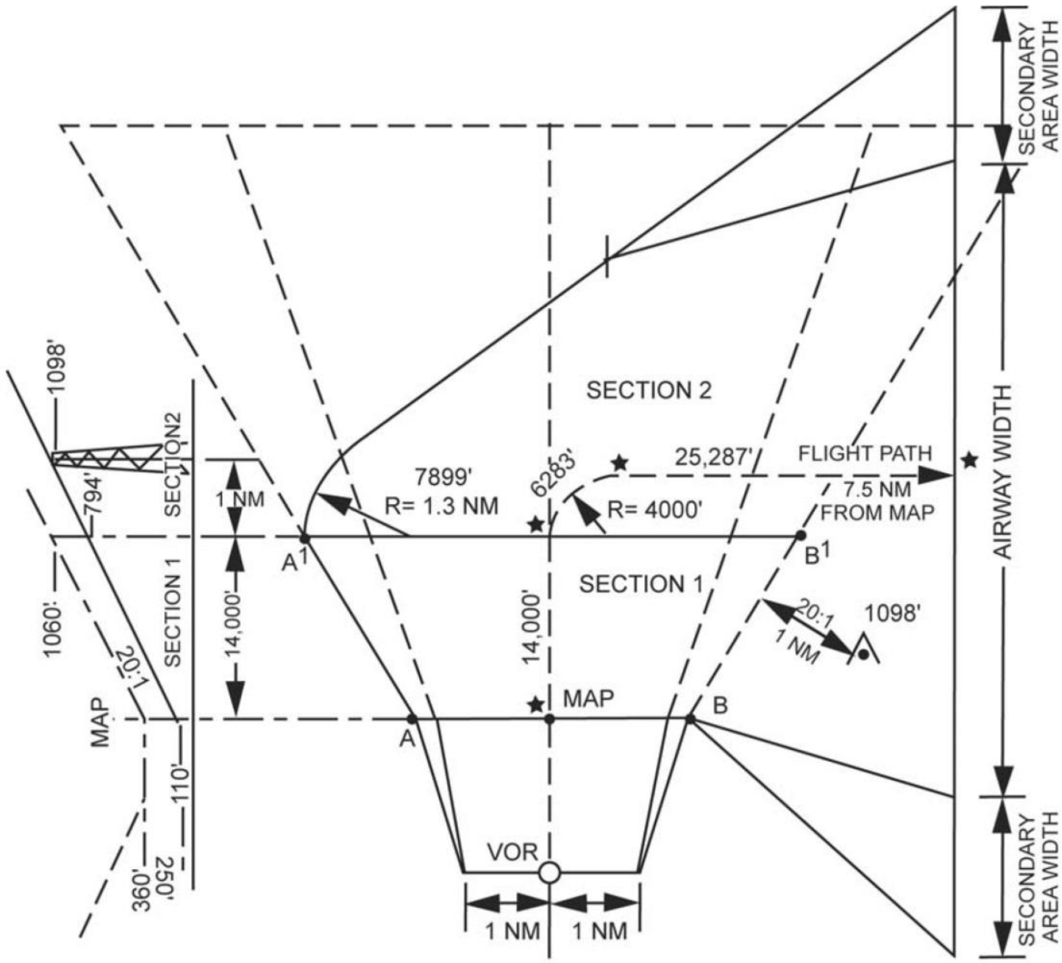


Figure 1-105: Helicopter Procedure Turn Area. Para 112.



EXAMPLE:

MDA is 360' MSL based on obstacles in the approach area. A 1098' MSL controlling obstacle is 1 NM (6076') from the near edge of Section 1.

A 20:1 surface that clears the obstacle has a height of 794' MSL at the near edge of Section 1.

$$6076' \div 20 = 304'$$
$$1098' - 304' = 794'$$

To determine minimum altitude at which the missed approach aircraft may start the turn add 250' obstacle clearance and round up the sum to the next higher 20' increment.

$$794' + 250' = 1044'$$
Rounded up = 1060'

To climb 700' from MDA 360' MSL to turning altitude (1060' MSL) at the 20:1 climb gradient requires 14,000'. This is the minimum length of Section 1.

Figure 1-106: Combination Missed Approach Area. Para 122.

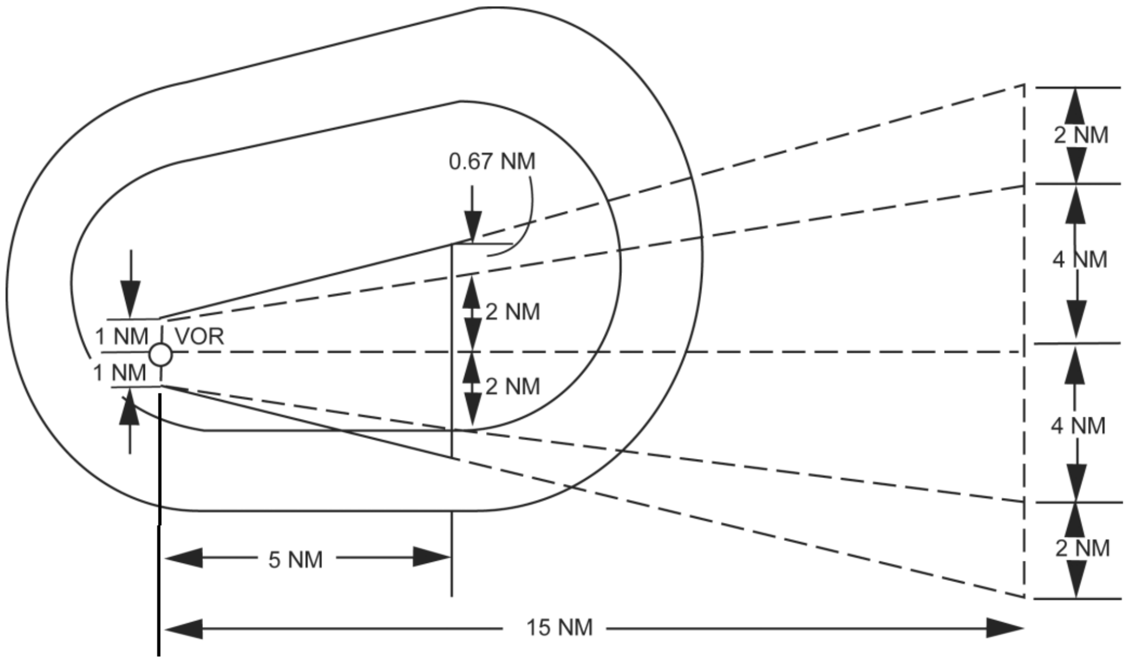


Figure 1-107: Final Approach Primary And Secondary Area. On Heliport VOR, No FAF. Para 132.b and Fig 1 110.

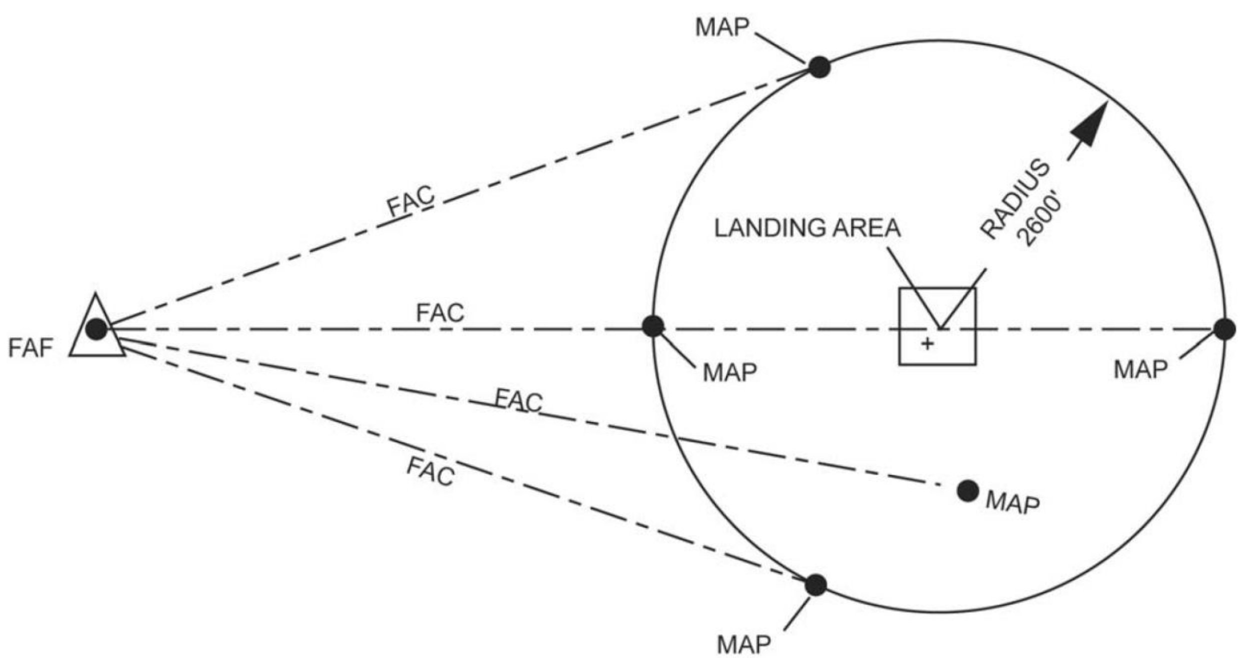


Figure 1-108: Missed Approach Points. Off-Heliport VOR with FAF. Para 135.

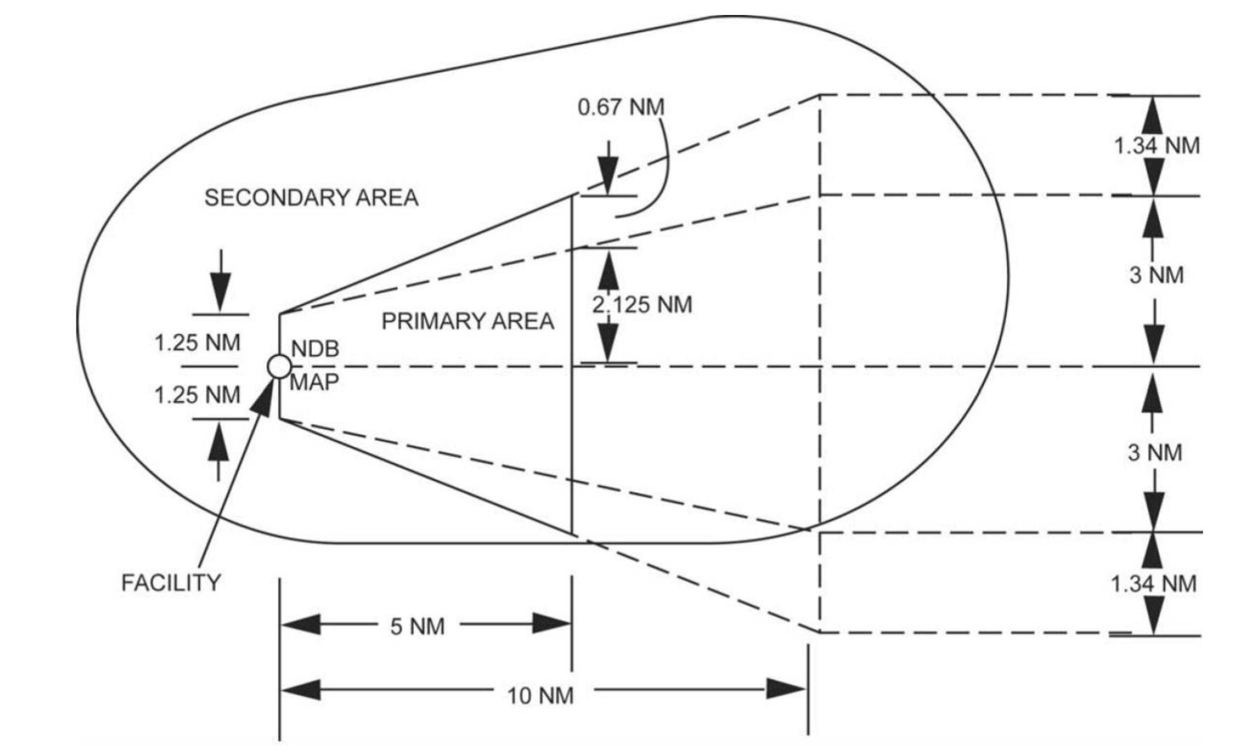


Figure 1-109: Final Approach Primary And Secondary Areas. On-Heliport NDB, no FAF. Para 140.

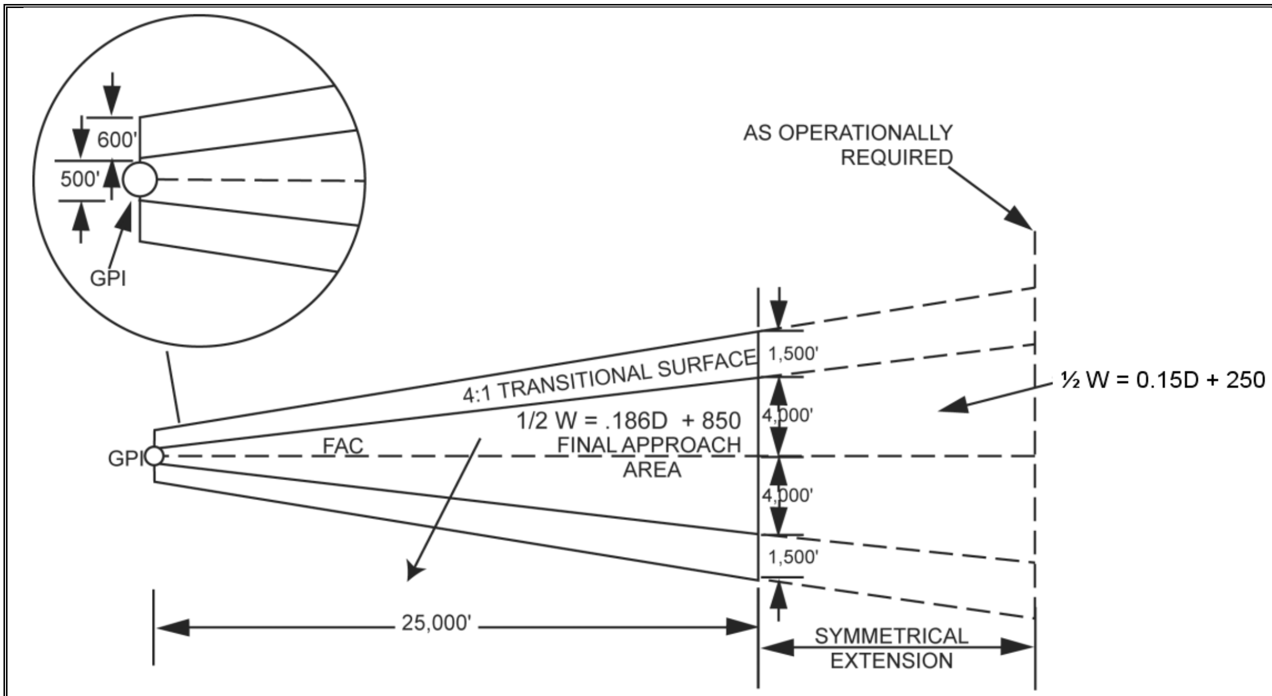


Figure 1-110: PAR Final Approach Area. Para 159 and 160.

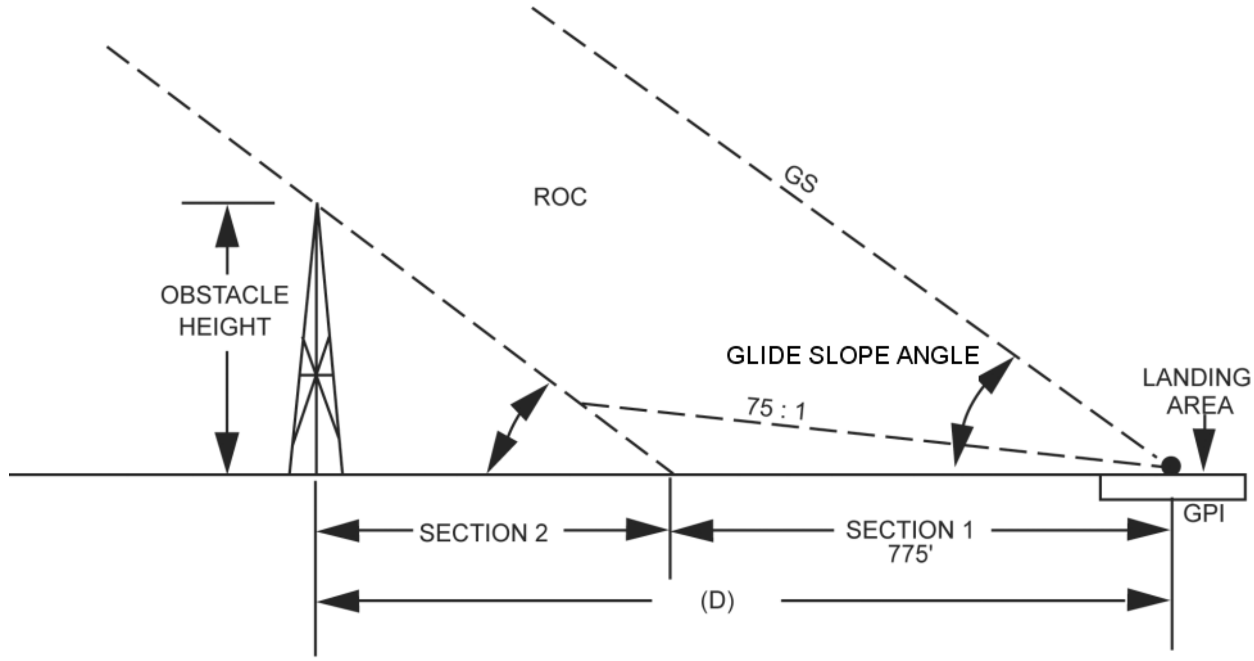


Figure 1-111: Final Approach Area Surface And Obstacle Clearance. Para 162 and 164.

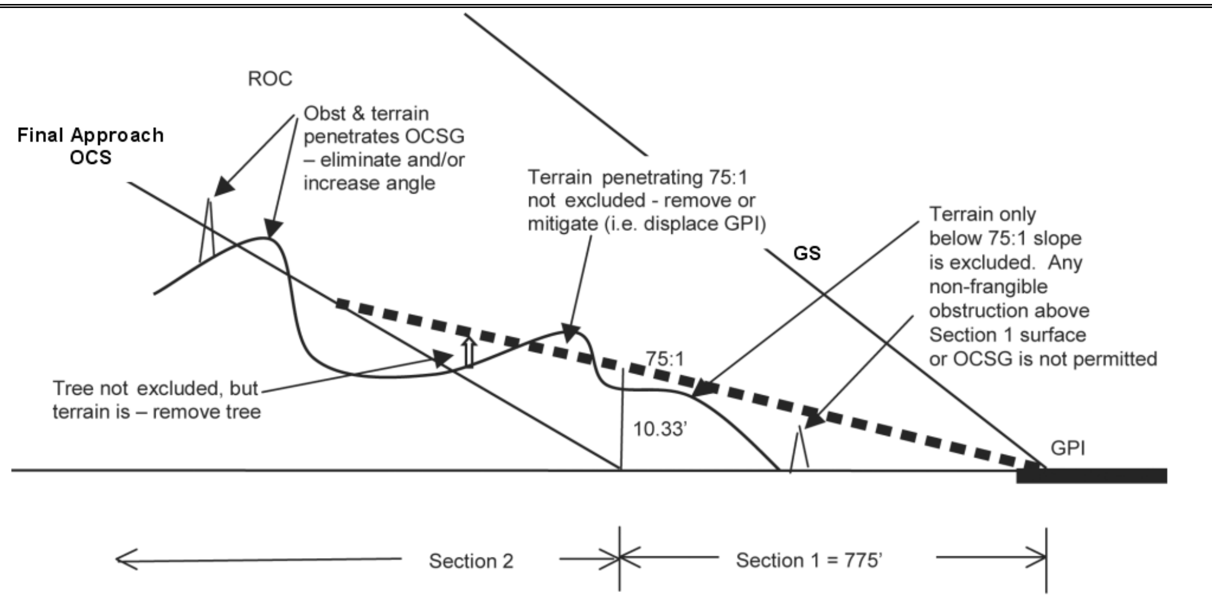


Figure 1-111A: Terrain Exclusion Area. Para 164 Note.

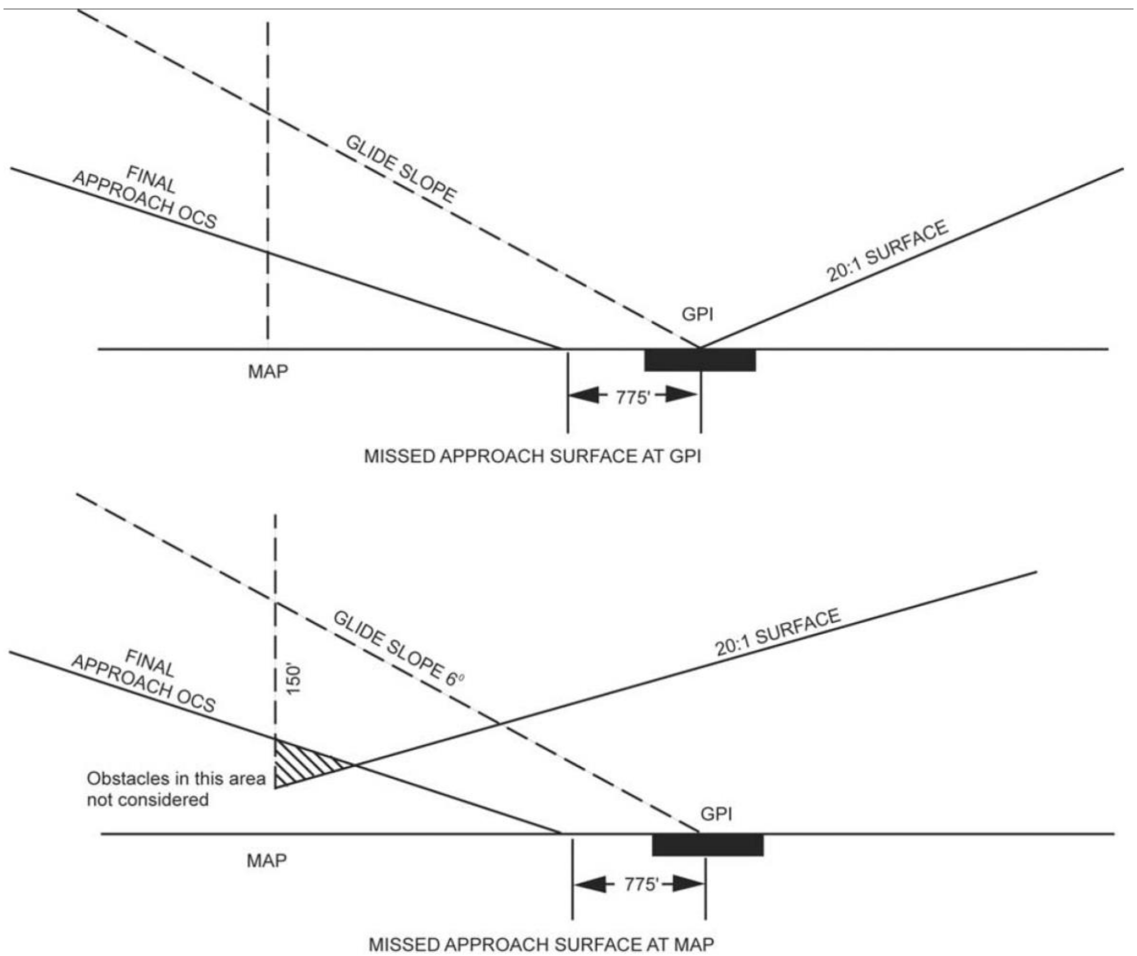


Figure 1-112: Missed Approach Surface Options. Para 168.

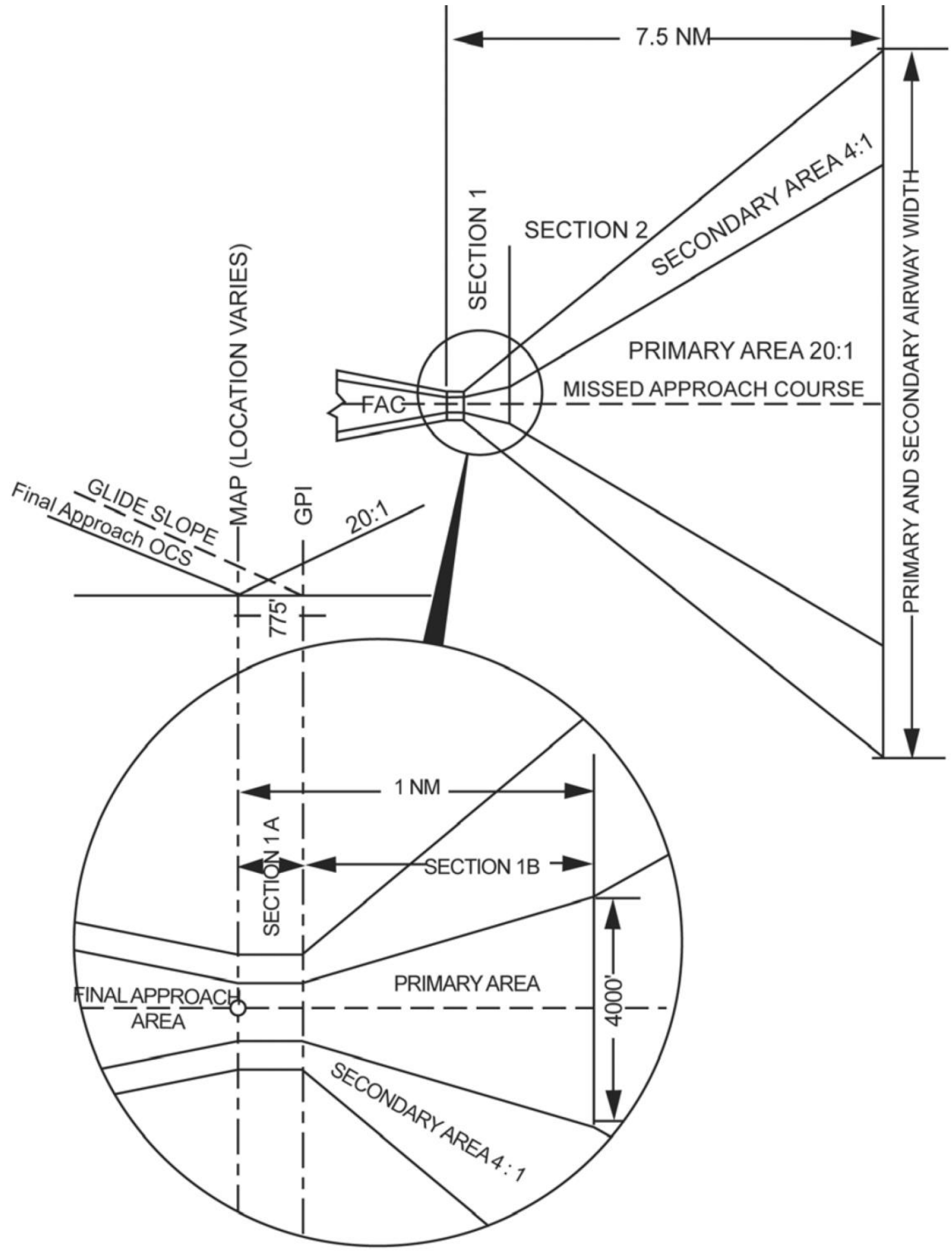


Figure 1-113: Straight Missed Approach. Para 169.

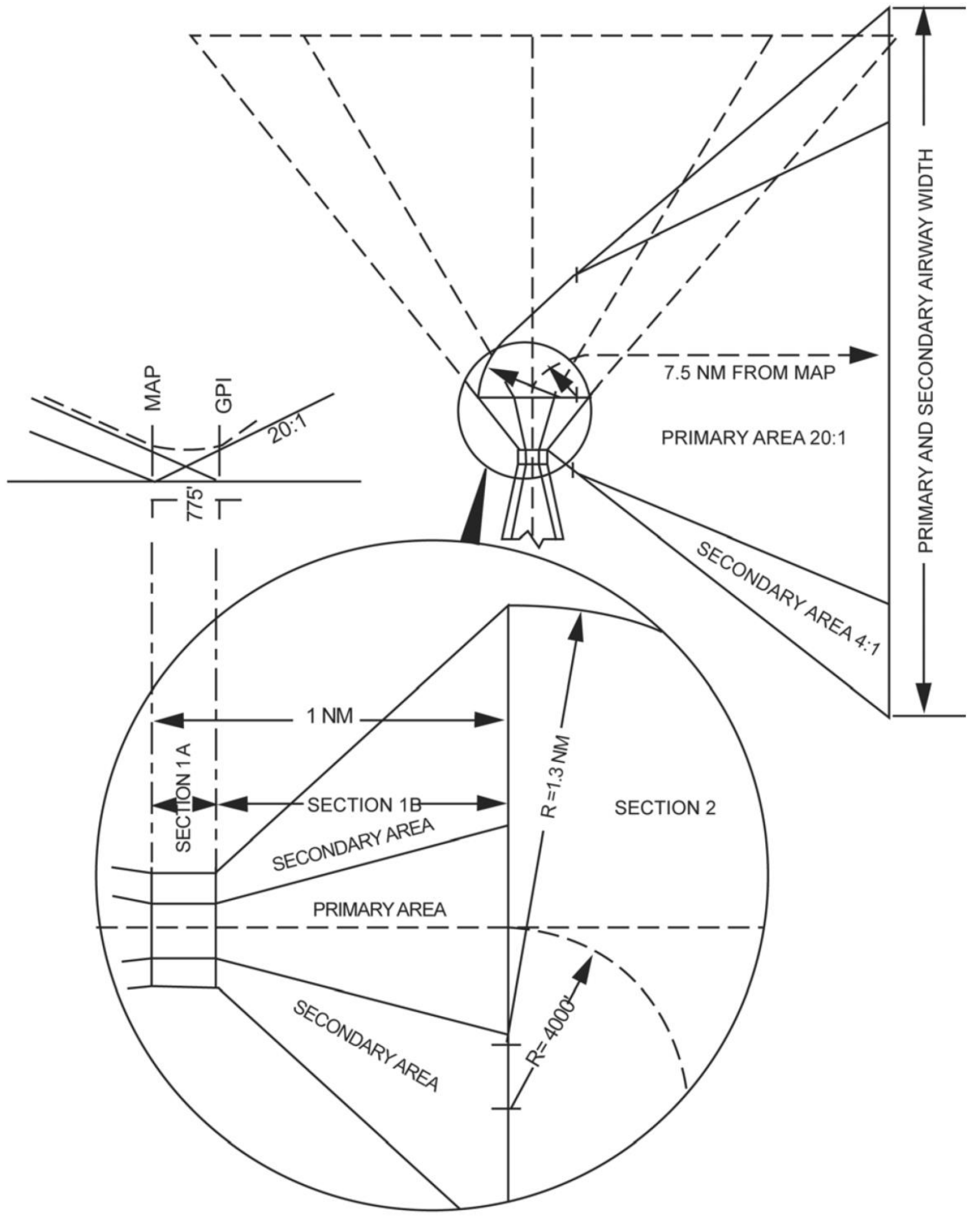
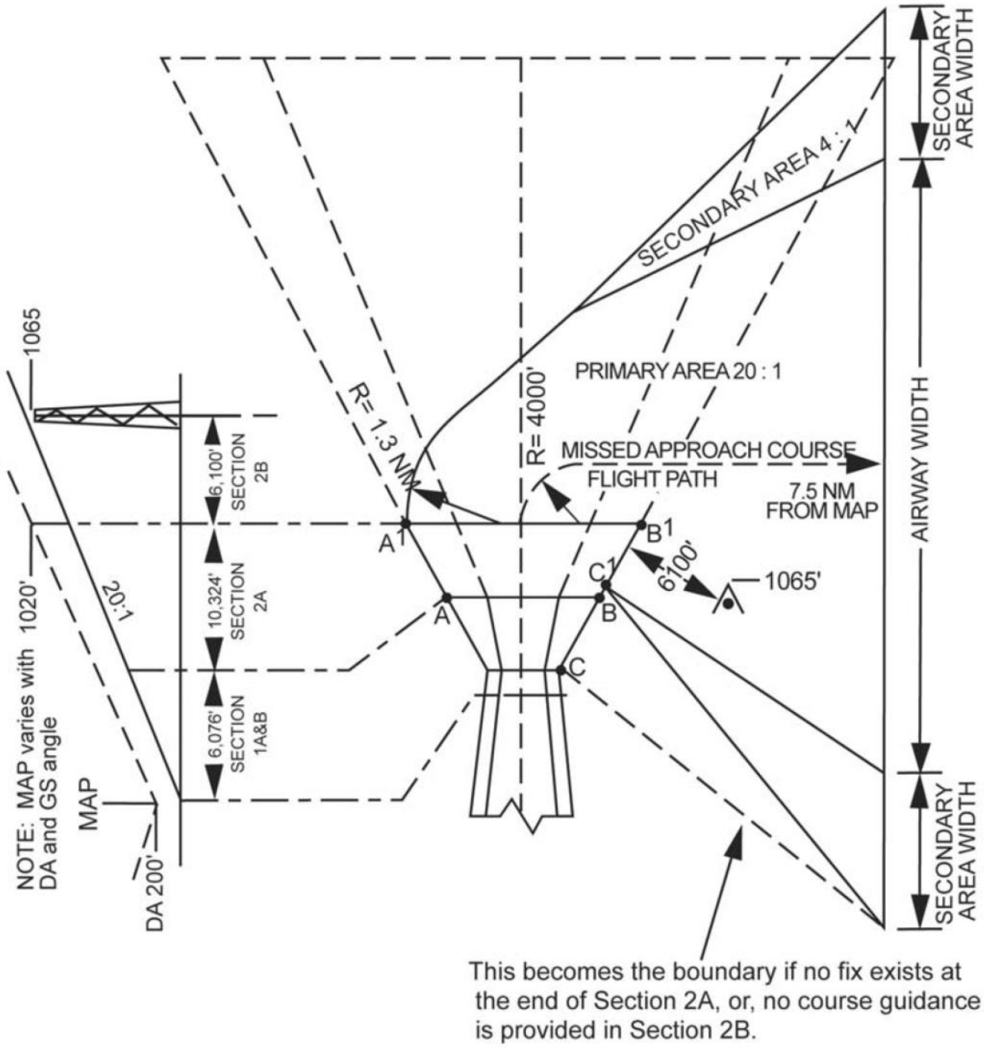


Figure 1-114: Turning Missed Approach Area. Para 170.



EXAMPLE:

DA is 200' MSL. A 1065' controlling obstacle is 6100' from the near edge of Section 2A

A 20:1 surface that clears the obstacle has a height of 760' MSL at the near edge of Section 2A.

6100' ÷ 20 = 305'
1065' - 305' = 760'

To determine minimum altitude at which the missed approach aircraft may start the turn add 250' obstacle clearance and round up the sum to the next higher 20' increment.

760' + 250' = 1010'
Rounded up = 1020'

To climb 820' from DH 200' to the turning altitude (1020' MSL) at the 20:1 climb gradient requires 16,400'. Section 1 is 6076' long; therefore, Section 2A is required to be 10,324' long.

Figure 1-115: Combination Straight And Turning Missed Approach. Para 171.

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CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

ANNEXES

TRANSPORT CANADA
NATIONAL DEFENSE

5 January 2017

Canada

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CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

ANNEX A

GLOSSARY

TRANSPORT CANADA
NATIONAL DEFENSE

5 January 2017

Canada

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ACRONYMS AND ABBREVIATIONS

AAF	Airway Facilities Service
AARN	Air Navigation Services and Airspace
ABM	abeam
AC	Advisory Circular
ADF	automatic direction finder
AGL	above ground level
AIM	Aeronautical Information Manual
AIS	Aeronautical Information Services
ALSF-1	approach lighting system with sequenced flashing lights (CAT I Configuration)
ALSF-2	approach lighting system with sequenced flashing lights (CAT II Configuration)
APT	Airport
APV	approach with vertical guidance (ICAO)
ARA	airborne radar approach
ARC	Airport Reference Code
ARDH	achieved reference datum height
ARP	aerodrome reference point
ARSR	air route surveillance radar
ASBL	approach surface baseline
ASL	above sea level
ASOS	automated surface observing system
ASR	airport surveillance radar
AT	Air Traffic
ATC	Air Traffic Control
ATS	Air Traffic Service
ATD	along track distance
ATRK	along track
ATS	Air Traffic Service
AVN	Aviation System Standards
AWO	all weather operations
AWOS	automated weather observation system
AWS	Aviation Weather System
BaroVNAV	Barometric vertical navigation
BAZ	back azimuth
BC	back course
BPOC	before proceeding on course
CAT	Category
CF	course to fix
CFIT	controlled flight into terrain
CG	climb gradient

CGL	circling guidance light
CIH	climb-in-hold
COP	changeover point
CP	critical point
CRM	collision risk model
CW	course width
DA	decision altitude
dB	decibel
DCG	desired climb gradient
DER	departure end of runway
DF	direct to fix
DG	descent gradient
DH	decision height
DME	distance measuring equipment
DND	Department of National Defense
DP	departure procedure
DR	dead reckoning
DRL	departure reference line
DRP	departure reference point
DTA	distance of turn anticipation
DVA	diverse vector area
EARTS	en route automated radar-tracking system
EDA	elevation differential area
ELEV	elevation
EOR	end of runway
ESA	emergency safe altitudes
ESV	expanded service volume
FAC	final approach course
FAF	final approach fix
FAP	final approach point
FAS	final approach segment
FATO	final approach and takeoff area
FAWP	final approach waypoint
FDC	Flight Data Control
FDR	Flight Data Record
FDT	fix displacement tolerance
FEP	final end point
FIFO	Flight Inspection Field Office
FMP	first maneuver point
FMPD	first maneuver point distance
FMS	flight management system
FMWP	first maneuver waypoint

FPAP	flight path alignment point
FPCP	flight path control point
FSC	final straight course
FSS	Flight Service Station
FTE	flight technical error
FTIP	foreign terminal instrument procedure
FTP	fictitious threshold point
FWP	feeder waypoint
GA	General Aviation
GCA	ground controlled approach
GH	Geoid Height
GLONASS	Global Orbiting Navigation Satellite System
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
GP	glidepath
GPA	glidepath angle
GPI	ground point of intercept
GPS	Global Positioning System
GRI	group repetition interval
GS	glide slope
HAA	height above aerodrome
HAE	height above ellipsoid
HAH	height above heliport
HAI	Helicopter Association International
HAL	height above landing area elevation
HAS	height above surface
HAT	height above touchdown zone elevation (TDZE)
HATh	height above threshold
HCH	heliport crossing height
HF	high frequency
HIRL	high intensity runway lights
HRP	heliport reference point
HUD	heads-up display
IAC	initial approach course
IAF	initial approach fix
IAP	instrument approach procedure
IAPA	instrument approach procedure automation
IAWP	initial approach waypoint
IC	intermediate course
ICA	initial climb area
ICAB	ICA baseline
ICAE	ICA end-line

ICAO	International Civil Aviation Organization
ICPS	Instrument Check Pilot School
ICWP	initial course waypoint
IDF	initial departure fix
IAF	Initial approach fix
IF	intermediate fix
IF/IAF	intermediate/initial approach fix
IFR	instrument flight rules
ILS	instrument landing system
IMC	instrument meteorological conditions
INS	inertial navigation system
IPV	instrument procedure with vertical guidance
IRU	inertial reference unit
ISA	International Standard Atmosphere
IWP	intermediate waypoint
kHz	kilohertz
KIAS	knots indicated airspeed
LAAS	Local Area Augmentation System
LAB	landing area boundary
LAHSO	land and hold short operations
LDA	landing distance available
LDIN	lead-in lighting system
LF/mf	low frequency/medium frequency
LIRL	low intensity runway lights
LNAV	lateral navigation
LPV	Lateral Precision Performance with Vertical Guidance
LOA	Letter of Agreement
LOB	lines of business
LOC	localizer
LORAN	long-range navigation system
LTP	landing threshold point
MAHWP	missed approach holding waypoint
MALS	medium intensity approach lighting system
MALSF	medium intensity approach lighting system with sequenced flashing
MALSR	medium intensity approach lighting system with runway alignment indicator lights
MAP	missed approach point
MAWP	missed approach waypoint
MCA	minimum crossing altitude
MDA	minimum descent altitude
MEA	minimum en route altitude
MHA	minimum holding altitude

MHz	megahertz
MIA	minimum IFR altitudes
MIRL	medium intensity runway lights
MLS	Microwave Landing System
MOA	military operations area
MOC	minimum obstacle clearance
MOCA	minimum obstruction clearance altitude
MOU	Memorandum of Understanding
MRA	minimum reception altitude
MSA	minimum safe/sector altitude
MSL	mean sea level
MTA	minimum turn altitude
MVAC	minimum vectoring altitude chart
NAD	North American Datum
NAVAID	navigational aid
NDB	nondirectional radio beacon
NCFIO	NAVCANADA Flight Inspection Office
NM	nautical mile
NOTAM	Notice to Airmen
NOZ	normal operating zone
NPA	nonprecision approach
NTZ	no transgression zone
OC	obstruction chart
OCA	obstacle clearance altitude
OCH	obstacle clearance height
OCL	obstacle clearance limit
OCS	obstacle clearance surface
ODALS	omnidirectional approach lighting system
OEA	obstruction evaluation area
OE/AAA	Obstruction Evaluation/Airport Airspace Analysis
OFA	object free area
OIS	obstacle identification surface
ORE	obstacle rich environment
OSAP	off-shore approach procedure
PA	precision approach
PAPI	precision approach path indicator
PAR	precision approach radar
PCG	positive course guidance
PDA	preliminary decision altitude
PFAF	precision final approach fix
PGPI	pseudo ground point of intercept
PinS	point-in-space

PLS	precision landing system
POC	point of contact
PRM	precision runway monitor
PT	procedure turn
PVG	positive vertical guidance
PVGSI	pseudo visual glide slope indicator
RA	radio altimeter
RAIL	runway alignment indicator lights
RAPCON	radar approach control
RASS	remote altimeter setting source
RCL	runway centerline
RDP	reference datum point
REIL	runway end identifier lights
RF	radius to fix
RNAV	area navigation
RNP	required navigation performance
ROC	required obstacle clearance
RPI	runway point of intercept
RRP	runway reference point
RVR	runway visual range
RWP	runway threshold waypoint
RWT	runway threshold
RWTE	runway threshold elevation
RWY	runway
SALS	short approach lighting system
SATNAV	satellite navigation
SCG	standard climb gradient
SDF	simplified directional facility
SDF	step-down fix
SER	start end of runway
SIAP	standard instrument approach procedure
SID	standard instrument departure
SM	statute mile
SSALF	short simplified approach lighting system with sequenced flashers
SSALR	short simplified approach lighting system with runway alignment indicator lights
STAR	standard terminal arrival route
STOL	short takeoff and landing
TAA	terminal arrival area
TACAN	tactical air navigational aid
TC	Transport Canada
TCH	threshold crossing height

TD	time difference
TDP	touchdown point
TDZ	touchdown zone
TDZE	touchdown zone elevation
TDZL	touchdown zone lights (system)
TERPS	terminal instrument procedures
TF	track to fix
THLD	threshold
TLOF	touchdown and life-off area
TLS	transponder landing system
TORA	takeoff runway available
TP	tangent point
TPD	tangent point distance
TRACON	terminal radar approach control facility
TWP	turn waypoint
UHF	ultra high frequency
VA	heading to altitude
VASI	visual approach slope indicator
VCA	visual climb area
VCOA	visual climb over airport
VDA	vertical descent area
VDP	visual descent point
VFR	visual flight rules
VGA	vertically guided approach
VGSI	visual glide slope indicator
VHF	very high frequency
VLF	very low frequency
VMC	visual meteorological conditions
VNAV	vertical navigation
VOR	very high frequency omnidirectional radio range
VOR/DME	very high frequency omnidirectional radio range collocated with distance measuring equipment
VORTAC	very high frequency omnidirectional radio range collocated with tactical air navigation
VPA	vertical path angle
VSDA	visual segment descent angle
VTOL	vertical take-off and landing
WAAS	Wide Area Augmentation System
WATCO	Wing Air Traffic Control Officer
WCH	wheel crossing height
WICP	wing instrument check pilot
WP	waypoint
XTRK	crosstrack

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GLOSSARY OF TERMS

Aerodrome	any area of land, water (including the frozen surface thereof) or other supporting surface used or designated, prepared, equipped or set apart for the use either in whole or in part for the arrival or departure, movement of servicing of aircraft and includes any buildings, installations and equipment in connection therewith.
Aerodrome elevation	the elevation of the highest point of the landing area measured to the nearest foot above or below mean sea level.
Aerodrome authorization for part VII operations	Where an aerodrome does not meet the full requirements for certification, an aerodrome authorization may be issued to accommodate Part VII operations. An Aerodrome Authorization is required by the aerodrome operator for each air operator applying to use the aerodrome. The requirements for issuing an Aerodrome Authorization are available from Transport Canada Aerodrome Safety in the document entitled *"Aerodrome Authorization for Part VII Operations"*.
Aerodrome operator attestation	When the aerodrome is not certified and/or does not have an Aerodrome Authorization, an Aerodrome Operator Attestation is required in order to support instrument approach procedures below 500 feet HAT. The Aerodrome Operator Attestation identifies the aerodrome physical characteristics and the obstacle environment required to support the instrument operational limits for the critical aeroplane wing span, used by operators at a specific aerodrome.
Aerodrome reference point (ARP)	The designated geographical location of an aerodrome given to the nearest second of latitude and longitude. The ARP is located as near as practicable to the geometric centre of the landing area taking into account possible future development (see Annex C, Para 13).
Altitude	The vertical distance of a level, a point or an object considered as a point, measured from mean sea level.
Angle of divergence (minimum)	The smaller of the angles formed by the intersection of two courses, radials, bearings, or combinations thereof.
Approach procedure with vertical guidance (APV)	An instrument approach procedure that utilizes lateral and vertical guidance that do not meet the requirements established for a precision approach. Minima shall be expressed as DA(H).
Approach surface baseline (ASBL)	An imaginary horizontal line at threshold elevation.
Bearing	The horizontal angle at a given point, measured clockwise from a specific reference datum, to a second point. Bearings are expressed as True, Magnetic, Relative, Astronomic, Grid, etc. according to the reference datum used.
Change over point (COP)	A point defined between navigation facilities along airway/route segments, which indicate the pilot should change over his navigation equipment to receive course guidance from the facility ahead of the aircraft instead of the one behind.

Circling approach	The visual maneuvering required, after completing an instrument approach, to bring an aircraft into position for landing on a runway that is not suitably indicated for straight-in landing.
Controlling obstacle	The obstacle on which the design of a procedure or establishment of a minimum altitude or angle is based on.
Dead reckoning	The estimating or determining of position by advancing an earlier known position by the application of direction and speed data. For example, flight based on a heading from one VORTAC azimuth and distance fix to another is dead reckoning.
Decision altitude (DA)	The DA is the barometric altitude, specified in feet above MSL, at which a missed approach shall be initiated if the required visual reference has not been established. The DA applies to approach procedures where the pilot is provided with glidepath deviation information; e.g., ILS, MLS, TLS, GLS, LNAV/VNAV, Baro VNAV, or PAR.
Decision height (DH)	The DH is the value of the DA expressed in feet above the threshold elevation. This value is also referred to as HATh.
Diverse vector	An instruction issued by a radar controller to fly a specific course, which is not a part of a predetermined radar pattern. Also referred to as a “random vector.”
DME arc	A track, indicated as a constant DME distance, around a navigation facility that provides distance information.
DME distance	The line of sight distance (slant range) from the source of the DME signal to the receiving antenna.
Elevation (Elev)	The vertical distance of a point or a level, on or affixed to the surface of the earth measured from mean sea level.
Final approach	That part of an instrument approach procedure from the time the aircraft has a. completed the last procedure turn or base turn, where one is specified; or b. crossed the final approach fix or point; or c. intercepted the last track specified for the procedure; until it reaches the missed approach point. It is in this portion of the procedure that alignment and descent for landing are accomplished.
Final approach fix (FAF)	A fix that indicates the commencement of the final approach segment of a non-precision instrument approach procedure.
Fix	A geographical location determined by means of radio aids or other navigation devices
Geographic centre of the aerodrome	The centre of the runway pattern; see Annex C for a method of determining the geometric centre of an aerodrome.
Glidepath (GP)/ glide slope (GS)	A descent profile that is electronically determined for vertical guidance during a final approach.
Glide path/ glide slope angle	The angle of the glide path/glide slope measured above the horizontal plane.

Ground point of intercept	A point in the vertical plane on the runway centerline at which it is assumed that the straight line extension of the glide slope intercepts the runway approach surface baseline.
Gradient	A slope expressed in feet per mile, or as a ratio of the horizontal to the vertical distance. For example, 40:1 means 40 feet horizontally to 1 foot vertically.
Heading	The direction in which longitudinal axis of the aircraft is pointed expressed in degrees from north (true, magnetic, compass or grid).
Height	The vertical distance of a level, a point or an object considered as a point, measured from a specified datum.
Height above aerodrome (HAA)	The height in feet of the MDA above the published aerodrome elevation. HAA will be published for all circling minima.
Height above touchdown zone elevation (HAT)	The height in feet above the touchdown zone elevation.
Height above touchdown zone elevation (HATh)	The height in feet above the threshold elevation
Holding procedure	A predetermined manoeuvre which keeps an aircraft within a specified airspace while awaiting further clearance.
Initial approach	That part of an instrument approach procedure in which the aircraft has departed an initial approach fix and is maneuvering to enter the intermediate segment of the approach.
Initial approach fix (IAF)	A fix at which an aircraft leaves the en route phase of operations in order to commence the approach.
Instrument approach procedure (IAP)	A series of predetermined maneuvers for the orderly transfer of an aircraft under instrument flight conditions from the beginning of the initial approach to a point from which a landing may be made visually.

Instrument runway	One of the following types of runways intended for the operation of aircraft using instrument approach procedures: a. Non-precision approach runway. An instrument runway served by visual aids and a non-visual navigation aid providing at least directional guidance adequate for a straight-in approach to a minimum descent height less than 500 ft above the runway threshold but not less than 250 ft above the runway threshold. b. Precision approach runway, Category I. An instrument runway served by visual and non-visual navigation aids where operations are conducted down to a decision height lower than 250 ft but not lower than 200 ft and a visibility not less than 2600 ft. c. Precision approach runway, Category II. An instrument runway served by visual and non-visual navigation aids where operations are conducted down to 100 ft decision height and a RVR not less than 1200 ft. d. Precision approach runway, Category III. An instrument runway served by non-visual guidance systems to and along the surface of the runway and: (1) CAT IIIa where operations are conducted or intended to be conducted down to an RVR not less than 600 ft (no decision height being applicable); (2) CAT IIIb where operations are conducted or intended to be conducted down to an RVR not less than 300 ft (no decision height being applicable); (3) CAT IIIc where operations are conducted or intended to be conducted with no decision height and no runway visual range limitations.
Intermediate approach	That part of an instrument approach procedure in which aircraft configuration, speed and positioning adjustments are made for entry into the final approach.
Intermediate fix (IF)	The fix at which the aircraft enters the intermediate approach segment of an instrument approach.
Landing area	That part of the movement area intended for the landing or take-off run of aircraft.
Localizer	The component of an ILS which provides lateral guidance with respect to the runway centerline.
Localizer type directional aid	A facility of comparable utility and accuracy to a LOC, but which is not part of a full ILS and may not be aligned with the runway.
Minimum descent altitude (MDA)	A specified altitude referenced to sea level for a non-precision approach below which descent must not be made until the required visual reference to continue the approach to land has been established.

Minimum sector altitude (MSA)	The lowest which will provide a minimum clearance of 1,000 feet, under conditions of standard temperature and pressure, above all obstacles located in an area contained within a defined sector of a circle of 25 nautical miles radius centred on an identified navigational facility or waypoint.
Missed approach point (MAP)	That point on the final approach track which signifies the termination of the final approach and the commencement of the missed approach. It may be: a. the intersection of an electronic glide path with a Decision Height; b. a navigational facility located on the aerodrome; c. a suitable fix (e.g., DME); d. specified distance past the facility or final approach fix, not to exceed the distance from that facility or fix to the nearest boundary of the aerodrome.
Missed approach procedure	The procedure to be followed, if for any reason, after an instrument approach, a landing is not affected.
Non-precision approach (NPA)	An instrument approach procedure which does not utilize vertical guidance. Minima shall be expressed as MDA(H).
Obstacle	An existing object, object of natural growth, or terrain at a fixed geographical location or that may be expected at a fixed location within a prescribed area, with reference to which vertical clearance is or must be provided for flight operations.
Obstacle clearance limit (OCL)	The lowest altitude that will satisfy the obstacle clearance requirement for the particular segment of an instrument approach procedure that is under consideration.
Obstacle clearance surface (OCS)	A surface above which obstacles may not penetrate if the required obstacle clearance is to be maintained.

Obstacle limitation surface (OLS).	A surface that establishes the limit to which objects may project into the airspace associated with an aerodrome so that aircraft operations at the aerodrome may be conducted safely. Obstacle limitation surfaces consist of the following: 1. Take-off/Approach surface. An incline plane beyond the end of the runway and preceding the threshold of a runway. The origin of the plane comprise: (a) An inner edge of specified length (strip width), perpendicular to and evenly divided on each side of the extended centre line of the runway, and beginning at the end of the runway strip; (b) Two sides originating at the ends of the inner edge, diverging uniformly at a specified rate in the direction of take-off; (c) The elevation of the inner edge is equal to the elevation of the threshold. 2. Transitional surface. A complex surface sloping up at a specified rate from the side of the runway strip and from part of the take-off/approach surface. The elevation of any point on the lower edge of the surface is: (a) Along the side of the take-off/approach surface, equal to the elevation of the take-off/approach surface at that point; and, (b) Along the runway strip, equal to the elevation of the centre line of the runway, perpendicular to that point.
Obstacle rich environment (ORE)	An environment is obstacle rich when it is not possible to construct an unguided discontinued approach using procedural means. Approach operations in an ORE require supplementary guidance to proceed along the published course to the missed approach point and achieve a climb to the minimum vectoring altitude or minimum IFR altitude.
Omnidirectional facility	A facility capable of receiving or transmitting in all directions. Omnidirectional facilities include VOR, TACAN, VORTAC, NDB and DME.
Operational advantage	An improvement that benefits the users of an instrument procedure without compromise to safety
Penetration turn	That part of the initial approach segment, which permits a high performance aircraft to reverse direction and to lose altitude while remaining within a limited area.
Precipitous terrain	Terrain characterized by steep or abrupt slopes.

Precision and non precision	These terms are used to differentiate between navigational facilities that provide a combined azimuth and glide slope guidance to a runway (Precision) and those that do not. The term nonprecision refers to facilities without a glide slope, and does not imply an unacceptable quality of course guidance.
Precision approach (PA)	An instrument approach procedure utilizing precision lateral and vertical guidance with minima as determined by the category of operation.
Precision approach radar (par)	Primary radar equipment used to determine the position of an aircraft during final approach, in terms of lateral and vertical deviations relating to a predetermined approach path, and in range relative to a predetermined touchdown point.
Procedure turn (PT)	A manoeuvre in which a turn is made away from a designated track, followed by a turn in the opposite direction, both turns being executed so as to permit the aircraft to intercept and proceed along the reciprocal of the designated track. **Note:** Procedure turns are designated left or right according to the direction of the initial turn.
Positive course (Track) guidance	A continuous display of navigational data which enables an aircraft to be flown along a specific course (track). **Note:** Radar vectors are considered meeting the requirements of positive course (track) guidance.
Primary area	The area within a segment in which full obstacle clearance is applied.
Radial	A bearing extending from a VOR, or TACAN facility.
Runway	A defined rectangular area, on a land aerodrome, prepared for the landing and take-off of aircraft along its length.
Runway environment	The runway threshold, lighting aids, markers or markings identifiable with the runway.
Runway visual range (RVR)	The maximum distance in the direction of take-off or landing at which the runway or specified lights or markers delineating it can be seen from a position above a specified point on its centreline at a height corresponding to the average eye-level of pilots at touchdown. **Note:** A height of 16 feet is regarded as corresponding to average eye-level of pilots at touchdown. RVR is determined from information provided by a transmissometer located near the touchdown point on a runway and where CAT II ILS is installed a second transmissometer is located near the midpoint of the runway length.

Safe altitude 100 nm	The lowest altitude that may be used that will provide a minimum clearance of 1,000 feet, under conditions of standard temperature and pressure, above all obstacles located in an area contained within a circle of 100 nautical miles radius of the geographic centre of the aerodrome.
Service volume	That volume of airspace surrounding a navigational facility within which a signal of usable strength exists and where the signal is not operationally limited by co-channel interference.
Segment	The basic functional division of an instrument approach procedure. The segment is oriented with respect to the course to be flown. Specific values for determining course alignment, obstacle clearance areas, descent gradients, and obstacle clearance requirements are associated with each segment according to its functional purpose.
Straight-in approach	An instrument approach where final approach is begun without first having executed a procedure turn. Straight-in approaches are not necessarily completed with a straight-in landing or made to straight-in landing minimums.
Straight-in landing minima	Approach minima published in association with an instrument approach procedure that conforms with specified final approach alignment and descent gradient criteria.
Strip	An area of specified dimensions enclosing a runway, intended to reduce the risk of damage to aircraft running off a runway, and to protect aircraft flying over it during take-off and landing operations.
Threshold	The beginning of that portion of the runway usable for landing.
Threshold crossing height	The height of the straight-line extension of the glide slope above the runway at the threshold.
Touchdown zone (TDZ)	The first 3,000 feet of runway, or the first one-third which ever is less, measured from the threshold in the direction of landing.
Touchdown zone elevation (TDZE)	The highest runway centreline elevation in the touchdown zone.
Track	The projection on the earth's surface of the path of an aircraft, the direction of which path at any point is usually expressed in degrees from North (true, magnetic, or grid).
Visibility	The ability, as determined by atmospheric conditions and expressed in units of distance, to see and identify prominent unlighted objects by day and prominent lighted objects by night.

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CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

ANNEX B

MINIMUM VECTORING ALTITUDE

TRANSPORT CANADA
NATIONAL DEFENSE

5 January 2017

Canada

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MINIMUM VECTORING ALTITUDE CHARTS

1. Chart Preparation

Radar vectoring charts are developed for areas where there are numerous minimum vectoring altitudes due to variable terrain features or man-made obstacles. The responsible ATC facility shall determine whether their radar systems require vectoring charts. Procedure design specialists or WICPs shall establish the minimum altitudes by ensuring all MVA charts meet the obstacle requirements outlined within this Annex. Completed charts will be reviewed and approved in accordance with the coordination signature blocks identified on form 26-0445.

2. Areas Of Consideration

The area considered for obstacle clearance shall be based upon the maximum range of the applicable radar. This area may be subdivided into sectors to gain relief from obstacles that are clear of the area in which flight is to be conducted. There is no limit on the size, shape or orientation of the sectors; however, they must be designed with consideration to aircraft maneuvering ability, obstacle clearance requirements and air traffic flow requirements.

To avoid excessively high MVAs within a sector, radars meeting the specifications of RAMP RADAR may isolate prominent obstacles by enclosing the obstacle within a buffer area whose boundaries are at least 3 NM from the obstacle up to and including 60 NM from the radar antenna and 5 NM from obstacle beyond 60 NM from the radar antenna. Radars not meeting RAMP RADAR specifications may isolate obstacles by 5 NM in all cases.

Rapidly rising terrain, although possibly not a factor in identifying prominent obstacles, may trigger activation of ground proximity warning devices onboard aircraft due to an aircraft descending to a MVA in these areas. Procedure designers should consider this when establishing sectors and MVAs with a view to eliminating this possibility during the development of MVA charts.

All MVAs shall be contained within controlled airspace.

3. Obstacle Clearance

Obstacle clearance shall be provided over all obstacles with all the designated vectoring areas or sectors irrespective of the minimum altitude radar coverage determined by a flight check. Selected altitudes shall provide clearance over all obstacles outside of the sector within 3 NM of the sector boundaries (5 miles beyond 60 NM from the radar antenna). In areas of overlapping radar coverage, where data from an antenna more that 60 NM away may be used, only 5 NM clearance shall be applied. Normally, 1000 feet of obstacle clearance is provided in non-mountainous areas and 1500 feet or 2000 feet, as appropriate, in areas designated as mountainous in the Designated Airspace Handbook. Chosen MVAs may be rounded off to the nearest 100 foot increment provided the required obstacle clearance within the appropriate sector is not violated.

4. Obstacle Clearance Reductions

Where lower MVAs are required in designated mountainous areas to achieve compatibility with terminal routes or to permit vectoring to an instrument approach procedure, obstacle clearances may be reduced to not less than 1000 feet when precipitous terrain is not a factor.

5. Radar Data Processing (RDP)

Radar information presented to the controller may be provided from multiple antennas. MVA charts for these facilities shall provide obstacle clearance determined by using the antenna location that is the greatest distance from the obstacle.

6. Construction

a. MVAC's should initially be drawn on an appropriately scaled aeronautical chart as per Figure B–1, Terminal Surveillance Radar (TSR), or Figure B–2, Independent Secondary Surveillance Radar (ISSR).

b. The **centre** of the chart should represent the radar antenna site, however, operations requirements may dictate otherwise. The chart may be divided into sectors as required by different obstacle clearance altitudes. The configuration of each sector, and the features to be displayed, depends upon the local terrain and operational considerations. The following guidelines should be to used when developing MVA charts:

(1) Depict each sector in relation to its magnetic bearing from the antenna site, radials from NAVAIDS, radar display range marks, or controller airspace boundaries. To facilitate a correlation between the chart and radar displays, make the sector boundaries coincide with map overlay or video map data, if possible.

(2) Make each sector large enough to permit the vectoring of aircraft within the sector. Establish the boundary of each sector at least 3 NM from the obstacle determining the minimum altitude (5 NM, if more than 60 NM from the antenna site).

(3) If there is a large sector with an excessively high altitude, due to an isolated prominent obstacle, the buffer area must have boundaries that are at least 3 NM from the obstacle (5 NM, if more than 60 NM from the antenna site).

(4) Determine and depict the minimum altitude in each sector that will provide the required obstacle clearance.

c. Complete the Minimum Vectoring Altitude Computations form, TC form 26-0445, to determine selected sector altitudes. See Figure B–3. The temperature difference, Section C.5 on the form, is calculated by finding the mean minimum temperature for each month. This temperature may be found in Environment Canada publication, "Principal Station Data," Table 1, line two, "Minimum". The lowest mean minimum temperature is then subtracted from the ICAO Standard Atmosphere (ISA) temperature for the elevation of the airport/altimeter setting source. This is the number used in Section C.5.

d. Transfer all data to the Minimum Vectoring Altitude Chart, TC form 26-0446. See Figure B–4. Complete the obstacle data for the controlling obstacle for each sector. Obtain the required signatures and retain on unit files.

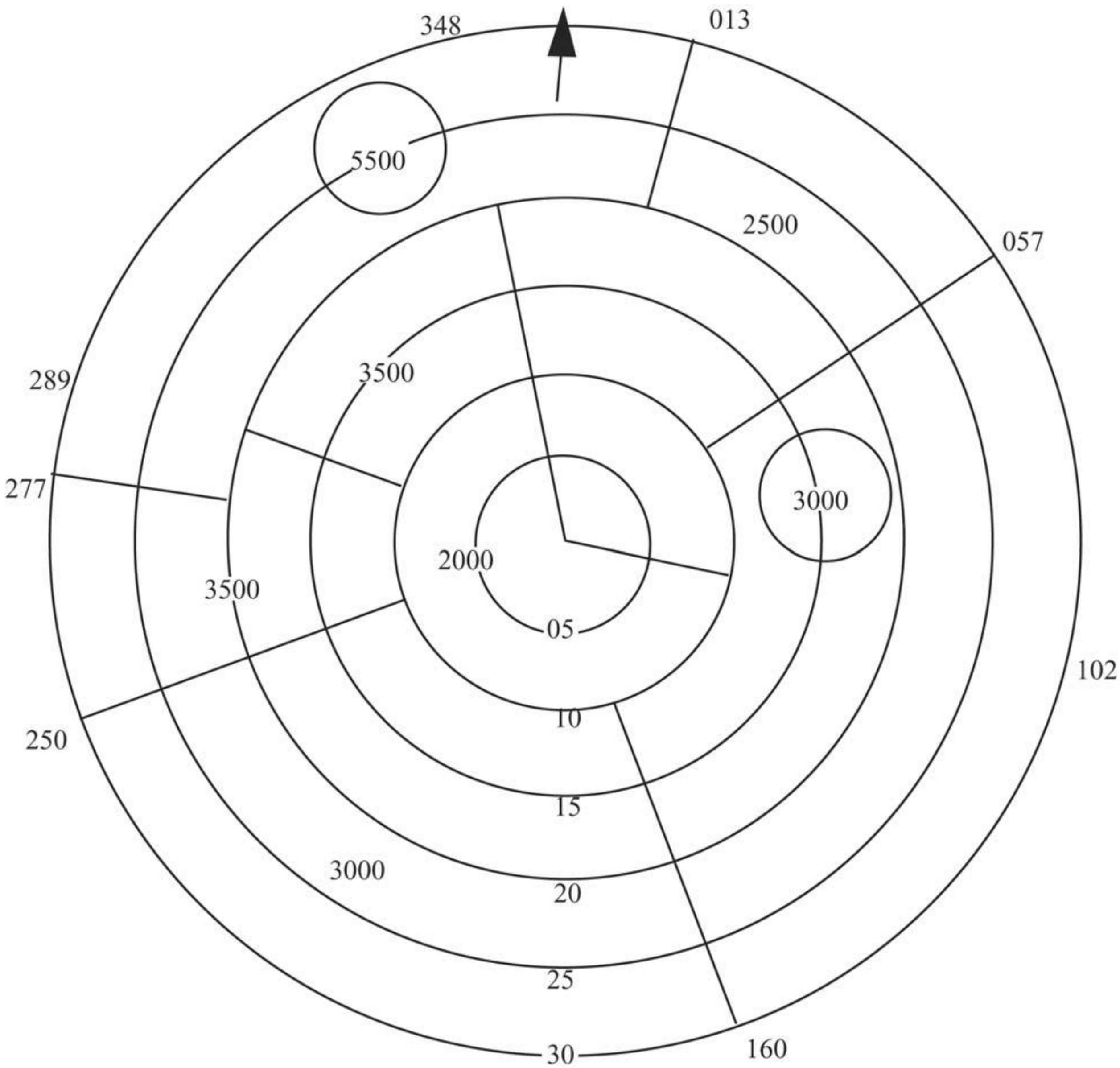

Figure B-1: Terminal Surveillance Radar (TSR)

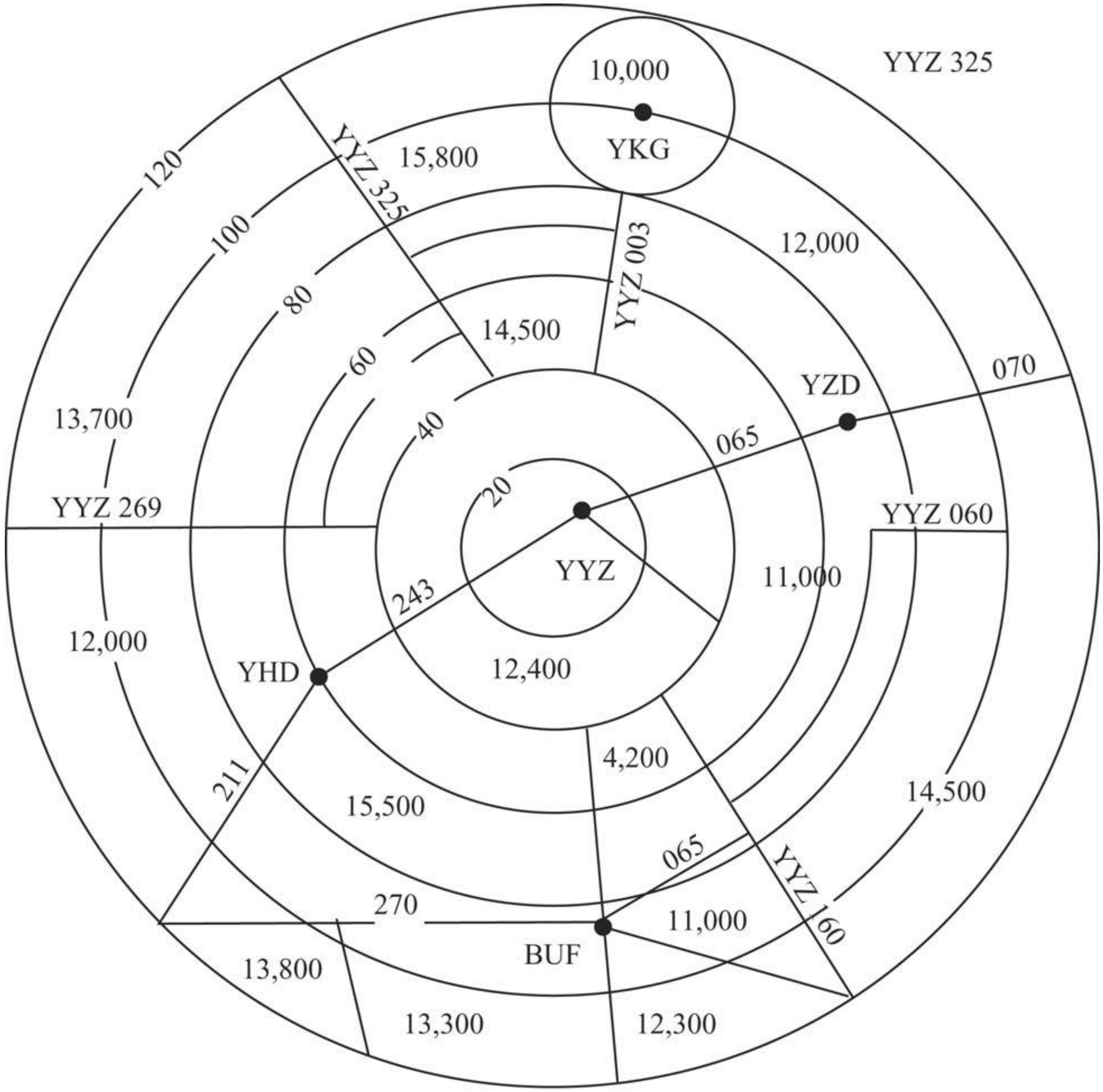

Figure B-2: Independent Secondary Surveillance Radar (ISSR)

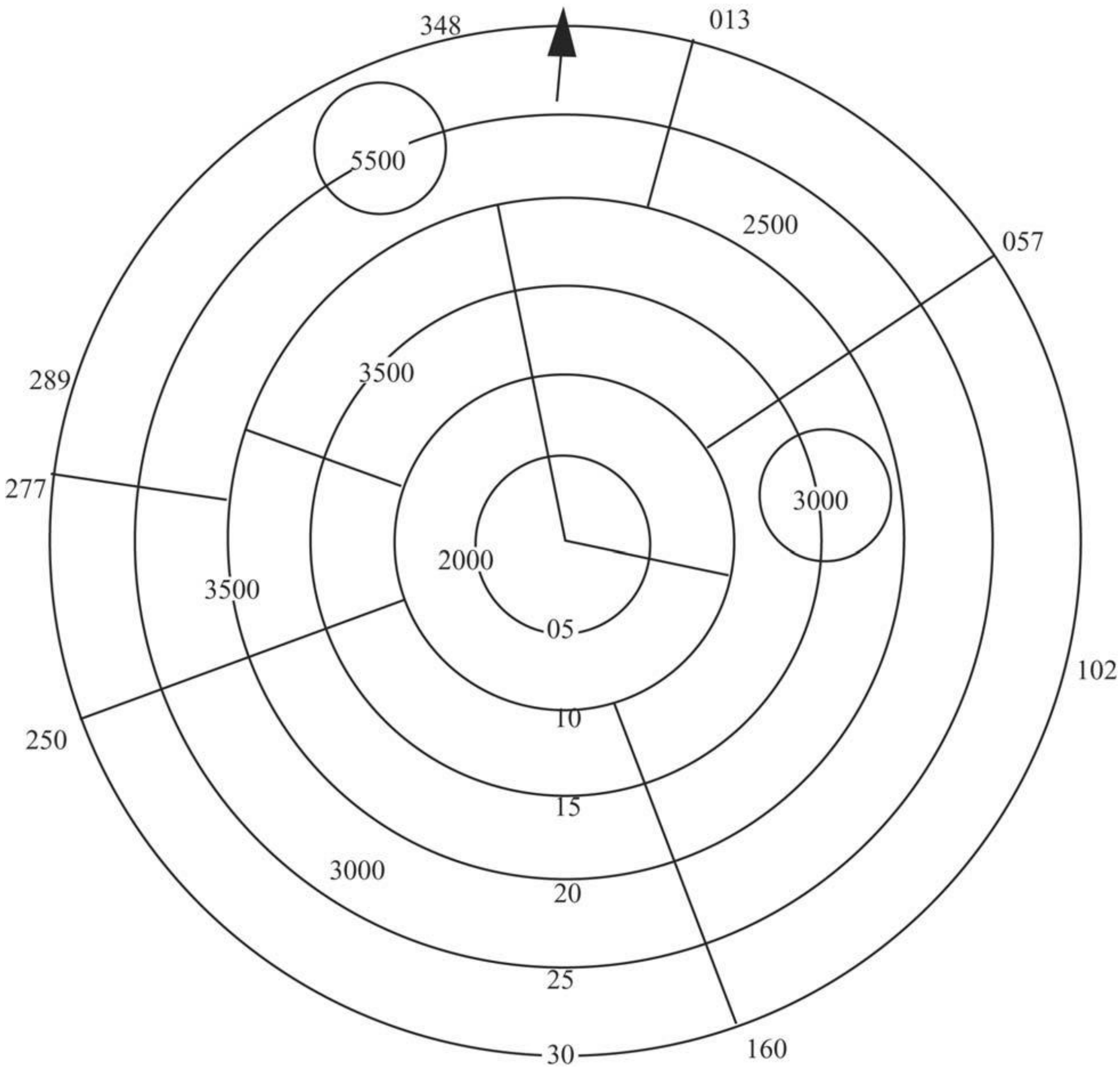

Figure B-4: Minimum Vectoring Altitude Chart.

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MINIMUM VECTORING ALTITUDE COMPUTATIONS

For completion instructions, see TP 308/GPH 209, Annex B.

Name of Facility >		**Sector** _____
Name of Airport >		**of** _____
SECTOR *(Enter Description)*		

A.	**MVA Required for Terrain Obstacle Clearance**	**Buffer Area**	**Sector**
1.	Controlling obstacle *(Enter Description)*		
2.	Controlling Obstacle Height (MSL)		
3.	Required Obstacle Clearance *(Normally 1000 (1500 or 2000 mountainous Area)*	+	+
4.	ROC Adjustment (Precipitous terrain – Para 323)		
5.	Required Altitude based on Obstacle Clearance	=	=
B.	**MVA Required for Airspace**		
1.	Floor of Controlled Airspace *(AGL)(if MSL, Skip 1&2)*		
2.	Highest Terrain in Sector		+
3.	Required Altitude Based on Airspace Floor		=
C.	**MVA Required for Temperature Correction**		
1.	Required Altitude based on Obstacle Clearance (A.5)		
2.	Airport/ Altimeter Setting Source Elevation		-
3.	Elevation Differential		=
4.	Elevation Factor (C.3/1000)		
5.	Temperature Difference (Standard ____°C Winter _____°C)		
6.	Temperature Correction (C.4 x C.5 x 4)		
7.	Required Altitude based on Obstacle Clearance (A.5)		
8.	Required Altitude Based on Temperature Correction		=
D.	**Selected Sector Altitude**		
1.	For months when mean temperature is > 0°C *(Highest of A.5 or B.3 rounded as per Para 1041.a.(3))*		
2.	For months when mean temperature is ≤ 0°C *(Highest of B.3 or C.8 rounded as per Para 1041.a.(3))*		
Remarks:			

26-0445 (JAN 08)

Figure B-3: Minimum Vectoring Altitude Computations Forms.

TSR/ISSR Magnetic Variation:	

Obstacle Data			
Sector	**Controlling Obstacle No.**	**Elevation MSL**	**LAT / LONG**
Remarks			

26-0445 (JAN 08)

Figure B-4: Minimum Vectoring Altitude Chart (continued).

CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

ANNEX C

PROCEDURES

TRANSPORT CANADA
NATIONAL DEFENSE

5 January 2017

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PROCEDURES

1. Administrative – Reserved
2. General Provisions – Reserved
3. Enroute Procedures – Reserved
4. Terminal Procedures – Reserved

4.1. General.

This section contains supplementary guidance for the development of RNAV instrument procedures. RTCA DO-201A, Standards for Aeronautical Information, has established operational requirements and standards that aviation authorities, procedure designers, and airspace planners must consider when developing en route, arrival, approach, departure, and aerodrome environments. This guidance provides a standardized method of processing RNAV instrument procedures using information from this RTCA document.

4.2. RNAV Approach Procedure Design.

a. **The RNAV procedure** should, **whenever** and wherever possible, match the ILS at the same runway in the following respects: final and intermediate segment procedure ground track, missed approach, altitudes, fix locations/names, glidepath angles (GPAs), and threshold crossing heights (TCHs). Nothing in this policy requires an RNAV procedure to emulate a procedure turn used on an underlying ILS procedure.

b. **Establish an LNAV FAF for all new RNAV procedures** at a location that will support a collocated PFAF for future RNP, LNAV/VNAV, and/or WAAS/LAAS procedures.

c. **RNAV RNP procedures** may be designed to support minimums with different RNP values in the final approach segment. The largest RNP value is the one that will be coded into the avionics database (pilots will have the ability to enter the lower values if their equipment permits).

d. **ILS and/or LOC procedures may be combined with RNAV (GPS) procedures**. This will permit use of an ILS/LOC with the same ground track as the RNAV (GPS) procedure. When combining procedures, consideration must be given to the number of lines of minima that are possible and the potential human factors implications.

e. **Remote Altimeter Setting for Baro-VNAV is not authorized**. When the primary altimeter source is from a remote location, LNAV/VNAV is not authorized to be flown using Baro-VNAV. When the primary altimeter source is local and a secondary altimeter source is remote, LNAV/VNAV minimums must be noted as not authorized (NA) to be flown with Baro-VNAV when the secondary altimeter is in use.

f. **Critical Temperature.** Temperature limits above and below which Baro-VNAV operations are not authorized are published on RNAV instrument approach procedures. Current RNAV criteria standards provides the formulas to compute the critical temperatures for the airport of intended landing based on a given deviation from International Standard Atmosphere (ISA) for the airport elevation. Maximum temperature published must not exceed 54°C (130°F).

g. **Due to limited WAAS coverage at certain locations**, a restriction may be required on procedures where WAAS can be used for vertical navigation on a procedure containing LNAV/VNAV minima. This restriction must be portrayed on the instrument procedure chart to signify WAAS signal outages may occur daily and that these outages will not be NOTAM'd. At locations where LNAV/VNAV minima are published and it has been determined that there is no WAAS coverage whatsoever, the chart must be annotated to indicate that the use of WAAS for VNAV is not authorized.

4.3. RNAV (RNP)

a. **As part of the minima box for RNAV (RNP) procedures**, enter "Authorization Required" in the title line.

b. **Document the RNP value** (e.g., RNP 1.0 or RNP 0.15) used for each segment (except the final segment). Additionally, when the RNP for feeder, initial and/or intermediate segments are less than standard (RNP 2.0 for feeder, RNP 1.0 for initial and/or intermediate), a chart note must be placed adjacent to the feeder fix or IAF stating the required RNP value.

c. **RNAV (RNP) speed restrictions** [see Order 8260.58, Volume 5] must be noted on the chart. For a missed approach RF turn, specify the point where the restriction starts and the point at which the restriction is no longer required.

d. **Certain RNP-equipped aircraft may not be capable of flying procedures that contain RF turns**, so the entire procedure or segment of the procedure must be annotated to alert the pilot of this limitation.

e. **RNP criteria require a wing (semi) span value** for narrow and wide body aircraft to be used when calculating the Vertical Error Budget (VEB). When the narrow body value is used, a note must be placed on the approach chart to alert the pilot of this limitation.

5. Airspace – Reserved

6. Military Procedures – Reserved

7. Planning – Reserved

8. Instrument Approach Procedure Data Transmittal System – Reserved

CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

ANNEX D

OLS VS OCS

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NOTE ON THE DISTINCTION BETWEEN OBSTACLE LIMITATION SURFACES AND OBSTACLE CLEARANCE SURFACES

Care should be taken to distinguish between Obstacle Limitation Surfaces (OLS) dealt with in TP 312/CETO C-98-001-003/MS-022, and Obstacle Clearance Surfaces (OCS) dealt with in TP308/GPH209, as their purpose is different.

a. Obstacle Limitation Surface (Take-off/Approach, Transitional, and Outer Surface) define the volume of airspace that should ideally be kept free from obstacles in order to minimize the dangers presented by obstacles to an aircraft, either during an entirely visual approach or during the visual segment of an instrument approach (see Figure F-1). The Obstacle Limitation Surfaces are intended to be of a permanent nature Values are fixed in relation to the proposed airport use and therefore they form the basis for an enactment of Zoning Regulations.[1]

b. Obstacle Clearance Surfaces are intended to be used by instrument procedure specialists for the construction of instrument flight procedures and for specifying minimum safe altitudes for each segment of the procedure. Obstacle Clearance Surfaces are designed to meet the needs of a particular runway environment based on the location and height of existing obstacles, aeroplane speed, the navigational aid being used and in some cases the equipment fitted to the aeroplane. Rarely would two sets of OCSs be the same for the same type on instrument approach at different runways.

The standards for Obstacle Limitation Surface described in TP 312/CETO C-98-001-003/MS-022 determine whether an aerodrome can be certified and whether a runway can be authorized as an instrument runway or non-instrument runway. Once Obstacle Limitation Surfaces are in place, it is possible to exercise some discretion on what to do when they are penetrated. TP 312/CETO C-98-001-003/MS-022 Para 4.1.2 states, "New objects or extensions of existing objects shall not be permitted...except when in the opinion of the certifying authority, the new object or extension would be shielded by an existing immoveable object."

In the case of Obstacle Clearance Surfaces, the Minimum Vertical Clearance is always based on existing obstacles. If a new obstacle appears, the entire instrument approach procedure must be reviewed.

In summary, TP 308/GPH 209 (OCS) specifies the size and dimensions of the obstacle-free airspace needed for an instrument approach, a missed approach initiated at or above the Obstacle Clearance Altitude and for the visual maneuvering (circling) procedure. Aeroplanes continuing their descent below the specified Obstacle Clearance Altitude, and therefore having visual confirmation that they are properly aligned, are protected by TP 312/CETO C-98-001-003/MS-022 (OLS) and related obstacle limitations and marking/lighting requirements.

[1] "Registered Zoning Regulations" is defined as the enactment of Registered Zoning Regulations pursuant to the *Aeronautics Act*, Part 1, Sections 5.4 to 5.8, for the protection of approach and departure paths surrounding an aerodrome. In normal Canadian practice a Registered Zoning Regulation forbids penetration of runway Take-off/Approach, Transitional, and Outer Surfaces as described in TP312/CETO C-98-001-003/MS-022.

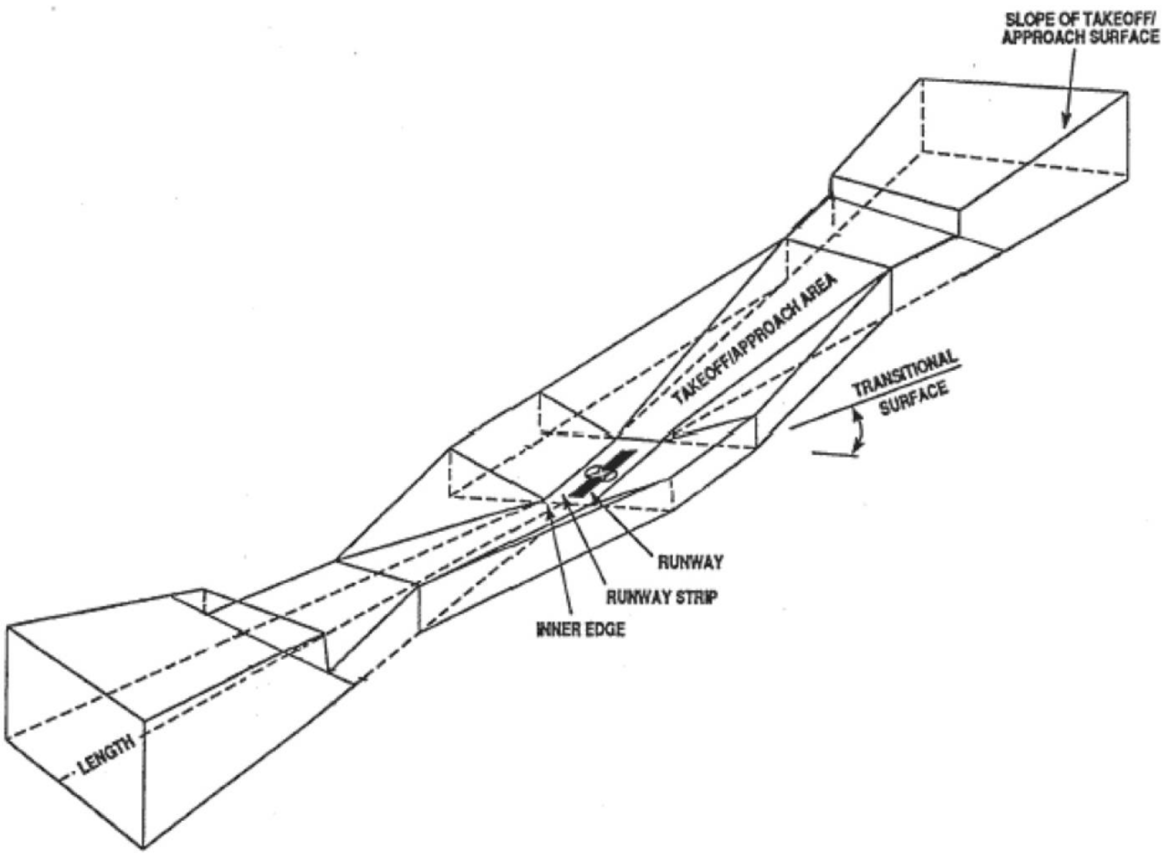

Figure F-1: Obstacle Limitation Surface

An example may serve to further clarify the above distinction. If a new object were to penetrate the Take-off/Approach Surface of an unzoned, precision approach runway, remedial options to be considered could include the following:

(1) Removal of the object,

(2) Displacing the threshold to retain a 2% gradient,

(3) Downgrading the level of operations to non-precision or non-instrument, or

(4) Marking the obstacle with a suitable hazard beacon.

(Although raising the glide path angle is another possibility, the size of the acceptable change - from the normal 3° to a maximum of 3.2° - is almost invariably too small to make this a practical option). If an Instrument Procedures Specialist determined that the obstruction would not affect landing minima, the certifying authority could chose to implement any of the above options. For example, if the object were a long way from threshold, and penetration were minimal, merely marking or lighting the obstruction could satisfy safety requirements. However, if the application of the Minimum Vertical Clearance to the penetration results in unacceptably higher minima, the certifying authority would have only the option of arranging removal of the obstruction or downgrading the level of operations. Of these, the one that least disrupted safety and regularity would be chosen.

Note: A Registered Zoning Regulation relates to lands "adjacent to or in the vicinity of airports", therefore it has no force with regard to lands inside the airport boundary. However, any penetration of an OLS inside the boundary would be sanctioned only if the object had to be so located for navigation or guidance purposes.

Note: Obstacles existing at the time a Registered Zoning Regulation comes into force are not affected by such Regulation. Removal of such an obstacle by legal means can only be done by acquiring the property under the Expropriation Act or payment of compensation.

Definitions:

Obstacle Limitation Surface (OLS). A surface that establishes the limit to which objects may project into the airspace associated with an aerodrome so that aircraft operations at the aerodrome may be conducted safely. Obstacle limitation surfaces consist of the following:

(1) Take-off/Approach surface. An incline plane beyond the end of the runway and preceding the threshold of a runway. The origin of the plane comprise:

  (a) An inner edge of specified length (strip width), perpendicular to and evenly divided on each side of the extended centre line of the runway, and beginning at the end of the runway strip;

  (b) Two sides originating at the ends of the inner edge, diverging uniformly at a specified rate in the direction of take-off;

  (c) The elevation of the inner edge is equal to the elevation of the threshold.

(2) Transitional surface. A complex surface sloping up at a specified rate from the side of the runway strip and from part of the take-off/approach surface. The elevation of any point on the lower edge of the surface is:

  (a) Along the side of the take-off/approach surface, equal to the elevation of the take-off/approach surface at that point; and,

  (b) Along the runway strip, equal to the elevation of the center line of the runway, perpendicular to that point.

Strip: An area of specified dimensions enclosing a runway, intended to reduce the risk of damage to aircraft running off a runway, and to protect aircraft flying over it during take-off and landing operations.

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CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

ANNEX E

TERRAIN AND OBSTACLE DATA (TOD)

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NATIONAL DEFENSE

5 January 2017

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TERRAIN AND OBSTACLE DATA (TOD)

1.0. General

The primary purpose of obstacle evaluation is to determine how an obstacle will affect instrument flight procedures. The evaluations provide accurate, consistent, and meaningful results only if procedure specialists apply the same rules, criteria, and processes during development, revision, and cyclical review. This annex establishes the minimum accuracy standards for obstacle data and its application in the development, revision, and cyclical review of instrument procedures. The minimum standards, regardless of the data source, are to be applied by instrument procedure specialists in all instrument procedure obstacle evaluations.

1.1. Obstacle Data Accuracy Standards

This paragraph identifies the MINIMUM requirement for accuracy of obstacle data used in the development of minimum vectoring altitudes (MVA) and instrument procedures; providing the minimum accuracy standards for each.

a. Concept. Obstacle data accuracy is not absolute, and the accuracy depends on the data source, different sources of data will have different accuracies. The magnitude of the inaccuracy does not preclude its use, provided it is identified, accounted for and documented. In some cases, upgrading obstacle accuracy can provide relief from operational restrictions in an instrument procedure. In no case, will the application of obstacle data accuracy preempt the requirement for the flight check of an instrument procedure for discrepancies.

b. Standards. The minimum accuracy standards in this annex are for use in the development, revision, and cyclical review of instrument procedures. They must be applied to all new procedures and to existing procedures at the next revision or cyclical review, whichever occurs first. The minimum accuracy standards are listed below. ADJUST the location/elevation data of the segment-controlling obstacle by the actual horizontal and vertical accuracy values, only if the specified accuracy value does not meet or exceed the following standards.

(1) ±20 ft horizontal and ±3 ft vertical accuracy: Precision and APV final and missed approach segments.

(2) ±50 ft horizontal and ±20 ft vertical accuracy: Non precision final segments; missed approach 40:1 surface evaluation; circling areas; and the Obstruction Evaluation Area (OEA) for a climb to 400 ft above DER on all departure procedures.

(3) ±250 ft horizontal and ±50 ft vertical accuracy: Intermediate segment. All areas outside of OEA for a climb to 400 ft above DER.

(4) ±500 ft horizontal and ±125 ft vertical accuracy: (1,000 ft ROC) Initial segments, feeder segments, en route areas, missed approach holding/level surface evaluation; MSA, Safe Altitude 100 NM and the level route portion for SIDs.

(5) ±1,000 ft horizontal and ±250 ft vertical accuracy: (1,500/ 2,000 ft ROC) Feeder segments, en route areas, Safe Altitude 100 NM, MVA and the level route portion for SIDs.

Note: The above values are assumed accuracy. If the data used does not meet that minimum value of accuracy, the obstacle data must be adjusted by the actual value of the accuracy data. If the data used meets the value of accuracy, the data can be used as is. By “meets that minimum value of accuracy” it is meant that the accuracy value is within that specified. (i.e ±5 ft meets a requirement of ±20 ft and as such that data could be used, but ±25 ft does not meet a requirement of ±20 ft and as such the ±25 ft would have to be used to adjust the obstacle data in this example)

1.2. Accuracy Standards Application

a. Determine the segment-controlling obstacle using raw obstacle data only (i.e., accuracy adjustments not applied) then, if required under paragraph 1.1.b., add the actual horizontal and/or vertical accuracy adjustments to the raw obstacle data to determine the obstacle’s most adverse location and elevation.

b. For any one segment the controlling obstacle needs to be determined using the raw obstacle data only (as if no accuracy data were available). Once that obstacle has been identified and determined not to meet the minimum requirement for accuracy, the accuracy data for only that one obstacle needs to be applied in the most adverse location and elevation (i.e. the location and elevation that will be most penalizing). For example if the controlling obstacle has a raw height of 250 feet and an accuracy of ±15 feet, that obstacle (and only that obstacle in that segment) would be considered to have a height of 265 feet.

c. Accuracy adjustments are not applied to obstacles evaluated relative to TP 308, volume 1, paragraph 289.

Examples:

1) **Non Precision Final Approach Segment** (±50 ft H, ±20 ft V Required Accuracy)
   - Controlling Obstacle: 175 ft with ±55 ft horizontal and ±20 ft vertical accuracy
   - Conclusion(s): Horizontal standard NOT met, vertical standard met.
   - Action(s): Adjust horizontal obstacle location data by 55 feet horizontally. No vertical adjustment is required.

   Note: This example is for a case where the minimum accuracy value (as stated in Annex E section 1.1) is not met (in fact for this example only the horizontal minimum accuracy value is not met, while the vertical minimum accuracy value is in fact met).

2) **Precision Final Approach Segment** (±20 ft H, ±3 ft V Required Accuracy)
   - Controlling Obstacle: 112 ft with ±20 ft horizontal and ±2 ft vertical accuracy
   - Conclusion(s): Both horizontal and vertical standards are met.
   - Action(s): Nil (no adjustment required)

   Note: This example is for the case where the minimum accuracy value (as stated in Annex E section 1.1) is met. In both examples the way to implement Annex E is provided.

CRITERIA FOR THE DEVELOPMENT OF INSTRUMENT PROCEDURES

TP 308 / GPH 209 – CHANGE 7

ANNEX F

PRECIPITOUS TERRAIN CALCULATIONS

TRANSPORT CANADA
NATIONAL DEFENSE

5 January 2017

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PRECIPITOUS TERRAIN CALCULATIONS

1.0. General

Precipitous Terrain Equations, Parameters, Interests, Weights, and Adjustment Values. A digital terrain data base (100 m or 3 arcsecond separation density or better) must be used for the determination of precipitous terrain. The precipitous terrain area will contain the prescribed segment (both primary and secondary, if applicable) and a 2 NM buffer surrounding that segment. For segments that are comprised of multiple legs, each leg should be evaluated separately. The digital terrain data within that defined area will be analyzed electronically to determine the values of five specific parameters [g(1) through g(5)], which will be transformed into interest values [I(1) through I(5)], weighted [W(1) through W(5)] and combined to determine the base precipitous adjustment,

a. Step 1. The equations, minimum and maximum thresholds, and weight values for each parameter are:

<u>Average elevation</u>

$$g(1) = \Sigma \frac{h(x,y)}{n}$$

min(1) = 600 $meters$

max(1) = 3000 $meters$

(1) = 0.05

<u>98th percentile – 2nd percentile height differential</u>

$$g(2) = h_{98percentile} - h_{2percentile}$$

min(2) = 250 $meters$

max(2) = 2500 $meters$

(2) = 0.30

<u>Slope gradient</u>

$$g(3) = \sqrt{\left(\frac{D_a}{D}\right)^2 + \left(\frac{D_b}{D}\right)^2}$$

min(3) = 0.015

max(3) = 0.060

(3) = 0.10

Standard deviation from plane of best fit

$$g(4) = \sqrt{\frac{\Sigma\left[h(x,y) - \left(\frac{D_a \times x}{D} + \frac{D_b \times y}{D} + \frac{D_c}{D}\right)\right]^2}{n}}$$

$min(4) = 40$ meters

(4) = 200 meters

(4) = 0.35

98th percentile max - min height differential within 0.50 NM of each terrain posting

$g(5) = (h_{max} - h_{min})_{98percentile}$

(5) = 100 meters

(5) = 1000 meters

(5) = 0.20

b. Step 2. The interest values are based on the parameter thresholds and are found via this piecewise function:

$g(i)$ < $min(i)$:

(i) = 0

(i) ≤ (i) ≤ max(i):

$$I(i) = \frac{g(i) - min(i)}{max(i) - min(i)}$$

(i) > max(i):

(i) = 1

c. Step 3. The combined interest (CI) is computed as follows:

$CI = W(1) \times I(1) + W(2) \times I(2) + W(3) \times I(3) + W(4) \times I(4) + W(5) \times I(5)$

d. Step 4. The base precipitous adjustment (BA) is also a piecewise function with a minimum threshold of 0.20 and a maximum of 0.60.

$CI < 0.20$:

$BA = 0$

$0.20 \leq CI \leq 0.60$:

$BA = 500 \times CI - 50$

$CI > 0.60$:

$BA = 250$

e. Step 5. Finally, BA is applied and rounded varyingly depending on the evaluated segment to derive the actual adjustment (A) [see Note 1].

Rounded to the next higher 1 foot increment:

<u>Precision and APV finals</u> [see Note 2]

$A = 0.10 \times HAT$

Rounded to the next higher 10 foot increment:

<u>Non precision finals</u>

$A = BA$

<u>Intermediate</u>

$A = 1.25 \times BA$

<u>Initial, holding, & missed approach level surface</u>

$A = 1.5 \times BA$

Note 1: Precipitous terrain evaluation is not required for departures and the sloping portion of missed approach. Where precipitous terrain evaluation is required, refer to additional guidance provided by criteria.

Note 2: When $BA > 0$, use the HAT output based on final and missed approach assessment, excluding remote altimeter adjustments.

Explanation of variables:

$h(x,y)$ = height (meters) of the selected terrain posting

x = x coordinate of the selected terrain posting

y = y coordinate of the selected terrain posting

n = number of terrain postings in the area

$h_{98percentile}$ = height (meters) of the 98th percentile terrain posting

$h_{2percentile}$ = height (meters) of the 2nd percentile terrain posting

h_{max} = height (meters) of the highest terrain posting within 0.50 NM of the selected post

h_{min} = height (meters) of the lowest terrain posting within 0.50 NM of the selected post

$$D = \begin{vmatrix} \sum x^2 & \sum x \times y & \sum x \\ \sum x \times y & \sum y^2 & \sum y \\ \sum x & \sum y & n \end{vmatrix}$$

$$D_a = \begin{vmatrix} \sum x \times h(x,y) & \sum x \times y & \sum x \\ \sum y \times h(x,y) & \sum y^2 & \sum y \\ \sum h(x,y) & \sum y & n \end{vmatrix}$$

$$D_b = \begin{vmatrix} \sum x^2 & \sum x \times h(x,y) & \sum x \\ \sum x \times y & \sum y \times h(x,y) & \sum y \\ \sum x & \sum h(x,y) & n \end{vmatrix}$$

$$D_c = \begin{vmatrix} \sum x^2 & \sum x \times y & \sum x \times h(x,y) \\ \sum x \times y & \sum y^2 & \sum y \times h(x,y) \\ \sum x & \sum y & \sum h(x,y) \end{vmatrix}$$

To compute the determinant, use the following:

$$\text{Matrix} = \begin{vmatrix} A & B & C \\ D & E & F \\ G & H & I \end{vmatrix}$$

$$D = A \times E \times I + B \times F \times G + C \times D \times H - A \times F \times H - B \times D \times I - C \times E \times G$$