



ICAO

Doc 9905

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

Third Edition, 2021



Approved by and published under the authority of the Secretary General

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Published in separate English, Arabic, Chinese, French, Russian
and Spanish editions by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 Robert-Bourassa Boulevard, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int

Third edition 2021

**Doc 9905, *Required Navigation Performance Authorization
Required (RNP AR) Procedure Design Manual***
Order Number: 9905
ISBN 978-92-9265-613-3 (print version)

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AMENDMENTS

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

RECORD OF AMENDMENTS AND CORRIGENDA

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FOREWORD

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

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

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

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

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

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

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

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

DEFINITIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ABBREVIATIONS AND ACRONYMS

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

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

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

Chapter 1

DESCRIPTION OF REQUIRED NAVIGATION PERFORMANCE AUTHORIZATION REQUIRED (RNP AR)

1.1 PURPOSE OF THE MANUAL

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

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

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

1.2 APPLICATION

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

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

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

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

Chapter 2

RNP AR APPROACH PROCEDURE DESIGN

2.1 UNDERLYING PRINCIPLES

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

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

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

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

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

2.3 STANDARD CONDITIONS

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

- a) final approach vertical protection is based on the use of a barometric VNAV system and the operational minimum DA/H is based on barometric altimeter;
- b) aircraft lateral dimensions are considered in certification (no additional procedure design action is required in the lateral protection); and
- c) early missed approach is safeguarded by the certification and approval process.

2.4 TERRAIN EFFECTS

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

2.5 LATERAL PROTECTION

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

Table 2-1. RNP navigation accuracy requirements

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

2.6 VERTICAL PROTECTION

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

- a final approach surface based on the VEB of the barometric altimeter system;
- a horizontal surface, connected to the final approach surface at threshold level, based on a height loss (HL) and a transition distance (TrD), and
- a missed approach (Z) surface, connected to the horizontal surface at threshold level.

Chapter 3

GENERAL CRITERIA

3.1 AIRCRAFT SPEED CATEGORIES

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

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

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

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

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

Restriction on aircraft category and indicated airspeed

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

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

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

Table 3-1 b). IAS (kt)

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

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

Calculating true airspeed

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

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

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

where:

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

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

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

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

3.2 CALCULATING TURN RADIUS AND BANK ANGLE

Speeds for turn calculations

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

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

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

Calculating the turn radius for turns

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

$$\text{TWC} = 12h + 87 \text{ km/h}$$

where:

h is in 1000 m above sea level;

or

$$\text{TWC} = 2h + 47 \text{ kts}$$

where:

h is in 1000 ft above sea level.

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

- 19 km/h (10 kt) at or below 152 m (500 ft) above AD elevation
- 37 km/h (20 kt) from 152 m (500 ft) to at or below 305 m (1 000 ft) above AD elevation
- 56 km/h (30 kt) from 305 m (1 000 ft) to at or below 610 m (2 000 ft) above AD elevation
- 74 km/h (40 kt) from 610 m (2 000 ft) to at or below 915 m (3 000 ft) above AD elevation

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

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

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

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

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

where:

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

or

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

where:

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

up to a maximum value of three degrees/second.

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

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

where:

V = (TAS + wind speed)

Turn radii based on non-standard bank angles

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

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

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

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

$$DTA = r \tan(A/2)$$

where:

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

A = turn angle.

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

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

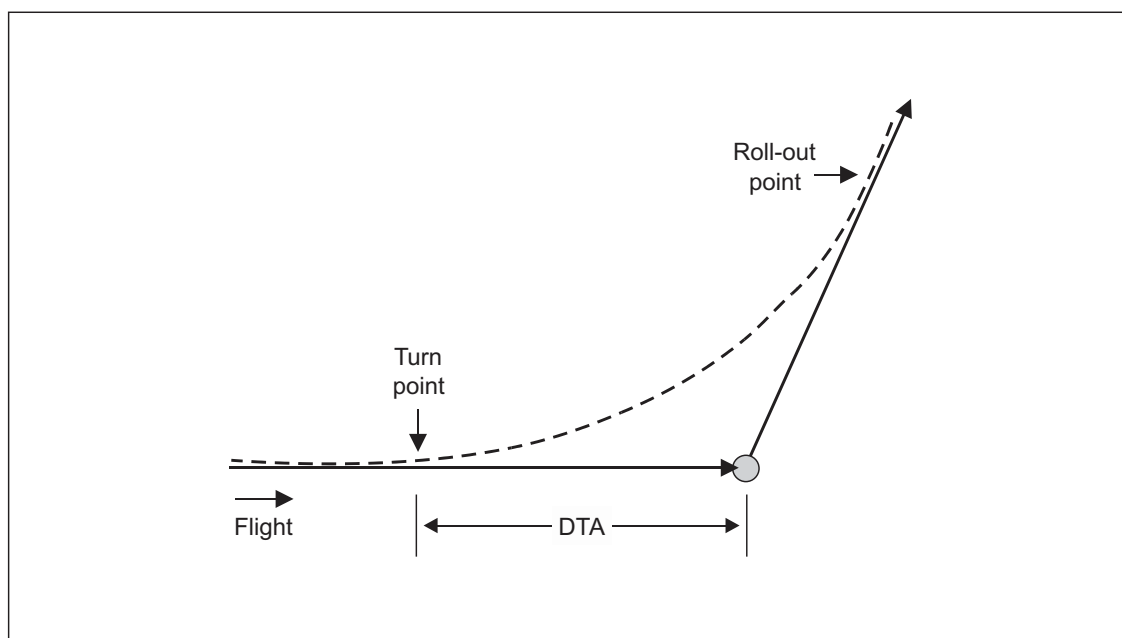


Figure 3-1. Distance of turn anticipation (DTA)