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Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation

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Prepared by: SC-227

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Foreword

This document was prepared by RTCA Special Committee 227 (SC-227) and approved by the RTCA Program Management Committee (PMC) on December 15, 2015.

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- Analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- Developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- Assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

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1. PURPOSE AND SCOPE

1.1 Introduction

This document contains Minimum Operational Performance Standards (MOPS) for airborne area navigation equipment operated in a Required Navigation Performance (RNP) operational environment. The MOPS documents the minimum requirements and guidance for one functional part of the airplane system that is described and specified by the MASPS, DO-236C Plus Change 1, and ED-75D. These standards specify system characteristics that should be useful to designers, manufacturers, installers and users of the equipment.

Equipment conforming to the requirements of this document is herein referred to as "RNP" equipment. The requirements of the MOPS are consistent with the definitions and navigation specifications for RNP contained in the ICAO PBN Manual, Doc 9613. This is because the MOPS presents a comprehensive set of minimum requirements for RNP that enables a manufacturer to develop equipment suited to designated system installations and PBN operational applications. The PBN manual navigation specifications represent end use criteria for aircraft systems and equipment that are oriented to specific operational needs, capabilities and performance. The result is that each navigation specification describes specific aircraft equipment, performance capabilities and functional requirements that, if common with the MOPS, are mostly just a subset of the total MOPS RNP requirements. Thus the RNP equipment that meets all of the requirements of this MOPS generally will not necessarily be the same as the RNP systems and equipment eligible in any one navigation specification even though they will have requirements in common.

In addition, barometric vertical navigation (VNAV) requirements are defined for aircraft that provide this capability to ensure accurate and predictable vertical paths. The VNAV requirements in this document are consistent with instrument approach procedures with vertical guidance (APV). Due to the wide disparity of climb performance of different aircraft types, this MOPS only addresses vertical path definition requirements for level flight and descent.

The committee also decided that to achieve the best alignment and implementation of RNP equipment to the planned operational requirements and applications, the MOPS should organize the appropriate requirements and guidance to fit the operational near term applications as well as allow for a step to far term applications.

Compliance with these standards is recommended as one means of assuring that the equipment will perform its intended function(s) satisfactorily under all conditions normally encountered in routine aeronautical operations. Any regulatory application of this document is the sole responsibility of the appropriate governmental agencies.

Section 1.0 of this document provides information needed to understand the rationale for the equipment characteristics and requirements stated in the remaining sections. It describes typical equipment applications and operational goals, as originally envisioned by Special Committee 181 then expanded by Special Committee 227, and forms the basis for standards stated in Sections 2.0 through 3.0. Definitions and assumptions essential to proper understanding of this document are also provided in this section.

Section 2.0 contains the minimum performance standards for the equipment. These standards specify the required performance under standard operating conditions and stressed physical environmental conditions. Also included are recommended bench test procedures necessary to demonstrate compliance.

Section 3.0 provides references to installation guidance material for installed equipment performance, and also describes the performance required of the installed equipment. Tests for the installed equipment are included when performance cannot be adequately determined through bench testing.

Section 4.0 describes the operational characteristics for equipment installations and defines conditions that will assure the operator that operations can be conducted safely and reliably in the expected operational environment.

Section 5.0 contains the committee membership list.

Appendix A contains glossary, acronyms, and abbreviations.

Appendix B contains example system compliance analysis.

Appendix C contains navigation system requirements and infrastructure characteristics.

Appendix D contains leg type definitions.

Appendix E contains the WGS-84 earth model and geodesic path example

Appendix F contains human factors considerations

Appendix G contains CNS-ATM system considerations

Appendix H contains temperature compensation requirements

Appendix I is intentionally left blank.

Appendix J contains examples of RNP Holding Pattern entries

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Appendix L contains test scenario templates for radius-to-fix (RF) leg performance tests.

Appendix M provides guidelines for the collection and analysis of flight technical error (FTE) data.

Appendix N contains Time of Arrival Control requirements.

Appendix O contains an example of ETA compliance analysis

Appendix P contains an example of VNAV compliance analysis

Appendix Q contains examples of descent paths

The term “equipment” as used in this document includes all components or units necessary (as determined by the equipment manufacturer or installer) for the equipment to perform properly its intended function. For example, the RNP “equipment” may include: a computer unit, as well as associated sensor(s), an input-output unit that interfaces with existing aircraft displays/systems, a control unit, a display, etc. In the case of this example, all of the associated components or units comprise the “equipment”. It should not be inferred from this example, however, that every RNP equipment will necessarily include all of the foregoing components or units. The particular components of the RNP equipment will depend upon the design used by the equipment manufacturer, subject to the constraint that the equipment must meet the applicable requirements of this MOPS.

Note: During the introduction of RNP, RNAV operations will need to be supported.

1.2 System Overview and Intended Function

The RNP equipment as addressed in this document provides the functions of position estimation, path definition, associated control displays and system alerting, along with interfaces for path steering, situational awareness and map displays. See Figure 1-1 for the Navigation Equipment Block Diagram. The associated control displays and system alerting functions may integral to the RNP equipment, or may be implemented externally. When implemented externally (as depicted by the dashed line box), the requirements of this MOPS apply to those RNP equipment interfaces that support these functions. Environmental qualification required by this MOPS is applicable to the navigation functions depicted. Display, flight director and autopilot systems are not considered part of the RNP equipment and do not require environmental re-qualification for use with RNP equipment.

> *Note: The intended function at the airplane systems level is still subject to assessment and a determination of acceptability through aircraft and operator qualification for RNP operations.*

Equipment compliance to these standards will facilitate approval of the installed system to the RNP RNAV requirements defined in RTCA/DO-236C, Change 1 to DO-236C, and EUROCAE/ED-75D.

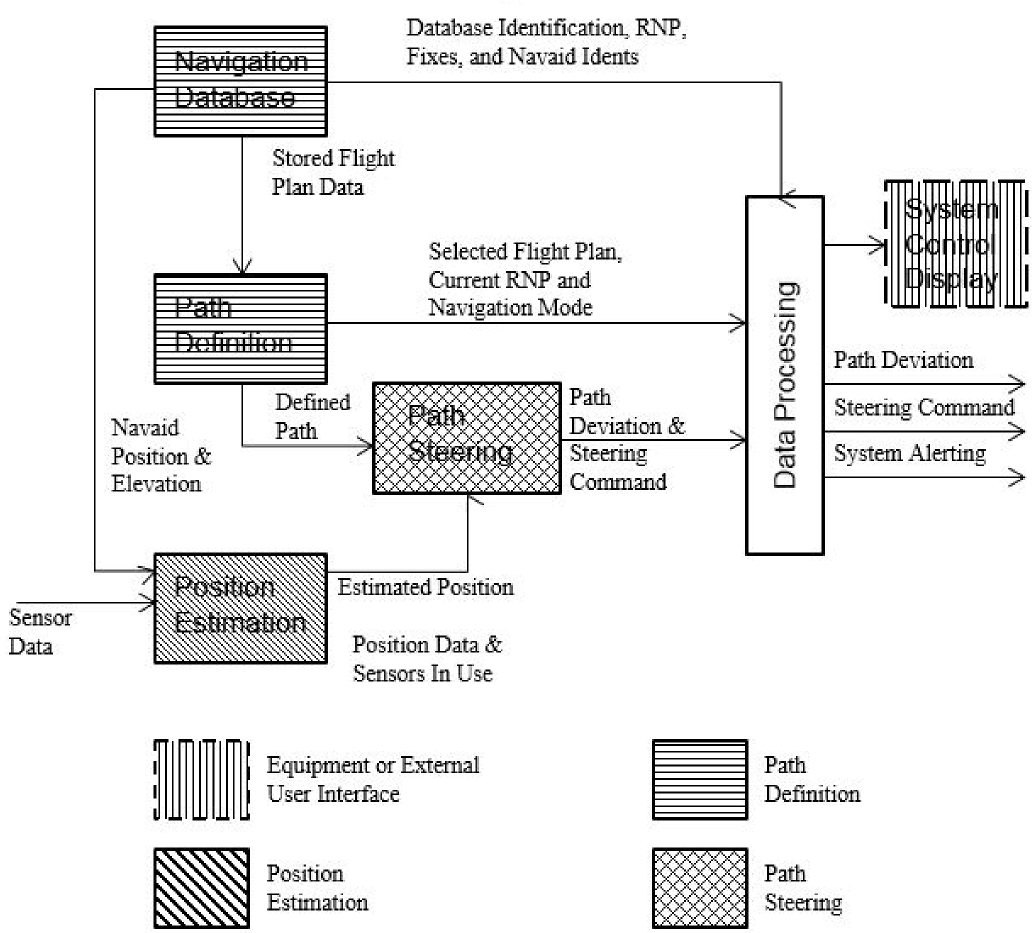

Figure 1-1: Navigation Equipment Block Diagram

1.2.1 Position Estimation

Position estimation is a means for determining the aircraft's position over the surface of the earth. Data is used, either from radio signals (received from ground-based navaids or from satellites) or from onboard autonomous navigation sensors, to derive an estimated position. The position estimation function obtains information concerning any ground-based navaids that are being used from a navigation database. The function also provides position data for display of parameters such as estimated position, estimate of position uncertainty, ground speed and track angle, based on the sensor data being processed.

The method by which the position estimation function may process the different types of sensor data is described herein. The document provides overall requirements for system performance which in itself may constrain the methods to be used through specification of accuracy, integrity, continuity, and availability of the data.

1.2.2 Path Definition

The path definition function computes the flight path to be flown in the vertical, horizontal and time dimensions. The elements of a flight path include fixes, path constraints (altitude, speed, location) and leg types such that a seamless horizontal and vertical path between the start and end of the planned flight can be achieved.

The lateral aspects of path definition determine a geographically fixed ground track from origin to destination. The sub-functions involved are:

1. Fix definition, whether derived from an airborne database, pilot entry, or data uplink;
2. Leg type definition;
3. Leg transition definition, e.g., turns;
4. Tactical operations, e.g. direct-to, lateral offsets and holds.

The vertical aspects of path definition determine a path profile from origin to destination. The vertical aspects are extensions to the sub-functions prescribed for the lateral path:

1. altitude/flight level constraints, associated with fix definition
2. vertical angle, associated with leg definition
3. speed restrictions, associated with fix definition

Note: Path definition should include an accurate lateral and vertical path, with a best estimate of times of arrival associated with each lateral and some vertical fixes.

As the ATM system evolves, the digital air/ground datalink interface will become an integral part of path definition through uplinks of pre-defined procedures to be used from the airborne navigation database or fixes that the system must use to create a route or procedure.

1.2.3 Path Steering

The defined path is used by the path steering function, where it is combined with the estimated position and time to determine parameters of path deviation and steering commands. These parameters are used for correcting errors relative to the defined path in terms of lateral, vertical and time of arrival.

1.2.3.1 Lateral Steering

Typical of the parameters for lateral control are the computations of cross-track error and track angle error. Having determined the lateral path steering errors, the lateral steering sub-function computes a steering command that may be used by the aircraft flight control system (autopilot, flight director), and a path deviation for display to the flight crew on their primary flight instruments. Both types of commands, the latter in combination with the pilot, attempt to correct the errors and hold the aircraft to the defined path. The overall navigation performance achieved will depend upon the type of steering command selected, i.e. automatic or manual.

1.2.3.2 Vertical Steering

Typical of the parameters for vertical control are the computation of speed, thrust, altitude, vertical track error, and flight path angle. Having determined the vertical path errors, the vertical steering and control sub-function computes commands and indications, a steering command that may be used by an aircraft flight control system (autopilot, flight director), and path guidance/deviation data for display to the flight crew on the flight instruments. These commands, where the steering management and display may be in combination with the pilot, attempt to correct the errors and hold the aircraft to the defined vertical path. The overall navigation performance achieved will depend upon the type of steering command selected, i.e. automatic or manual, and aircraft flight performance.

1.2.4 Displays and System Alerting

The user interface is achieved through displays, alerting functions, and system controls. These functions provide facilities for system initialization, flight planning and progress, active guidance control, and presentation of navigation data for situational awareness. These functions should be compatible with the overall flight deck philosophy for the aircraft. Similarly, flight crew interaction with the navigation system should be efficient and the design should take into account the effects of crew workload.

1.2.5 Aircraft Flight Control System

Lateral and vertical steering guidance is provided by an interface with the aircraft flight control system, specifically, the flight director and autopilot systems. The flight director interface provides a visual indication of the required steering. The pilot may steer manually, or the autopilot interface may provide automatic steering.

These interfaces may reduce the lateral and vertical flight technical error by providing the improved anticipation, maneuvering, and control afforded by flight control systems. The overall system navigation performance may depend on the steering mode selected, either manual or automatic, and on aircraft performance.

1.3 Operational Goals and Applications

This MOPS establishes requirements for the airborne navigation component of the CNS/ATM operating environment, and supports operations concepts predicated on a systematic application of improved capabilities for traffic planning, operations, management, surveillance and infrastructure. The navigation system described in this MOPS will be compatible with and a catalyst in both existing and future airspace operations.

1.3.1 Path Definition

Operation in RNP airspace, especially at lower RNPs, will be characterized by reliable, predictable and repeatable ground tracks. This should be achieved by aircraft equipment and operating environments that utilize the same airspace and path definitions. Additionally, the aircraft equipment and operating environment will support the conduct of operations where a vertical descent profile and/or time of arrival is specified, including arrival and approach procedures with displayed guidance and path keeping control, as appropriate.

1.3.2 Containment Methodology

An aircraft meeting the required navigation performance will remain within the confines of the RNP airspace with a predefined level of confidence. Application of this MOPS will enable assignment of a value to that level of confidence and provide a methodology to demonstrate that the aircraft system meets the specified RNP. Following consideration of typical performance of existing navigation systems and evaluating what was necessary to obtain operational benefit, a lateral containment limit of two times the RNP (2xRNP) has been chosen. The lateral containment limit is also an enabling element for the ICAO PBN requirement for on-board performance monitoring and alerting.

An aircraft meeting vertical navigation performance will remain in proximity to the vertical path and its constraints with a predefined level of confidence. Application of this MOPS will enable assignment of a value to that level of confidence. Following consideration of typical performance of existing equipment and systems, a vertical path performance limit (VPPL) that represents 99.7% performance has been chosen. The VPPL is defined to be independent of the lateral containment limit.

These limits and their corresponding assurance levels should be used to support the development of optimal RNP airspace and procedures.

1.3.3 Contribution to Increased Capacity

In certain regions of the world, current air traffic systems are at, or rapidly reaching capacity limits. Continued growth will rely on improvements in navigation, communication and surveillance techniques. The application of the path definition, position estimation and containment requirements in this document will assist the airspace planner in designing airspace or procedures which may support increased capacity.

1.3.4 User-Preferred Trajectories and Trajectory Based Operations

The concept of user-preferred trajectories may be a means to improve aircraft operations. The path definition and steering concepts of this document may be used to support conflict probing and detection which is regarded as an important element for the implementation of user-preferred trajectories.

Trajectory Based Operations (TBO) represent a change in the CNS/ATM operations paradigm where flexibility and adaptability are introduced into airspace operations through aircraft flight trajectories that can be quickly created or redefined by ground planning and ATM systems, and communicated to and applied by the aircraft. A core element of TBO is RNP which establishes the basis for aircraft performance and behavior in the airspace as well as for the new or revised procedures sent to the aircraft.

1.3.5 Advanced RNP Applications

Advanced RNP (A-RNP) is an ICAO navigation specification that combines several functional elements into one specification. Additional information can be found in Section 1.4.6.

1.4 Required Navigation Performance (RNP)

1.4.1 Area Navigation

The CNS/ATM operating environment is expected to be based on navigation defined by geographic fixes. Routes and instrument procedures will not be restricted to the location of ground-based navigation aids. This concept, known as Area Navigation, is not new. An element that has been missing is the level of confidence of navigation accuracy. The standards defined in the MASPS, DO-236C/ED-75D, integrate the concepts of Required Navigation Performance with that of Area Navigation to provide this level of confidence. These standards also include optional vertical navigation and time of arrival control requirements.

1.4.2 PBN and RNP Concept

Performance-based navigation (PBN) has been defined in the ICAO PBN Manual.

PBN (as defined by the ICAO PBN Manual): Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.

The ICAO PBN Manual also states:

> *Performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity and functionality needed for the proposed operation in the context of a particular airspace concept. Availability of GNSS signal in space (SIS) or some other NAVAID infrastructure is considered within the airspace concept in order to enable the navigation application.*

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

RNP system (as defined by ICAO PBN Manual): An area navigation system which supports on-board performance monitoring and alerting.

This MOPS represents the minimum requirements for RNP that enables manufacturer development of the airborne equipment that is installed into an airplane intended to perform RNP operations. For clarity as well as to maintain consistency with RNP as defined by ICAO, the term RNP is used to describe MOPS equipment.

The term "RNP RNAV" is only used when describing or discussing the aircraft system, performance, and more comprehensive capabilities defined in the MASPS, DO-236C. Additionally, the term "VNAV" has been further developed to address the vertical aspects that are expected to be associated with RNP operations. All of these terms are described in Section 1.7.

> *Note: The PBN manual has a Navigation Specification for RNP AR operations. This MOPS does not address the equipment requirements to support such operations.*

1.4.3 Application of the Term RNP

The term RNP is applied as a descriptor for airspace, routes and procedures (including departures, arrivals, and instrument approach procedures). The descriptor is flexible and can apply to a unique approach procedure or to a large region of airspace. Examples of its use are RNP airspace, RNP route, etc.

1.4.4 Navigation Accuracy

This document uses the navigation accuracies, i.e. the RNP, that are consistent with those defined by the ICAO PBN Manual as the basis for establishing requirements. These include those defined in the PBN navigation specifications for RNP APCH, Advanced RNP, RNP 0.3, RNP 1, RNP 2, and RNP 4.

The committee also recognized that it is impossible to anticipate the complete range of potential applications of RNP requirements. The requirements in this MOPS are intended to be applicable to any RNP, not only those that are described below. While the accuracy and containment requirements in Section 2.0 of this document can be scaled to any RNP, the requirements in the MOPS apply to discrete values of RNP. The following RNPs are intended to be applicable to the following initial operational usage situations:

RNP-0.3 to RNP 1.0	Approach
RNP-1.0	Terminal area
RNP-2.0	En route domestic, En route (continental) airspace, and oceanic/remote operations with reduced separation (e.g. up to RNP 4)

1.4.5 Vertical Navigation (VNAV)

The CNS/ATM operating environment is expected to support vertical profiles defined by flight level/altitude constraints, speeds and/or vertical angles. The use of vertical navigation (VNAV) is intended to provide a level of confidence in vertical navigation performance.

The MOPS specifies aircraft equipment with barometric vertical performance that, when installed, is only required to meet a 99.7% accuracy level.

1.4.6 Advanced RNP

A-RNP encompasses the PBN navigation specifications (i.e., RNAV 5, RNAV 2, RNAV 1, RNP 2, RNP 1, and RNP APCH) and therefore is intended to simplify the RNP equipment approval process. Operationally, selected A-RNP functions may be required for a specific operation while others would not be invoked until an operation requiring their function is performed.

The committee considers the entire MOPS as appropriate in support of development of RNP equipment that satisfies the criteria for RNP applications. For information, Table 1-1 lists the additional functional elements contained in the A-RNP navigation specification (ICAO PBN Manual, Table II-C-4-2) and the MOPS requirements that are associated with each one. The list does not reflect how or when the A-RNP additional functional elements are addressed in operational implementations or equipment classes.

Table 1-1: Advanced RNP Functions

Advanced RNP Function	Equipment Requirement
Radius-to-Fix (RF)	2.2.1.2.1
RNAV Holding	2.2.1.2.6
Scalable RNP	2.2.1.4.1.2
Fixed Radius Transition (FRT)	2.2.1.2.9.2
Time of Arrival Control (TOAC)	2.2.4
Continuity	2.2.1.5.3

Note 1: It is recognized that only the highest class of RNP equipment will contain a fully functional RNP holding feature as defined in this MOPS. Other equipment classes may choose to implement RNAV holding as defined in PANS-OPS Volume 1. However, equipment manufacturers are encouraged to incorporate the fly-by holding entries depicted in Appendix J as an interim step to RNP airspace implementation.

Note 2: The TOAC function, as defined at the system level in DO-236C Change 1 and ED-75D, is not sufficiently mature from a total ground/air system perspective and is therefore optional for RNP equipment.

Note 3: Continuity has typically referred to complete loss of function. However, in this MOPS and other documents such as the MASPS and ICAO references, continuity is applied in the context of the RNP operation and the concept has been expanded to include the requirement that functions such as the current RNP, lateral containment, vertical path performance, and time of arrival control operations can be maintained.

Note 4: The continuity requirement for A-RNP, 4.3.3.5.2.3 of the ICAO PBN Manual, is about loss of function, and the committee agreed that the only correlation to the MOPS is to the loss of navigation performance requirement in 2.2.1.5.3. Higher Continuity is associated with a dual system configuration.

1.5 Assumptions

The concept of RNP has been developed with the objective of defining all applicable requirements associated with navigation performance, including both airborne and external navigation elements. Airborne elements (e.g., engines, generators) other than those included as part of the navigation system are assumed to be functioning normally. This section states the assumptions that have been made within the MOPS for the purpose of defining the airborne requirements. These assumptions form requirements or guidance that must be followed by the external navigation elements to realize the airspace optimizations possible with RNP.

1.5.1 Navigation Infrastructure

All navigation aids are assumed to comply with the signal-in-space assumptions defined in Appendix C. If a particular facility does not comply or a facility type is not authorized for use, it is assumed the facility is NOTAM'ed such that it can be inhibited from use for RNP operations. If a class of facilities does not comply (e.g., VOR facilities), it is assumed that navigation procedures are not based on those facilities and the procedure clearly identifies the sensor as not authorized.

1.5.2 Defining Airspace

1.5.2.1 RNP

As stated in the ICAO PBN Manual, RNP may be specified for a route, a number of routes, or airspace which an airspace planner or authority chooses.

The RNP RNAV containment limit is intended to serve at least two purposes in the development of airspace. It should provide a means to facilitate the safety assessments for separation and obstacle clearance in the development of routes, areas and procedures. By providing a demonstrated bound on error performance, it should enable reductions in separation buffers derived from traditional collision risk methods. The containment limit is also a performance assurance element of the ICAO PBN requirement for on-board performance monitoring and alerting.

1.5.2.2 VNAV

VNAV is a tool to facilitate the application of vertical navigation (three dimensional point-to-point) for level flight and descent. Due to the wide disparity of climb performance of different aircraft types, this MOPS does not address VNAV path definition requirements for the climb segment. However, speed restrictions and altitude constraints must still be considered in all phases of flight.

It is expected that the required implementation of speed restrictions as defined in this MOPS will be understood by regulatory authorities and airspace/procedure designers. The operational use of speed restrictions in the airspace must take care to reflect the actual avionics design for RNP RNAV systems.

It is expected that airspace and procedure designs will take into account any deceleration required prior to a waypoint- or altitude-based speed restriction, as well as ensure the careful application of altitude constraints intended to define or bound a vertical flight path.

For flight operations outside the final approach segment, it is expected that airspace and procedure designs will take into account the impact of horizontal coupling error (the vertical error resulting from horizontal along track position estimation error coupling through the desired vertical path).

1.5.3 Navigation Error

This document addresses all navigation errors associated with the RNP equipment, excluding those due to human error.

1.5.4 Navigation Data

This MOPS assumes the navigation data is current and complies with RTCA/DO-201A/EUROCAE ED-77, Standards for Aeronautical Information, and all data is processed in accordance with the requirements of RTCA DO-200B/EUROCAE ED-76A, Standards for Processing Aeronautical Data.

1.5.4.1 Reference Earth Model

All navigation data is assumed to be referenced to the WGS-84 earth model in accordance with ICAO Annex 15 for lateral and precision landing path points. All altitude data will be referenced to the MSL geoid and standard atmospheric pressure model.

1.5.4.2 Desired Path

An RNP flight plan is generally defined by a series of fixes derived from one or several of the following ATS Route "types" (per ICAO definition):

- Routes (e.g. airways, oceanic tracks);
- User preferred trajectories;
- Standard instrument departure (SID) procedures
- Standard terminal arrival (STAR) procedures
- Instrument Approach procedures

RNP routes and user preferred trajectories are assumed to use a series of fixes. The desired path is defined by a series of geodesic tracks joining successive fixes. Also, RNP procedures are assumed to use the path/terminator (legs) concept for SIDs, STARs, and Instrument approaches. The desired path is defined by a series of path/terminators (leg types). The procedure designer should note that only a limited set of leg types are allowed for RNP procedures (see Section 2.2.1.2).

Note: These assumptions have been made in order to maintain compatibility with existing database specifications, as stated in Aeronautical Radio, Inc. (ARINC) 424 Specification, titled Navigation System Database.

1.5.4.3 Flight Plan Leg Transitions

1.5.4.3.1 Lateral

For airspace planning purposes, when transitioning between flight path legs, the RNP is assumed to be the largest RNP associated with the two legs defining the transition (e.g., when transitioning from an RNP 1 leg to an RNP 0.3 leg, the airspace planners will assume transition containment based on RNP 1).

The track change at a fly-by fix which is part of an RNP route or procedure is assumed to be 120 degrees or less at altitudes below FL195, or 70 degrees or less at or above FL195.

Where a track change greater than these values is required as part of an RNP procedure or route, the procedure or airspace designer is expected to utilize the radius to a fix (RF) leg or fixed radius transition (FRT), as appropriate.

Note: Applying an offset to the RF or FRT for large course changes may result in unflyable paths.

If fly-over transitions are used, for example at the missed approach point, the leg following the fly-over fix is assumed not to have the requirements of RNP applied to it, as far as the path is not repeatable and airspace protection cannot follow the RNP concept.

If a fixed radius transition at a fix along a route is used, the transition is assumed to be specified in the navigation data base.

1.5.4.3.2 Vertical

When transitioning from one profile segment to another, (e.g., level flight to descent, descent to level flight, or from one descent profile to another, etc.) the vertical path performance limit is assumed to be consistent with the airspace limits on either side of the transition.

VNAV as described in this document is based upon the vertical fly-by transition. The vertical fly-by is a controlled maneuver between two vertical path segments (reference Section 2.2.2.2.6.1.3) such that a smooth transition onto the next vertical path segment is performed. It is assumed the procedure designer will use the vertical fly-by in their assessment of obstacle identification and vertical separation. Where vertical fly-by transitions occur, it is assumed that the airborne systems will provide a means for look-ahead maneuver anticipation (e.g. constant “g” capture) and guidance such that the aircraft altitude will follow a known trajectory. The procedure designer is assumed to use this in assessments of obstacle identification and vertical separation.

1.5.5 Datalink Considerations

Where existing legacy datalink interfaces, such as those for FANS, are used to create an ad hoc ATC clearance in RNP airspace (i.e., a route or procedure not contained in the navigation database), the clearance lacks the capability to specify a performance requirement for the fixes and legs to be flown. Additionally, the same datalink interface will also preclude the specification of procedures containing turns with a fixed-radius. ATC and Operators should consider this in the implementation of PBN operations that utilize datalink.

As the ATM system evolves, the digital air/ground datalink interface will become an integral part of path definition through uplinks of pre-defined procedures to be used from the airborne navigation database or fixes that the system must use to create a route or procedure. It is expected that when the next generation of datalink services is implemented, the datalink interface will have the capability that:

- allows the uplink of performance requirements for fixes as well as turns with a fixed radius.
- makes requests for aircraft calculated estimated times of arrival as part of ADS contracts
- allows for clearances containing time constraints (AT, AT or BEFORE, AT or AFTER)
- allows for variable RNP to be applied to the aircraft flight plan
- supports ground requests for estimated time of arrival, and earliest/latest time of arrival.

1.5.6 Polar Navigation

Terminal area operations with an associated RNP are assumed not to be conducted at latitudes north of 85° N and south of 85° S. In these regions, holding patterns, parallel offset functions and desired track changes larger than 45° are assumed not to be required.

1.5.7 Dispatch Assessment

The dispatch assessment for an intended aircraft operation within RNP airspace is assumed to consider the available navigation infrastructure, including serviceability of State-identified facilities, relating to the intended routes, procedures, etc. If the aircraft operation intends to derive navigation performance from other than those facilities, an assessment should be performed to ensure that the alternative sensor source, when used by the navigation equipment, conforms with the accuracy, integrity, continuity, and availability for the intended RNP/VNAV operations and is acceptable to the State.

1.6 Test Requirements

The test requirements specified in Section 2 are intended to be used as recommended means of demonstrating compliance with the minimum acceptable performance parameters specified herein. Although specific test procedures are cited, it is recognized that other methods may be suitable. These alternate procedures may be used if they provide equivalent validation. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

a. Environmental Tests

Environmental tests are specified in Section 2.3. These tests, like bench tests, are performed at the equipment level. The procedures and their associated limit requirements provide a laboratory means of determining the electrical and mechanical performance of the equipment under conditions expected to be encountered in actual aeronautical operations. Test results may be used by equipment manufacturers as design guidance, in preparation of installation instructions, and, in certain cases, for obtaining formal approval of equipment design and manufacture.

b. Bench Tests

The test procedures specified in Section 0 provide a means to demonstrate equipment performance in a simulated environment. Test results may be used as design guidance for monitoring manufacturing compliance and, in certain cases, for obtaining formal approval of equipment design and manufacture.

1.7 Definitions

The definitions of several key terms used throughout this document follow. These terms provide the terminology framework for the body of the MOPS. A complete glossary can be found in Appendix A. Italics are used to denote a term listed in the glossary.

1.7.1 Required Navigation Performance

REQUIRED NAVIGATION PERFORMANCE (RNP): A statement of the navigation accuracy necessary for operation within a defined airspace. Note that there are additional requirements beyond accuracy applied to a particular RNP.

RNP RNAV: An area navigation capability that meets all of the requirements of the MASPS document.

RNP AIRSPACE: Area(s), route(s), or procedures(s) where minimum navigation performance requirements have been established and aircraft must meet that performance while flying in the designated environment.

RNP: An RNP is established according to navigational accuracy in the horizontal plane, that is, lateral and longitudinal position fixing. The RNP is identified by an accuracy value expressed in nautical miles.

RNP x: A designator used to indicate the minimum navigation system requirements needed to operate in an area, on a route or on a procedure (e.g., RNP 1, RNP 4). The designator invokes all of the navigation equipment requirements specified in this document. The term RNP is used to refer to a generic RNP.

VNAV: A vertical navigation capability that meets all of the requirements of this MOPS

1.7.2 Error Terms

1.7.2.1 Lateral

There are a number of error sources and error terms that must be considered when evaluating RNP compliance. Figure 1-2 shows the error terms considered in the cross-track dimension. These terms refer to the actual error, and not an uncertainty. In addition, this MOPS defines only the lateral (cross-track) errors for path definition and path steering. Both cross-track and along-track components of position estimation error have been included in order to facilitate evolution to along-track containment. The definitions of these terms follow.

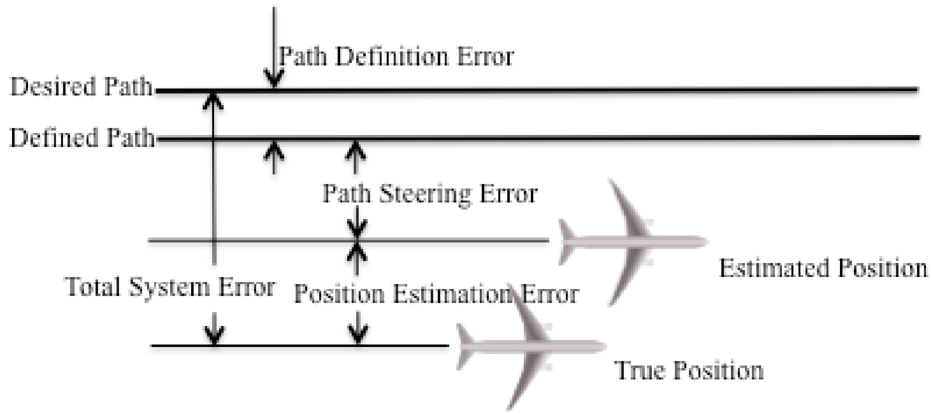

Figure 1-2: Lateral Components of Navigation Error Terms

DEFINED PATH: The output of the path definition function.

Note: This MOPS does not include along-track path definition error.

DESIRED PATH: The path that the flight crew and air traffic control can expect the aircraft to fly, given a particular route leg or transition. The desired path for various leg types is described in Section 2.2.1.2.

ESTIMATED POSITION: The output of the position estimation function.

FLIGHT TECHNICAL ERROR (FTE): The accuracy with which the aircraft is controlled as measured by the indicated aircraft position with respect to the indicated command or desired position. It does not include blunder errors.

PATH STEERING ERROR (PSE): The distance from the estimated position to the defined path. The PSE includes both FTE and display error (e.g., CDI centering error).

PATH DEFINITION ERROR (PDE): The difference between the defined path and the desired path at a specific point and time.

POSITION ESTIMATION ERROR (PEE): The difference between true position and estimated position.

TOTAL SYSTEM ERROR (TSE): The difference between true position and desired position. This error is equal to the vector sum of the *path steering error*, *path definition error*, and *position estimation error.*

1.7.2.2 Vertical

Figure 1-3 shows the error terms considered in the vertical dimension. These terms refer to the actual error, and not an uncertainty. This does not include the effects of temperature on the altimeter. The definition of these terms follows.

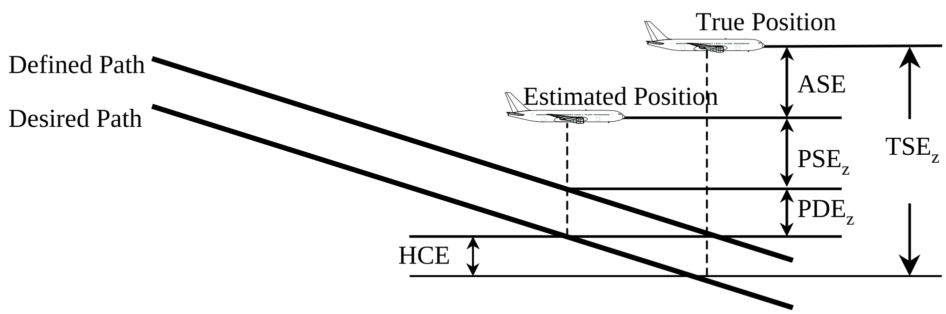

Figure 1-3: Vertical Components of Navigation Error Terms

ALTIMETRY SYSTEM ERROR (ASE): The errors attributable to the aircraft altimetry installation including position effects resulting from normal aircraft flight attitudes.

Note: *Conformance and ongoing assurance is expected to be as specified in ICAO Document 9574, Manual on the Implementation of 1000 Ft Vertical Separation Minimum Between FL290 -FL410.*

HORIZONTAL COUPLING ERROR (HCE): The vertical error resulting from horizontal along track position estimation error coupling through the desired path.

VERTICAL FLIGHT TECHNICAL ERROR (FTE_Z): The accuracy with which the aircraft is controlled as measured by the indicated aircraft position with respect to the indicated vertical command or desired vertical position. It does not include blunder errors.

VERTICAL PATH DEFINITION ERROR (PDE_Z): The vertical difference between the *defined vertical path* and the *desired vertical path* at the estimated lateral position. For an approach procedure, this could be the vertical angle error (VAE).

VERTICAL PATH STEERING ERROR (PSE_Z): The distance from the *estimated vertical position* to the *defined path.* It includes both FTE_Z and display error (e.g., vertical deviation display centering error).

VERTICAL POSITION ESTIMATION ERROR (PEE_Z): Altimetry system error.

VERTICAL TOTAL SYSTEM ERROR (TSE_Z): The difference between true vertical position and *desired vertical position at the true lateral position.* This error is equal to the sum of the vertical *path steering error*, *path definition error*, *position estimation error (altimetry system error)* and *horizontal coupling error*.

1.7.3 Lateral Containment Concept

Several terms are introduced by this MOPS in order to define the additional requirements, beyond accuracy, applied to a particular RNP. The foundation of these parameters is the concept of containment. It proposes that a region around the desired path can be defined, and that the probability that the aircraft does not remain within that region can be bounded. The term *containment* as used by this MOPS is the same as on-board performance monitoring and alerting as described in the ICAO PBN Manual. Figure 1-4 depicts the parameters associated with containment in the cross-track dimension. The definitions of these terms can be found below.

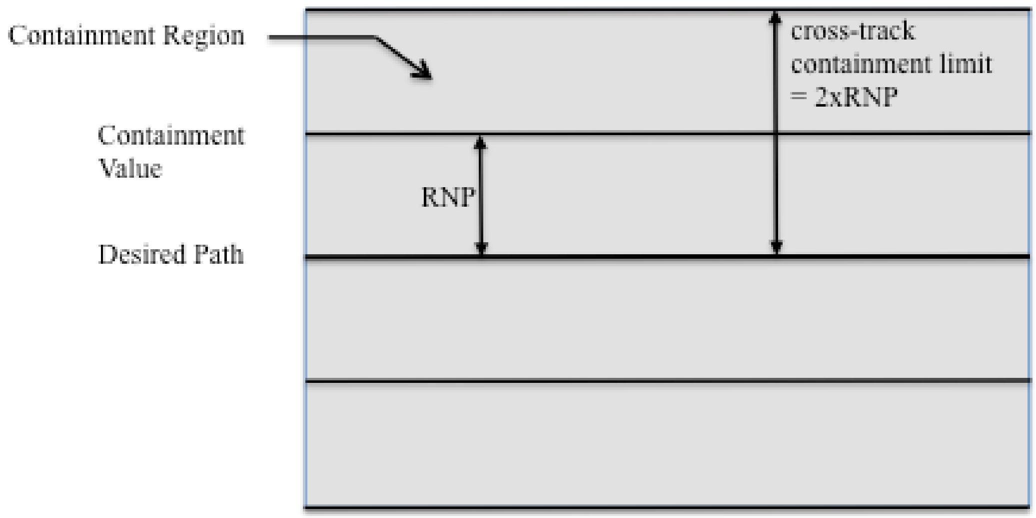

Figure 1-4: Cross-Track Containment Parameters

The containment integrity and containment continuity requirements define the allowable probabilities of certain types of failure for the navigation system. In particular, the integrity requirement limits the probability of a malfunction of the navigation system which causes the cross track component of total system error to exceed the cross-track containment limit associated with the current RNP without annunciation. The continuity requirements limit the probability of loss of function, which occurs when the system indicates that it is no longer RNP capable. In this context, *function* or *RNP capability*, is defined as the ability to meet the containment integrity requirements.

The set of possible navigation system states is related as shown in Figure 1-5. The system is considered operationally RNP capable when it meets the containment integrity requirement for the RNP.

Figure 1-5 illustrates the possible system operational states at a given instant in time. The two containment related requirements can be interpreted with the help of this diagram. In the figure, C represents the applicable containment limit, which is twice the RNP, and TSE refers to the cross-track Total System Error (TSE).

TSE < C & **No alert of loss of RNP capability** **E1**	**TSE > C &** **No alert of loss of RNP capability** **E2**
Alert of loss of RNP capability E3	

Note: P(E1) + P(E2) + P(E3) = 1

Figure 1-5: Navigation System Operational States

Subset E2 represents the set of events associated with lack of knowledge of the true value of TSE, hence it is the measure of system integrity relative to the containment limit. The containment integrity requirement is intended to limit the exposure of the aircraft to conditions where the containment limit is exceeded without annunciation. This corresponds to the probability that the TSE can be greater than the containment limit without knowledge of the system or its user. This probability, P(E2), must be less than 10^{-5} per flight hour.

Subset E3 represents the set of events associated with annunciation that the system is not RNP capable for any reason, including hardware failures, performance degradation, etc. This does not necessarily mean the system is unusable, but only that the capability for the current RNP has been lost or has been falsely annunciated as lost. The containment continuity requirement is intended to limit the frequency that this event occurs, and it includes all possible events that cause the system to lose current RNP capability. The probability of E3 must be less than 10^{-4} per flight hour. This requirement limits the combined rate of detected equipment failures and conditions.

Note: The alerting on E3 includes the effects of infrastructure changes or losses, but the continuity only applies to the system when the infrastructure is present.

Showing compliance to RNP involves evaluating P(E2) and P(E3) relative to the containment limit, as well as demonstrating that the applicable existing requirements are met. The first of these two requirements effectively limits the aircraft exposure to a potentially unsafe operation. The second limits the frequency that the crew is advised that the navigation system is no longer fully RNP capable, that is, it is not RNP capable for the current RNP. This concept and definition expands upon the current requirements defined for the total loss of the airborne navigation function, but does not replace those requirements. For example, under FAA AC 25-11B, total loss of the display of navigation information must be improbable (i.e. occur less often than 10^{-5} per flight hour).

Continuity requirements generally have applied to the complete loss of navigation function. The application of continuity in this MOPS has been placed in the context of RNP operation, where containment concepts are necessary to achieve the goals identified in Section 1.3.

In addition to the containment parameters shown in Figure 1-4, two additional parameters are defined to provide situational awareness to the flight crew. Both of these parameters refer to the PEE in the horizontal plane, rather than in the cross-track dimension, since RNAV positioning accuracy is generally independent of the aircraft track. These parameters are shown in Figure 1-6 and defined below.

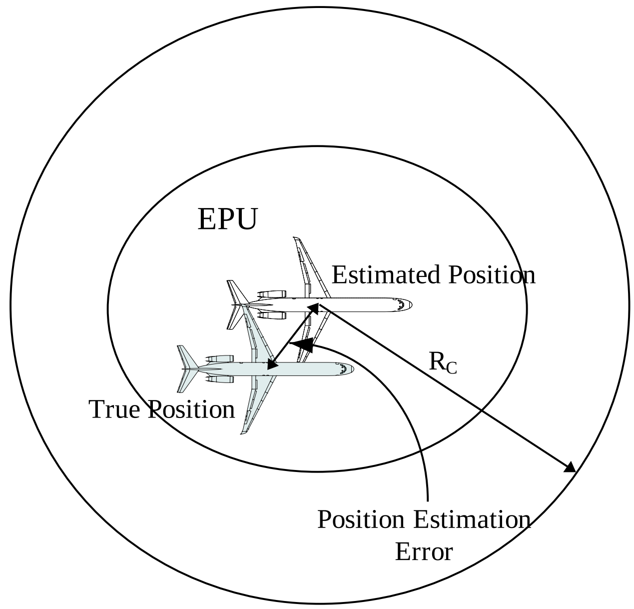

Figure 1-6: Position Estimation Performance Measures

CONTAINMENT: A set of interrelated parameters used to define the performance of an RNP RNAV navigation system. These parameters are containment integrity, containment continuity, and containment region.

CONTAINMENT INTEGRITY: A measure of confidence in the estimated position, expressed as the probability that the system will detect and annunciate the condition where TSE is greater than the cross track containment limit. Containment integrity is specified by the maximum allowable probability for the event that TSE is greater than the containment limit and the condition has not been detected. That is, P(E2) = Pr(TSE > containment limit and no warning is given).

CONTAINMENT CONTINUITY: The capability of the total system to satisfy the containment integrity requirement without nonscheduled interruptions during the intended operation. Nonscheduled interruption in operation is defined to be either 1) total loss of navigation capability; 2) a failure of the system which is annunciated as loss of RNP capability, or 3) a false annunciation of loss of RNP capability while the system is working properly. Containment continuity is specified by the maximum allowable probability for interruption. That is, P(E3) = P(system not RNP capable with warning) + P(system RNP capable with warning), and thus both the true and false alarm rates are bounded.

CONTAINMENT RADIUS (Rc): A radius of a circle in the horizontal plane, centered on estimated position, such that the probability of the true position lying outside the circle without being detected is 10^{-5} per flight hour. This uncertainty only includes position estimation uncertainty.

CONTAINMENT REGION: A region, centered on the *desired path*, to which the *containment integrity* and *containment continuity* are referenced. This MOPS only specifies containment requirements in the cross-track dimension, which is defined by a *cross track containment limit*. It is anticipated that when a horizontal two-dimensional containment region is defined, it will be defined by separate cross-track and along-track containment. Similarly, when a vertical containment region is defined, it is likely to be defined by a vertical containment limit.

CROSS-TRACK CONTAINMENT LIMIT: A distance that defines the one-dimensional containment limit in the cross-track dimension. The resulting *containment region* is centered upon the desired path and is bounded by +/- the cross-track containment limit. There is a required cross-track containment limit associated with a particular RNP.

ESTIMATE OF POSITION UNCERTAINTY (EPU): A measure in nautical miles which conveys the current position estimation performance.

1.7.4 Vertical Performance

1.7.4.1 Vertical Path Performance Limit (VPPL)

A vertical path performance limit will be specified for a defined vertical profile (Figure 1-7). VPPL will represent a 99.7% limit for system vertical error.

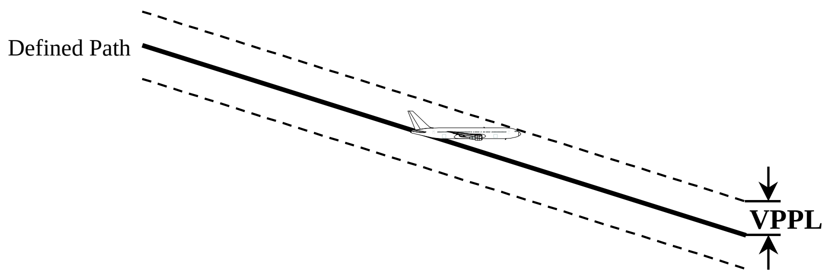

Figure 1-7: Vertical Path Performance Limit

1.8 Equipment Classes

This MOPS has established equipment classes that reflect two needs. The Class A equipment is consistent with the Advanced RNP (A-RNP) operations described in the ICAO PBN Manual. The Class B equipment is consistent with the RNP APCH operations and RF leg capability described in the ICAO PBN Manual, Volume II, Part C, Appendix 1. Equipment developed to this MOPS should be identified with the applicable class that describes the equipment capabilities for lateral and vertical navigation and time of arrival control, as summarized below.

1.8.1 Class A

Class A equipment is intended to provide the required navigation performance functions that enable PBN operations, including all advanced functions. The minimum requirements for Class A equipment are identified in Table 2-13.

1.8.2 Class B

Class B equipment provides a subset of the Class A capability that supports RNP instrument approach. The minimum requirements for Class B equipment are identified in Table 2-13.

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2. EQUIPMENT PERFORMANCE REQUIREMENTS AND TEST PROCEDURES

2.1 General Requirements

The following general requirements shall be met by all RNP equipment.

2.1.1 Airworthiness

Design and manufacture of the airborne equipment shall provide for installation so as not to impair the airworthiness of the aircraft.

2.1.2 General Performance

The equipment shall perform its intended function as addressed in this MOPS.

> *Note: Manufacturers may choose to include additional functions within RNP equipment that are not specifically addressed in this MOPS. To facilitate approval of the equipment, the manufacturer should consider defining the intended function of each additional function in the operational context of its use.*

2.1.3 Fire Resistance

Except for small parts (such as knobs, fasteners, seals, grommets, and small electrical parts) that would not significantly contribute to the propagation of fire, all materials shall be self-extinguishing.

2.1.4 Displays and Controls

The RNP equipment shall provide the means to support a user interface capability that enables data input, data output and control of all equipment operations and functions.

If the RNP equipment includes the control and display and system alerting functions intended for flight crew use, the equipment designer should take into account the human factors considerations of Appendix F.

2.1.5 Accessibility of Functions Not Intended for Use in Flight

The RNP equipment shall not allow access during normal flight operations to equipment functions that are intended for use only on the ground.

2.1.6 Equipment Interfaces

The interfaces with other aircraft equipment shall be designed such that, when properly installed with adequately designed other equipment, normal or abnormal RNP equipment operation shall not adversely affect the operation of the other equipment nor shall normal or abnormal operation of other equipment adversely affect the RNP equipment except as specifically allowed.

The RNP equipment interfaces with other aircraft systems should be designed (to the maximum extent practicable) such that transitions between RNP equipment-generated guidance and other aircraft lateral and vertical guidance can be automated, or require only minimal crew action to effect the transfer.

> *Note: Normal operation of the RNP equipment should not inhibit a transition in guidance/control mode from an RNP equipment source to another guidance source. For example, the transition from RNP equipment-generated LNAV/VNAV guidance to autopilot capture of a localizer and*

glide slope should be possible with minimal switch selection by the flight crew. RNP equipment should therefore avoid causing an interruption in the lateral path that results in several flight crew actions to achieve the transition from lateral navigation to approach navigation. Arming APPROACH for localizer and glide slope capture would be an example of minimal crew action.

2.1.7 Reserved

2.1.8 Effects of Tests

The design of the equipment shall be such that the application of the specified test procedures shall not produce a condition detrimental to the performance of the equipment, except as specifically allowed in this MOPS.

2.1.9 Development Assurance

The hardware and software shall be designed such that the output of misleading lateral or vertical information, considered to be a major failure condition, shall be improbable. To demonstrate compliance it will be necessary to conduct a safety assessment to evaluate the system's implementation against known failure conditions.

Note: The design requirements applicable to this hazard classification depend upon the aircraft type. The following two paragraphs define acceptable means of compliance for the most stringent application of this hazard classification.

2.1.9.1 Hardware Compliance

An acceptable means of compliance is to show that failures of the equipment that result in misleading lateral or vertical information are not more probable than 10^{-5}/flight hour. For complex firmware implementations such as application-specific integrated circuits (ASIC's), processes defined in RTCA DO-254, Design Assurance Guidance for Airborne Electronic Hardware, or similar to those described in RTCA/DO-178C provide an acceptable means of compliance with applicable airworthiness requirements.

2.1.9.2 Software Compliance

AC 20-115C, which references RTCA/DO-178C, provides an acceptable means for showing that software complies with applicable airworthiness requirements. One acceptable approach to software development is to develop all software that affects navigation and integrity functions to at least the Level C criteria, as defined in RTCA/DO-178C. Another acceptable approach is to substantiate software levels in the safety assessment.

2.2 Equipment Performance - Standard Conditions

2.2.1 2D (RNAV) Function and Performance

2.2.1.1 Position Estimation

2.2.1.1.1 Estimate of Present Position

The equipment shall estimate the present position of the aircraft and provide an alphanumeric display in latitude and longitude. The resolution for displayed latitude and longitude shall be in accordance with Table 2-3.

2.2.1.1.2 Estimate of Position Uncertainty (EPU)

The equipment shall make its current Estimate of Position Uncertainty (EPU), in nautical miles, available for display. The display resolution shall be in accordance with Table 2-3.

The displayed EPU value shall be consistent with the alert provided when the equipment fails to comply with the containment integrity. That is, the displayed EPU shall be scaled such that the containment alert occurs no later than when the displayed EPU value exceeds the RNP in effect.

Note: The intended use of EPU is to provide the flight crew a measure of confidence of the system's current navigation performance. EPU can be related to the required RNP for the following information:

- *If the EPU is less than the RNP, there should be a high level of confidence the system can meet the requirements of a given RNP.*
- *The margin between EPU and the RNP should be an indication of the flight technical error margin available. If the margin is low, the flight crew may decide or be required to couple the autopilot system.*

2.2.1.1.3 Containment Radius

The equipment shall determine the current containment radius under the prevailing conditions of flight. Prevailing conditions include airborne equipment condition, airborne equipment in use, and external signals in use. The containment radius is the radius of a circle, centered on the estimated position, such that the probability of the true position lying outside the circle without being detected is not greater than 10^{-5}/hour.

Note: This requirement may be satisfied without explicit computation or display of containment radius. This MOPS provides an error allocation in Table 2-7 to allow compliance with the equipment portion of the containment integrity requirement, which removes the need for explicitly computing containment radius.

2.2.1.1.4 Position Initialization

If the system requires position initialization, it shall provide the capability to allow entry and display of initialization parameters to a resolution consistent with Table 2-3.

2.2.1.1.5 Navigation Aid Selection

2.2.1.1.5.1 Equipment

The RNP equipment shall be capable of identifying, selecting and/or tuning navaids to obtain the data necessary for position estimation or navigation. The navaids may be ground-based or space-based.

2.2.1.1.5.2 Ground-Based Navaids

The RNP equipment shall be capable of either manually or automatically tuning or selecting (or de-selecting) the station frequencies of ground navaids where RNP 2 or less airspace operations are intended. The RNP equipment shall perform reasonableness and integrity checks of the radio navigation data. The frequencies and/or identifiers associated with a ground navaid selected for navigation shall be available for display. The RNP equipment shall provide the capability to inhibit the selection of individual navaids from the automatic selection process. If a ground navaid is required for navigation, the system shall not preclude the pilot from manually selecting the ground navaid for display of raw data.

The reasonableness and integrity checks are intended to prevent navigation aids being used for navigation update in areas where the data can lead to position fixing errors due to co-channel interference, multipath and direct signal screening. In lieu of using ground-based navigation aid designated operational coverage (DOC), the system should provide checks which preclude use of duplicate frequency navaids within range, over-the-horizon navaids, and use of navaids with poor geometry.

2.2.1.1.5.3 Space-Based Navaids

The RNP equipment shall be capable of automatically using space-based navaids, at least one GNSS constellation as a minimum.

2.2.1.1.6 Navigation Sensors

The equipment shall estimate the position using any one or combination of the following sensors:

- GNSS
- DME/DME
- Inertial navigation

The equipment shall provide the capability to inhibit the use of any supported sensors not authorized for a particular RNP operation.

Note: The above list does not preclude use of other navigation sensors or combinations of sensors to supplement the standard sensors. It is the equipment manufacturer's responsibility to demonstrate that the performance of the other sensors or sensor combinations meets the requirements of this document. Such combinations may not be operationally viable due to the issues identified in Section 1.5.1.

2.2.1.2 Path Definition

2.2.1.2.1 Leg Types

The system shall be capable of utilizing the following ARINC 424 leg types-(Table 2-1):

Table 2-1: Leg Types

Leg Type	Description
CF	Course to Fix leg
DF	Direct to Fix leg
FA	Fix to Altitude leg
HA, HM, HF	Hold legs
IF	Initial Fix
RF	Radius to Fix leg
TF	Track to Fix leg

Refer to Appendix D for additional details for each of the leg types.

The navigation system shall construct the flight path associated with airways contained within the navigation database as though each fix segment is defined as a TF leg.

Note: This is because ARINC 424 defines airways as a series of fixes, and not as specific leg types.

In the case where all or part of a route is created through the manual entry of fixes, from the navigation database or user-defined fixes, a TF leg type shall be used to define the path between a manually entered fix and the preceding and following fixes.

2.2.1.2.2 Flight Planning

The equipment shall provide the capability for the crew to create, review, and activate a flight plan.

The equipment shall provide the capability for modification (e.g., deletion and addition of fixes and creation of along-track fixes), review and user acceptance of changes to the flight plan. When this capability is exercised, guidance outputs shall not be affected until the modification(s) is/are activated. Activation of any flight plan modification shall require positive action by the flight crew.

The equipment may provide for insertion of along-track reference points into an existing flight plan. If implemented:

1. These waypoints shall not modify the desired track of the original flight path on which they are inserted.

2. These waypoints should only be entered on CF, DF, RF, or TF legs.

Note: Examples of along-track reference points are along-track fixes, abeam fixes, and lat/long crossing points.

The equipment shall also have the capability to create flight plans by selection of individual fixes, by identifier, from the database. A minimum 5-character field for input and display of database fix identifiers shall be required. The system shall provide the means to extract from the database and review, for incorporation into a flight plan, flight departure procedures, including SIDS/DPs, and flight arrival procedures, including STARs and arrival transitions, for the appropriate/selected airport runway. The equipment shall also have the capability of creating flight plans by joining routes or route segments from the navigation database and by the use of ATS route identifiers. The system shall indicate to the crew any flight plan discontinuities. A flight plan discontinuity is a point in the flight plan after which no desired path is defined.

Equipment providing approach capability shall provide the means to extract approach procedures from the database for review and incorporation into the flight plan. These approach procedures shall include approach transitions and missed approach procedures for the selected airport runway.

Additional methods of flight plan entry may consist of the insertion of individual fixes and related data, the selection of individual fixes from the database, the extraction of routes or portions of routes from the database or via datalink uplink.

2.2.1.2.3 Direct-To Function

The equipment shall provide the capability of establishing a direct leg to any fix from the aircraft's present position. The equipment shall be capable of generating a geodesic path to the designated TO fix. The equipment shall provide guidance and/or cues such that the aircraft is capable of capturing this path without "S-turning" and without undue delay.

Note: The purpose of the Direct-To function is to navigate the aircraft expeditiously from the aircraft's present position to the crew designated TO fix.

2.2.1.2.4 Entry of User-Defined Fixes

The RNP equipment shall provide the capability to manually enter the coordinates of a fix in terms of latitude and longitude in accordance with the resolution of Table 2-3.

The RNP equipment shall provide the capability to manually enter a fix as a range and magnetic bearing from another fix (place/bearing/distance). The RNP equipment shall provide the capability to manually enter a fix as a magnetic bearing from two fixes (place/bearing-place/bearing). The range and bearing resolution shall be in accordance with Table 2-3.

Note 1: Consideration should be given to allow entry of true bearing for RNP equipment that will be approved for use at higher latitudes.

Note 2: The type of user-defined fix capability of the RNP equipment should be commensurate with its intended operational use. For RNP-1 or less, user-defined fixes should not be used for systematic route creation and are only intended for use in tactical situations and temporary route diversions. It is not intended that user-defined fixes be inserted into approach or missed approach procedures once drawn from the database, and the ramifications of doing so should be clearly understood by the flight crew.

Note 3: RNP equipment that allows storage of user-defined fixes should provide a means for automatic deletion of these temporary fixes prior to the next flight. This does not preclude the capability to store temporary user-defined fixes by deliberate crew action.

2.2.1.2.5 User-Defined Course-to-a-Fix

The equipment shall provide the capability to intercept a user-defined course to a fix.

The resolution of the defined course shall be in accordance with Table 2-3.

2.2.1.2.6 Holding

If the equipment provides RNP holding capability, the following applies.

The equipment shall provide the capability to establish a flight path, with associated guidance and/or cues, to a selected fix and to facilitate a fly-by of the fix for entry into a hold from any direction, while maintaining the aircraft within the holding area. Once established in the hold, the equipment shall provide guidance and/or cues for tracking the holding pattern path and to ensure flight over the hold fix along the defined inbound track.

Systems choosing to automate the holding pattern path definition should utilize the ARINC 424 HA, HM and HF holding leg types.

For HF, HA, and HM holding patterns within RNP airspace, the equipment shall determine the boundaries of the holding area as defined in this section. This boundary defines the maximum size of an RNP holding pattern. The equipment shall have the ability to establish containment consistent with the boundaries defined in this section.

Note The committee has determined that the RNP hold concept described herein is fundamentally sound. However, it is also recognized that the details of its integration into the future air traffic management system are not all known at the time of publication of this version of the MOPS.

2.2.1.2.6.1 RNP Holding Area Dimensions

For airspace planning purposes, an RNP holding area will be derived from the assumption that the RNP equipment will execute a racetrack pattern whose position and dimensions are defined by:

a. A holding fix;

b. A holding altitude, in feet, relative to mean sea level;

c. An inbound track to the holding fix, in degrees relative to true north;

d. The maximum length of the inbound track to the holding fix (d_1), in nautical miles;

e. An assigned RNP

f. The maximum IAS in knots;

g. An allowance for the maximum wind expected to be encountered

The equipment is not required to fly the actual racetrack to ensure compatibility with such a holding area. However, the equipment shall establish an entry and holding pattern path that maintains the aircraft within this holding area during the entry procedure and for hold execution subject to:

- The actual airspeed being at or below the maximum IAS for the hold
- The actual wind speed being at or below the maximum wind speed used in the holding area airspace calculation

The values associated with a. through e. above are typically provided by the navigation database. The equipment shall also accommodate pilot entry of these parameters.

The maximum holding airspeed is normally dependent upon altitude. Where this is not provided in the database, the values set out in Table 2-2 below shall be used.

The maximum wind speed used in airspace planning will not normally be known to the equipment. The equipment shall therefore use the actual wind measured by the system, subject to a maximum of the ICAO accountable wind speed for the altitude flown.

In cases where the holding altitude is not provided to the navigation system, the current altitude upon initiating the hold and at each recomputation of the hold dimensions at the inbound to the hold fix shall be used to define the holding altitude.

When performing an entry into the holding pattern, the equipment is permitted to use an inbound leg length (d1) that is equal to the holding pattern width (d2) instead of the length defined in the database or from pilot entry

Note 1: The inbound track may be published in degrees relative to magnetic north; in this case, true reference systems are expected to apply the magnetic variation in order to calculate the holding area.

A plan-view of the holding area so defined is shown in Figure 2-1 along with the path definition terms.

Note 2: Value d_4 in Figure 2-1 represents an allowance of airspace added to the holding fix-end to prevent aircraft from having to fly away from the hold fix before initiating a turn to the hold fix during entries from the holding side which have high intercept angles relative to the inbound track (S turning). See Appendix J Sector 4 entries.

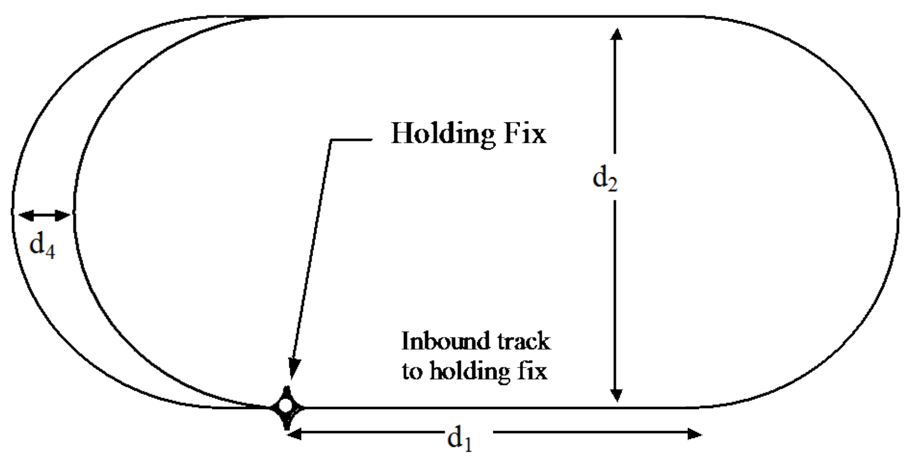


Figure 2-1: Holding Pattern Definition

The holding area parameters defining the maximum holding track width (d_2) and protected area (d_4) are calculated as follows.

The maximum holding track width d_2 is defined as:

$$d_2 = (TAS + w)^2 / (34313 \tan \phi) \quad (NM)$$

where,

TAS is the lower of:

1. The true airspeed at the entry to the hold and at each inbound to the hold fix

or

2. the true airspeed at the holding altitude for the maximum holding IAS at International Standard Atmosphere (ISA) +15° (kts) or Mach, including the effects of compressibility

w is the lower of:

1. the measured wind at the entry to the hold and at each inbound to the hold fix

or

2. the ICAO accountable omnidirectional wind speed for the given hold altitude (kts);

ϕ is the maximum bank angle.

The distance d_2 defined by the above formula is conservative with respect to aircraft turn performance in that the accountable wind speed is assumed to be a tailwind throughout the entire turn, and the bank angle achievable by the aircraft will generally exceed the maximum value assumed in the computation.

The maximum indicated airspeeds or Mach to be used in defining d_2 are presented in Table 2-2, and are derived from PANS-OPS Volume II, Part II — Section 4, Chapter 1, Table II-4-1-2. The corresponding true airspeed to be used in the calculation of d_2 is presented in the PANS-OPS Volume II, Part II — Section 4, Chapter 1, Appendix A, Table II-4-1-App A-2. Alternatively, the formula of paragraph 6.1 of the same Attachment A can be used to calculate the required TAS.

Table 2-2: Maximum Holding Airspeeds (KIAS)

Levels [1]	Indicated Airspeed
up to 6,000 ft. (inclusive)	100 kt (cat H aircraft only)
up to 14,000 ft. (inclusive)	230 kt 170 kt (cat A & B aircraft only)
above 14,000 ft. to 20,000 ft. (inclusive)	240 kt
above 20,000 ft. to 34,000 ft. (inclusive)	265 kt
above 34,000 ft.	0.83 M

[1] The levels tabulated represent altitudes or corresponding flight levels depending upon the altimeter setting in use.

The ICAO accountable omnidirectional wind speed [PANS OPS Volume II, Part II — Section 4, Chapter 1, Appendix A] to be used in defining d_2 is defined as follows:

$$w = (2h + 47) \text{ kts}$$

where, w is the wind speed in knots, limited to 120 kts and h is the hold altitude in thousands of feet.

The bank angle to be used in the calculation of d_2 is defined as:

$$\phi = 23° \text{ for FL} < 245$$

$$\phi = 15° \text{ for FL} \geq 245$$

The distance d_4 is the protection area for Sector 4 entries (see Appendix J) and is calculated using the formula:

$$d_4 = d_2 (1 - \sin 20°)/ (2 \cos 20°) \quad (NM)$$

2.2.1.2.6.2 RNP Holding Area Entry Procedures

The equipment shall facilitate entry from any direction and maintain the aircraft within the holding area after penetration into the holding area.

Note 1: Appendix J describes acceptable fixed path hold entries used to establish an aircraft within an RNP hold.

The aircraft is not required to fly over the hold waypoint during entry. The aircraft is required to fly over the hold waypoint along the defined inbound track once established in the hold.

Note 2: Equipment not performing a fixed path entry may require complex alerting algorithms to ensure containment continuity is maintained (i.e. avoiding false alarms).

2.2.1.2.6.3 RNP Holding Area Exit Procedures

The protected area for a hold exit should be the composite of the hold pattern, and the associated transition at the hold fix. The transition shall be a fly-by unless otherwise specified. The fly-by transition should use the inbound course to the hold fix and the track to the following leg.

2.2.1.2.7 Parallel Offsets

The RNP equipment shall have the capability to create a parallel path at a selected offset distance as specified in this section.

Note 1: The parallel offset is defined as a path parallel to, but offset from, the original active path. The basis of the parallel offset is the original flight plan leg(s) and one or more offset reference points as computed by the RNP equipment.

The offset reference point shall be located so that it lies on the intersection of lines drawn parallel to the host route at the desired offset distance and the line that bisects the track change angle (reference Figure 2-2). An exception to this occurs if there is a route discontinuity (or end of route). In this case, the offset reference point is located abeam of the original flight plan waypoint at the offset distance.

When executing a parallel offset, the RNP and all performance requirements and constraints of the original path in the active flight plan shall be applicable to the offset path, with the exception of holding patterns.

The earth model shall be in accordance with Section 2.2.1.2.13 and each offset reference point shall have the same or better resolution as the host route waypoint. The offset path for CF, DF or TF legs shall be a geodesic path between the offset reference points at the start and end of the leg.

The parallel offset function shall be available for terminal and enroute legs, and the geodesic portion of the DF leg.

Note 2: The parallel offset function enables an aircraft to be flown on a flight path offset from the centerline of a route while maintaining all characteristics of the original path, as if it were being flown centrally on the route.

Examples for the use of offsets are weather avoidance, air traffic conflict avoidance, etc.

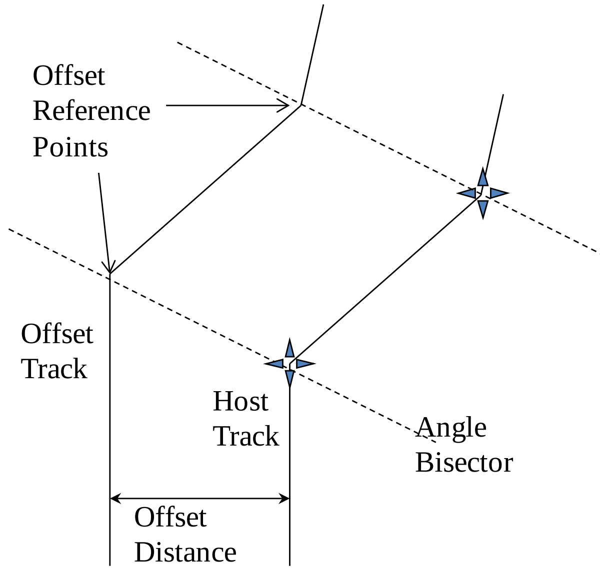


Figure 2-2: Offset Path Definition

The RNP equipment shall:

1) Utilize a standard 30 degree track change from the path being flown (original or offset) to define the transition path (original to offset or offset to original).

   Note: This does not preclude the manual override of the default intercept angle or the availability of additional crew-selectable intercept angles.

2) Provide for entry of offset distances in increments of 0.1 nautical miles, left or right of course, to at least 20 NM.

   Note: There is no defined operational need for offsets of 0.1nm precision beyond 10 NM at this time.

3) Provide the capability to offset predefined curved paths as specified below:
   a. Fixed Radius Transition (FRT): Radius shall be preserved by offsetting the turn center along the bisector of the turn.
   b. Radius-to-Fix (RF): If the equipment provides the capability to offset RF legs, the radius shall be changed by the amount of the offset.
4) Provide for manual initiation and cessation of parallel offset paths.
5) Provide for a single, pre-planned parallel offset using specified start and end fixes (multiple pre-planned parallel offsets are not required).
   a. Provide automatic initiation and cessation of the offset at the start and end waypoints.
   b. Begin transition to the offset path at the start waypoint on the original path to join the intercept path. In the event a fly-by transition exists on the original path at the offset start point, it is acceptable to leave the original path prior to the start of the fly-by transition on the original path (reference Figure 2-3).

*Note: Offset end point transitions are equivalent to those shown in **Figure 2-3**).*

c. Begin the return to the original path such that the return transition ends at the end waypoint on the original path (reference Figure 2-3). In the event a fly-by transition exists on the original path at the offset end point, it is acceptable to return on the original path prior to the start of the fly-by transition on the original path.

6) When in offset mode, provide reference parameters (e.g., cross-track deviation, distance-to-go, time-to-go) relative to the offset path and offset reference points and display the offset path.

Note: The transition path should also be displayed.

7) Automatically terminate a parallel offset at the first fix of an instrument approach procedure (IAF, IF or FAF).

8) Not propagate an offset through route discontinuities or unflyable flight path geometries.

Note: Examples of an unflyable geometry may include:

- *Course changes greater than 120 degrees*
- *A combination of ground speed, track change geometry and closely located fixes that prevent the definition of a flyable path*
- *When an offset of an RF leg results in an unflyable turn radius.*

9) Not transfer a holding pattern defined at a fix of the original path to the corresponding offset reference point.

Note: This does not preclude the capability to transfer a flight-planned holding pattern to the offset path if desired.

10) Provide a clear indication to the flight crew that the RNP equipment is operating in an offset mode.

11) Provide the means for a clear indication to the flight crew of the start and the end of the offset path, in particular for the case where the offset is initiated or terminated automatically by the RNP equipment. An indication of the detection of an unflyable path shall be provided in a sufficiently timely fashion that the crew can take action to resolve the situation.

Note: Since ATC is responsible for separation, RNP is neither a factor nor required during the transitions to and from the offset path described above. RNP equipment that incorporates actual aircraft cross-track distance as part of a monitor should exercise care to prevent nuisance alerts when transitioning to, from, or between offset paths and the equipment designer may also take the following into consideration:

a. When transitioning from an RNP path to an offset path, the original RNP path ends when the pilot activates the offset path and begins to exit the original path.

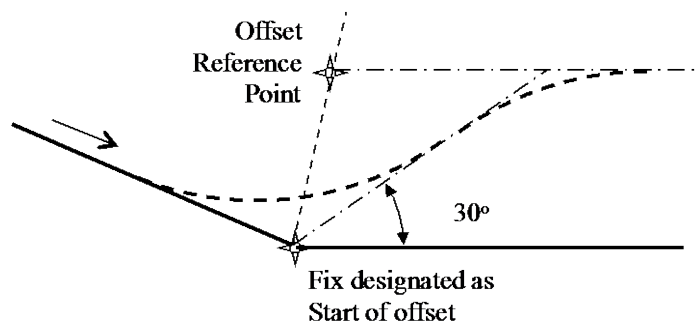
b. Any alert which contains actual cross-track deviation as one of its components should be inhibited from the initiation of the transition to or from the offset path until the aircraft's cross-track distance from the offset path (or from the original path on the return) is within 1/2 *of the RNP, unless the sum of the other components would cause the alert without the contribution of the cross-track deviation.*

c. *When transitioning from one offset value to another offset value, the active offset path ends when the pilot activates a new value for the offset and begins to exit the active offset path.*

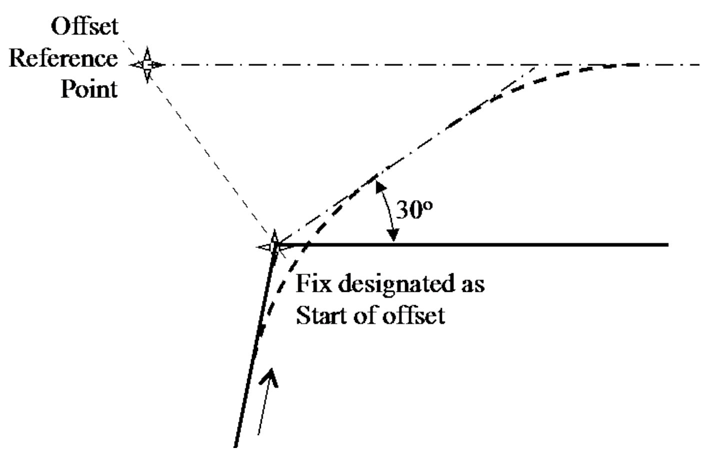
d. *The RNP portion of the new offset path begins when the aircraft is established on the new offset path.*

e. *When rejoining the original RNP path from an offset path, the offset path ends when the pilot terminates the offset and begins to exit the offset path.*

f. *When terminating an offset, the RNP portion of the original path begins when the aircraft is re-established on the original path.*



(a) Fly-by with "inside" course change



(b) Fly-by with "outside" course change

Figure 2-3: Typical Fly-by Transitions at Offset Start Point

2.2.1.2.8 Magnetic Variation

The source of the magnetic variation used for path definition computations for the CF, FA, and HA/HF/HM legs shall be in accordance with the following:

a. If the leg is part of a database terminal area procedure, the magnetic variation to be used shall be the value specified for that procedure.

b. If the leg is part of a terminal area procedure from the database, and the magnetic variation for the procedure is not specified, the magnetic variation shall be either the magnetic variation of record for the airport or the recommended VHF navaid magnetic declination of the leg if specified.

c. If the leg is not part of a procedure and the terminating fix is a VOR, the magnetic variation to be used shall be the station declination for the VOR.

d. If the leg is not part of a procedure and the terminating fix is not a VOR, the magnetic variation to be used shall be defined by the system using an internal model.

Note 1: In the navigation environment, there are a number of different sources of magnetic variation that are used for flight path definition where magnetic course information is required. For flight path segments that require magnetic course information, a common source of magnetic variation would have to be used to define the flight path in order to provide repeatability between aircraft for the flight paths flown.

If a user-defined fix is based on a VOR, the RNP equipment shall use the station declination of the VOR from the database for the conversion between Magnetic and True North when computing the location of the place/bearing/distance or place/bearing-place/bearing fix.

The RNP equipment shall have the capability of assigning a magnetic variation at any location within the region that flight operations may be conducted using Magnetic North reference. For locations with a magnitude of the local magnetic main field inclination less than 72 degrees, the assigned magnetic variation used for path definition shall be within two degrees of the value determined at the same location and time by an internationally recognized and current magnetic model that is valid for the time of computation (e.g. USGS, IGRF).

Note 2: The above requirements represent the minimum standard. It is left to the equipment designer to determine the appropriate test methodology if the intended function and operational use will include regions where the magnitude of the local magnetic main field inclination exceeds 72 degrees.

The RNP equipment's intended function and the planned location of its operational use may impose additional requirements for the accuracy of the equipment's magnetic model. Manufacturers shall define the intended function of the magnetic variation model of the RNP equipment, any additional support requirements, and any associated continued airworthiness requirements needed to maintain the model within its design specifications.

Note 3: The magnetic inclination (or dip angle) is the angle between the horizontal plane and the total magnetic field vector from 0 to 90 degrees with positive values pointing into the Earth.

Note 4: The time of computation refers to the optimization date for the information used when the model or table is created. This date is typically the date in the future, compared to the model's calendar release date, at which the errors in the magnetic variation modeled are expected to be at their global minimum over the lifetime of the model.

The RNP equipment shall have the means to accept an input that identifies the type of aircraft heading reference in use (Magnetic/True). The source of the input may be either by manual entry or external means.

The RNP equipment shall alert the flight crew when a Magnetic versus True discrepancy is detected between the aircraft heading reference and the active leg heading reference.

Note 5: Consideration should be given to advising the crew in advance of the alert as soon as a discrepancy in heading reference can be detected in the active flight plan. For example, the aircraft is operating in True heading but a terminal or approach procedure using Magnetic heading has been loaded in the flight plan, or a change in destination has been made to one referenced to Magnetic north.

Note 6: The requirement that the RNP equipment contains magnetic variation model data is derived from requirements such as the following:

- *The ability to create place/bearing/distance user-defined fixes;*
- *The ability to create place/bearing-place/bearing user-defined fixes; and*
- *The ability to create legs specified by a course to a fix.*

Note 7: The user-defined fixes above are not expected to be utilized with RNP in areas with rapidly changing magnetic variation values.

Note 8: Equipment designers should take into consideration the fact that updates to the various magnetic variation elements related to a given procedure are generally unsynchronized; for example, update of the ILS localizer magnetic variation may occur without a concurrent update of the procedure magnetic variation or the recommended VHF navaid station declination.

Note 9: Equipment designers should give consideration to providing a means to harmonize magnetic variation tables with other airborne equipment, such as inertial reference systems, such that a consistent display of magnetic bearings is presented on the flight deck.

2.2.1.2.9 Transitions Between Legs

The navigation system shall provide a means to automatically transition from one leg to another. Two categories of transition between fixed path segments can be defined:

- Fly-by transitions; and
- Fixed radius transitions.

The navigation system shall be capable of accomplishing both of these transitions. Fly-by transitions shall be the default transition when the transition type is not specified.

Note 1: For fly-by transitions, no predictable and repeatable path is specified, because the optimum path varies with airspeed and bank angle. Fly-by transitions use a transition area. The aircraft should remain within the transition area for fly-by transitions.

Note 2: In contrast, fixed-radius transitions have a repeatable path. The fixed radius transition is a transition at an enroute fix with a database-specified radius. Fixed radius transitions are intended to define transitions along airways in the case where separation between parallel routes must be maintained in the transition.

Note 3: The fixed radius transition described in this section should not be confused with the RF leg. The RF leg is a database-defined element currently used as part of a terminal area procedure.

Note 4: The path definition error for fly-by transitions is defined to be the difference between the defined path and the theoretical transition area. If the path lies within the transition area, there is no path definition error. The path definition error for fixed-radius transitions is the difference between the desired path defined in Section 2.2.1.2.9.2 and the defined path.

2.2.1.2.9.1 Fly-By Transitions

The transition area for fly-by transitions is shown in Figure 2-4. While the inner boundary of the transition area is defined as an arc of a circle, it is not required that such an arc should be flown by the aircraft. For fly-by transitions the defined path shall remain within the shaded area shown in Figure 2-4. An infinite number of acceptable ground tracks can be defined per individual airborne system design.

The standard formulas for a coordinated turn relate the radius of turn (R)to the ground speed (GS) and bank angle (Φ) as follows:

Radius of turn $R = (GS)^2/g\mathrm{Tan}(\Phi) = (GS)^2/(68625.4 * \tan(\Phi))$ NM

Acceleration of Gravity (g) = 68625.4 NM/hr^2

Turn Initiation Boundary Distance (Y) = $R * \tan(0.5*\alpha)$ NM

Where: GS = V+W is the groundspeed, in knots, assumed for the transition turn, and

α = track change, in degrees, and

Φ = the planned aircraft bank angle, in degrees

The following values for GS, α, Φ, shall be used for Low Altitude transitions (i.e. when the aircraft barometric altitude is less than FL195.

GS = 500 kts

$\Phi = \min(0.5 * \alpha, 23°)$

The following values for GS, α, Φ, shall be used for High Altitude transitions, i.e. when the aircraft barometric altitude is equal to or greater than FL195.

GS = 750 kts

$\Phi = 5°$, by default.

If 5° results in Y > 20 NM, then

Y = 20 NM and $R = 20/\tan(0.5*\alpha)$

The initiation of a turn shall not occur prior to 20 NM to the fix, regardless of the track angle change.

Note 1: Defining the high altitude transition area in terms of the largest expected ground speed and 5º bank angle results in a wide turn and a large protected airspace requirement. Equipment manufacturers are encouraged to consider higher bank angles for high altitude transitions to mitigate airspace and air traffic conflicts.

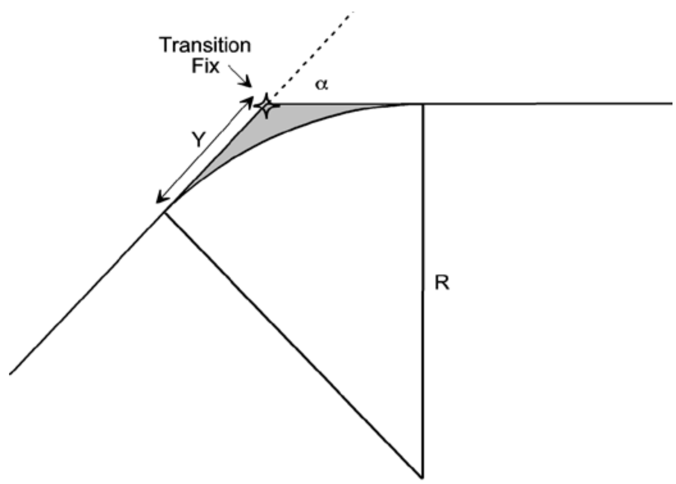
Note 2: When passing through FL 195 during a fly-by transition, the high altitude values may be applied for determining the theoretical boundaries throughout the transition.

Note 3: It is recognized that care will be needed in implementation of the limits specified in this requirement to avoid instability in the design path that might be caused by the interaction between path length (and altitude change) and the design bank angle limits above and below FL195.

Note 4: The transition area requirements for fly-by transitions are only applicable if the following assumptions are followed:

- *course changes do not exceed 120 degrees for Low Altitude transitions; and*
- *course changes do not exceed 70 degrees for High Altitude transitions.*

When course changes exceed those assumed above, there may be cases where a route could be created in which transition containment will not be possible due to factors such as aircraft performance, course change and leg length. In effect, the defined path is not flyable. This situation should not occur in a database-defined procedure, but may occur as a result of user modification to the defined flight plan. For situations such as this, the navigation system should attempt to stay within the containment area to the extent practicable, but may deviate from the defined path based upon operational considerations.



Note: Shaded area indicates Fly-By Transition Area

Figure 2-4: Fly-By Theoretical Transition Area

2.2.1.2.9.2 Fixed Radius Transitions

The system shall be able to define a transition at a waypoint along an enroute airway using a fixed turn radius as illustrated in Figure 2-5

The system shall use the navigation database-specified radius associated with each waypoint along an airway, and if there is a blank entry in the database field for a particular waypoint no fixed-radius transition is required.

Where there is a transition from one airway to another airway, both requiring an FRT at the common transition waypoint, the smaller of the two radii applicable to the common transition waypoint shall be selected. For an entry or exit transition from one airway to another airway, where only one airway requires an FRT at the common transition waypoint, a fly-by transition shall be used.

Note: An FRT at a waypoint may not be applicable in the following cases:

a) The waypoint has been designated as an overfly (either specifically by the crew or by the system such as for a hold)

b) The waypoint is the start or the end of a discontinuity

c) The waypoint is the start or the end of an offset transition path.

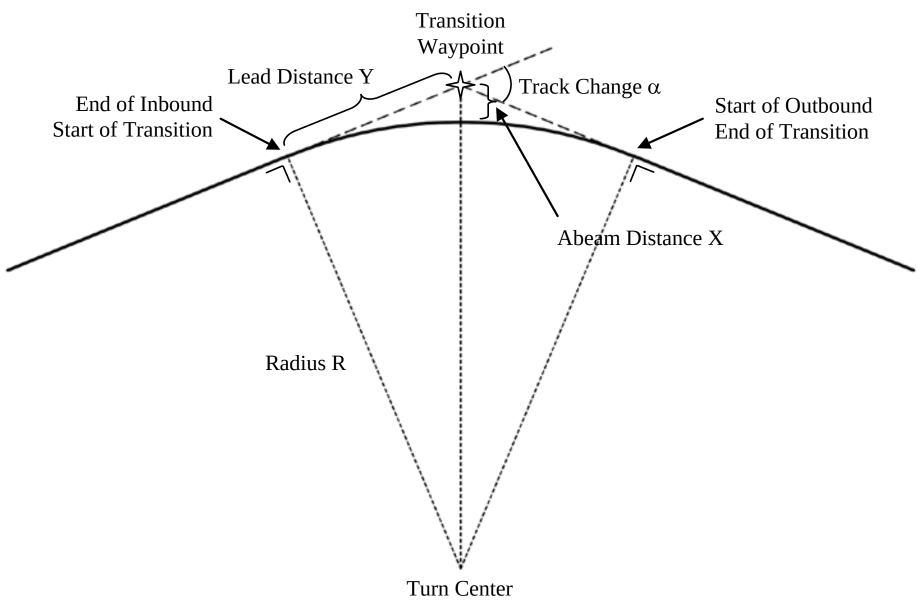


Figure 2-5: Fixed-Radius Transition

The geometry of the Fixed-Radius Transition is defined by the track change α (difference between outbound and inbound track in degrees) and the radius R. Those two parameters define the turn center, the Lead Distance Y which is the distance from turn initiation towards the transition waypoint and the Abeam Distance X which is the distance between the transition waypoint and the point where the aircraft crosses the bisector of the turn. The latter two values are determined by the following equations:

$$Y = R \tan(\alpha/2)$$
$$X = R((1/\cos(\alpha/2))-1)$$

2.2.1.2.9.3 Application of Waypoint Constraints During Leg Transitions

The reference location for all leg transitions shall be the intersection of the predicted or actual lateral path and the bisector of the angle defined by the inbound and outbound legs at the waypoint (reference Figure 2-4 and Figure 2-5). All waypoint altitude, speed and time constraints shall apply at the lateral bisector.

Distance-to-go, estimated time of arrival and time-to-go reference parameters shall be relative to the lateral bisector.

Note: The above requirements are intended to standardize airspace operations for future applications (such as Time of Arrival Control and Interval Management) that are dependent upon consistent equipment operational methods.

2.2.1.2.10 Data Resolution

The resolution at which the fix coordinates, turn radius, and course data are stored and operated upon may contribute to the path definition error. The data resolution should be equal to or better than that defined in DO-201A/ED-77. If it is not, the error contribution shall account for the difference between the data resolution in the equipment and that used by the source.

When the data resolution in the equipment is equal to or better than that defined in DO-201A/ED-77, the following sections do not apply.

2.2.1.2.10.1 Coordinate Resolution

For all leg types, the path definition error term shall include or account for the resolution of the fix coordinates. This error contribution is directly equivalent to the coordinate resolution.

2.2.1.2.10.2 Turn Radius Resolution

For systems which compute the ground track of an arc leg using the turn center and the specified turn radius, the path definition error term shall include or account for the turn radius resolution. This error contribution is directly equivalent to the turn radius resolution.

For systems which compute either the turn center or turn radius (in lieu of using the specified value), the error term shall account for both the data resolution as well as the difference between the computed and specified coordinates or radius.

Note: The above requirements are intended to address both RF and FRT curved path constructions.

2.2.1.2.10.3 Course Resolution

For leg types that are specified by magnetic course, the path definition error term shall include or account for the resolution of the defined course. The effect of this inaccuracy will vary with the distance from the fix and is computed as the product of the current distance from the leg termination fix and the course resolution in radians.

2.2.1.2.10.4 Magnetic Variation Resolution

For leg types that are specified by magnetic course, the path definition error term shall include or account for the resolution of the defined magnetic variation. The effect of this inaccuracy will vary with the distance from the fix and is computed as the product of the current distance from the leg termination fix and the magnetic variation resolution, in radians.

2.2.1.2.11 Navigation Database

2.2.1.2.11.1 Database Standard

The RNP equipment shall be capable of using an electronically updateable navigation database containing all the data required to support the functionality of the equipment.

Note 1: The operator/user will define the completeness and timeliness requirements for the data, or accepts the requirements defined by its data supplier.

The equipment manufacturer shall ensure that the requirements for generating their navigation database are specified in Data Quality Requirements (DQR) documentation that follows DO-200B/ED-76A.

The DQR shall require that the process generating the navigation data meets the standards specified in DO-200B/ED-76A.

The RNP equipment manufacturer shall ensure that their DQR documentation defines and describes the content contained in the navigation database that is used to enable the RNP equipment functionality.

Note 2: Guidance on defining data quality requirements is contained in Appendix B of DO-200B/ED-76A.

2.2.1.2.11.2 Database Interface

The navigation database shall provide access to navigation information in support of the RNP equipment's reference and flight planning features. Manual modification of the electronically updateable database shall not be possible. When data are recalled from storage they shall also be retained in storage. This requirement does not preclude the storage of "user defined data" within the equipment. The equipment shall provide a means for the operator to differentiate between duplicate waypoint identifiers in the database, including waypoints in the navigation database and user defined waypoints.

2.2.1.2.11.3 Database Version and Operating Period

The equipment shall provide a means to identify the navigation database version and valid operating period.

Note 1: Where a time reference is available, consideration should be given to providing an alert or indication, as appropriate, when the navigation database operating period is not valid, or requiring the pilot to acknowledge an out-of-date database upon start up of the system.

Note 2: Consideration should be given to the effects of the expiration of the navigation database while the aircraft is in flight. .

Note 3: Consideration should be taken to ensure flight plans and user-defined fixes are always referenced to the active database.

2.2.1.2.12 RNP

2.2.1.2.12.1 Flight Plan RNP

The RNP equipment shall automatically use the RNP for each leg segment in the flight plan as defined in the system navigation database, or as received by datalink as part of an uplinked flight plan.

The equipment shall be capable of manual override of automatic entries. A manual entry of an RNP shall be readily distinguishable by the flight crew. The equipment shall provide a means to remove the manual entry of the RNP and resume automatic entries.

Note: The ability to enter an RNP addresses the need for operational flexibility in an RNP airspace environment.

2.2.1.2.12.2 RNP Associated with a Flight Plan Leg

The equipment shall assign the RNP of a leg in the following order of precedence:

a. use the pilot entered RNP, if defined

b. use the RNP for the current leg or route, if defined

c. use the RNP coded in the navigation data base for the area, if defined.

Note 1: The above requirement anticipates the future definition of RNP for specified airspace regions, such as the North Atlantic Track System.

d. Use an equipment default RNP, if available.

If the original leg is divided into multiple legs by insertion of along-track reference points, the RNP of the original leg shall be applied to each newly created leg.

When constructing a flight path based on an airway contained in the navigation database, an RNP defined at a waypoint on the airway shall be associated with the path to that waypoint when the airway is constructed in the direction of increasing sequence numbers. When the airway is constructed in the direction of decreasing sequence numbers, the RNP shall apply to the path from the associated waypoint.

Note 2: The ARINC 424 airway definition is a sequence of waypoint records each with a sequence number, and each of which may have an associated RNP. The RNP is intended to apply to a specific segment of airspace rather than only at the waypoint, and typically the airway may be flown in either direction. This requires that the RNP be associated with the appropriate airspace segment.

2.2.1.2.12.3 RNP Associated with a Transition

The equipment shall assign the RNP during a leg transition to be equal to the RNP for either leg defining the transition.

Note: There are two different aspects associated with RNP when transitioning between legs. One aspect is related to airspace planning/obstacle clearance concerns and the other is related to navigation computer containment/alerting.

The RNP for airspace planning is the largest RNP associated with the two legs defining the transition (e.g., when transitioning from an RNP 1 leg to an RNP 0.3 leg, the airspace planners should assume transition containment based on RNP 1). The intent is to eliminate the need for the airborne equipment to specify when the transition from one leg to another is completed.

2.2.1.2.13 Earth Reference Model

WGS-84 earth reference model is the standard reference earth model. If geodesic path definition based on WGS-84 is not employed, any differences between the selected earth model and the WGS-84 earth model shall be included as part of the path definition error.

2.2.1.3 Path Steering

2.2.1.3.1 Fix/Leg Sequencing

The equipment shall provide the capability for automatic sequencing of fixes. The equipment shall have the means to indicate leg sequencing clearly to the crew.

Note 1: The above requirements are intended to ensure that, when manually steering to raw guidance data, the pilot has the necessary guidance to comply with any altitude, speed or time restrictions.

Note 2: "Sequencing" refers to the point at which there is a change in the active fix, waypoint, or flight plan leg.

Automatic sequencing may not apply for the transition into the missed approach for equipment where a specific pilot action is required.

Note 3: The fix sequencing exception at the missed approach point (MAP) is not intended to restrict systems that do not require a specific pilot action to correctly fly the missed approach upon passing the MAP.

2.2.1.3.2 Continuous Lateral Path Steering

2.2.1.3.2.1 Takeoff

When used to conduct a departure procedure off the runway, the RNP equipment shall be capable of providing lateral path guidance not later than 50 feet above the departure runway. Additionally, it shall be possible to enable such functionality at the pilot's discretion at any point prior to initiating the takeoff.

Note: Coupling to the autopilot / flight director system is not necessary to support this requirement.

2.2.1.3.2.2 Approach

When used to initiate a go-around through activation of a go-around mode (TOGA or some other means), the RNP equipment shall continue to provide continuous lateral path guidance (e.g. "TOGA-to-LNAV" guidance). The lateral path guidance shall continue to comply with the remainder of the lateral path defined by the instrument approach procedure, and at the end of the final approach segment of the instrument approach procedure, transition to the lateral path defined in the active flight plan's missed approach procedure.

2.2.1.4 Displays and System Alerting

Table 2-3 presents the minimum requirements for display/entry resolution for the lateral navigation function of the RNP equipment (e.g., the control display unit or integral display capability).

Note: Where the RNP equipment does not include a control and display function intended for flight crew use, the requirements of Table 2-3 apply to the resolution supported by the data input and output interfaces.

Table 2-3: Display/Entry Resolution

Parameter	Resolution	
	Display	Entry
Numeric Cross- track (XTK)	0.01 NM for values <1.0 NM, 0.1 NM for values >=1.0, and <10 NM, 1 NM for values >=10 NM	Not Applicable
Distance	0.1 NM for values <10 NM, 1 NM for values >=10 NM	0.1 NM for values <10 NM, 1 NM for values >=10 NM
Desired Track (DTK)	1 degree	1 degree
User-defined range from a Fix	0.1 NM	0.1 NM
User-defined Bearing from a Fix	1 degree	1 degree
User-defined Course or Track to a Fix	1 degree	1 degree
Track Angle Error (TAE)	1 degree	Not Applicable
Groundspeed	1 knot	Not Applicable
Fix latitude/longitude	0.01 min	0.1 min
Bearing	1 degree	1 degree
Track Angle	1 degree	Not Applicable
RNP	0.01 NM for values <1.0 NM, 0.1 NM for values >=1.0, and <10 NM, 1 NM for values >=10 NM	0.01 NM for values <1.0 NM, 0.1 NM for values >=1.0, and <10 NM, 1 NM for values >=10 NM
EPU	0.01 NM for values <1.0 NM, 0.1 NM for values >=1.0, and <10 NM, 1 NM for values >=10 NM	Not Applicable
Present Position latitude/ longitude	0.1 min	0.1 min
ETA	1 min	Not Applicable

Note 1: The fix latitude/longitude display requirement is intended to allow pilot verification of navigation database fix coordinates to the required resolution.

Note 2: With all displayed information, it is desired to display computed values rounded rather than truncated.

2.2.1.4.1 Cross Track Deviation Display

2.2.1.4.1.1 Numeric Display Information

The equipment shall provide a numeric display or output of cross-track deviation to at least ±20 NM (left and right) in accordance with Table 2-3.

> *Note: The numeric display need not be located with the cross-track display nor in the pilot's primary field of view.*

2.2.1.4.1.2 Non-Numeric Display/Output Requirements

The equipment shall provide either a non-numeric display or an electrical output to support an external non-numeric display as described in subsections 2.2.1.4.1.2.1 or 2.2.1.4.1.2.2 as applicable.

The RNP equipment shall provide a means to enable the display of non-numeric cross-track deviation and scale sensitivity, i.e., full scale deflection. The full-scale-deflection shall be consistent with the RNP in use.

The above requirements for RNP-based variable lateral deviation scaling apply equally to all values of RNP.

> *Note: An electronic map display (EMD) may satisfy the requirements for a non-numeric display if the EMD satisfies the requirements of 2.2.1.4.1.2.1.*

2.2.1.4.1.2.1 Display

If the equipment provides a non-numeric display of cross-track deviation, the equipment shall continuously provide a display with the characteristics shown in Table 2-4.

Table 2-4: Non-Numeric Display of Cross-Track

Readability (Percentage of full scale)	10%
Minimum Discernable Movement (Percentage of full scale)	2%
Accuracy of Centered Display (Percentage of full scale)	3%
Linearity of Display (Percentage of full scale)	5%

2.2.1.4.1.2.2 Electrical Output

If the equipment does not include a non-numeric cross-track display, or is intended to drive other displays, it shall continuously provide an electrical output capable of driving a display. The electrical output shall have the following characteristics shown in Table 2-5.

Table 2-5: Electrical Output of Cross-Track

Resolution of Electrical Output (Percentage of Full Scale)	1%
Accuracy of Centered Display (Percentage of Full Scale)	3%
Linearity of Display or electrical output (Percentage of Full Scale)	5%

2.2.1.4.2 Fix Distance Display

The equipment shall provide, on demand, the distance to the active fix, next fix, and the destination in accordance with Table 2-3. The distance display shall accommodate distances of at least 999 NM, but should accommodate the maximum range of the intended aircraft application.

> *Note: Distance displays up to 9999 NM should be accommodated where feasible, but it is recognized that existing electro-mechanical displays may only provide for a 3 digit (999NM) display capability.*

2.2.1.4.3 TO-FROM Indication

If appropriate, the equipment shall have the means to support a continuous display or electrical output to show whether the active fix is ahead of or behind the aircraft.

Note: For RNP operations, course selection and waypoint sequencing are intended to be automatic, with the navigation system flying "To" the active waypoint. A moving map display normally provides an adequate indication of the location of the aircraft relative to the active fix. However, a TO-FROM indication may be desirable in installations where a map display is not provided, or for the situation where the active leg has a manual termination, or to provide additional situational awareness, such as during holding patterns and off-path vectoring situations.

2.2.1.4.4 Bearing and Distance to Fix

The equipment shall provide the capability to compute the bearing and distance to any fix in the navigation data base or defined by the pilot in accordance with Table 2-3.

2.2.1.4.5 Display of Fix Identifier

Provisions shall be made to display the identification of the active fix, the next fix in the flight plan, and the destination. These fix identifications need not be displayed simultaneously. Means shall be provided to indicate whether or not the displayed fix is the active fix.

Note: When an offset is active, the system may display the identifier of original fixes. Because offsets are the result of pilot action, the pilot should be aware that tactical data (e.g. distance-to-go, ETA, etc.) are related to the offset path and not to the original path.

2.2.1.4.6 Display of Fix Latitude/Longitude

The equipment shall provide for the display of the navigation data base or user-defined fix latitude and longitude in accordance with Table 2-3.

2.2.1.4.7 Desired Track

The equipment shall provide for the display of desired track in accordance with Table 2-3.

2.2.1.4.8 Groundspeed

The equipment shall provide for the display of groundspeed in accordance with Table 2-3.

2.2.1.4.9 Track Angle and Track Angle Error

The equipment shall provide for the display of track angle in accordance with Table 2-3. The equipment should provide for the display of track angle error in accordance with Table 2-3.

2.2.1.4.10 Selection of RNP

The RNP equipment shall provide for the display of the currently selected RNP.

The equipment shall be capable of entry and display of the RNP in accordance with Table 2-3.

2.2.1.4.11 Navigation Sensor Indication

The equipment shall provide the flight crew with an indication of the current navigation sensor(s) in use.

2.2.1.4.12 Failure/Status Indications and Alerting

The equipment shall indicate:

a. The absence of primary power

b. Navigation equipment failures

c. Inadequate or invalid navigation signal(s) or source(s)

d. Inadequate or invalid navigation displays or output signals

e. When the equipment does not comply with the containment integrity requirement.

f. When a manually entered RNP is larger than the RNP associated with the current airspace, as defined in the navigation database or as defined by system defaults. Any subsequent reduction of the RNP associated with the current airspace shall reinstate this annunciation. Upon termination of a parallel offset, when a manually entered RNP is larger than the RNP associated with the current airspace, as defined in the navigation database or as defined by system defaults.

   Note: The intent is to reinstate the indication in case a manually entered RNP has been entered for the parallel offset operation.

g. When approaching RNP airspace from non-RNP airspace, care should be taken to avoid false alerts caused by PSE.

   Note: One acceptable solution is to inhibit alerting until the cross-track to the desired path is equal to or less than one-half (1/2) the RNP and the aircraft has passed the first fix in RNP airspace.

h. When the equipment detects that the current performance will not comply with the containment integrity requirement at the next waypoint. This indication should be provided sufficiently in advance of the waypoint such that the flight crew can take action to resolve the situation.

The equipment portion of the time to alert requirement (see Section 3.2 herein) is intended to ensure that a timely warning is provided to the flight crew, following the detection of a failure that results in the inability to meet a procedure's RNP and integrity requirements. The failure may occur in a satellite or ground navigation aid or an airborne sensor or it may be the instant at which the aircraft enters unsatisfactory navigation coverage.

The RNP equipment element of the total time to alert covers the interval between the instant when the data, which will result in an alert, arrives at the input of the equipment and the instant when the equipment issues the appropriate alerting output (whether that output is the alert or the signal that will result in the alert being issued.). The time interval for the equipment should not exceed 4 seconds in order to support expected total-time to alert requirements for all flight phases and operations.

The above requirements for RNP-based monitoring and alerting apply equally to all values of RNP.

Note 1: Some equipment will utilize complex algorithms to derive navigation outputs such that it will be impractical for the flight crew to monitor unaided the changing parameters that affect the navigation performance *and accuracy. Therefore, it is expected that the equipment should monitor those parameters for degraded performance which result from propagation, reception, geometric or other effects to the maximum extent possible and be capable of automatic or manual de-selection, compensation of station data, or should at least annunciate degraded operation.*

Note 2: The requirement to provide a caution that indicates the navigation system's inability to comply with current RNP containment integrity requirements is not intended to specify a particular implementation. For example, in a system with real-time estimation of position uncertainty and monitoring of FTE, this caution may be activated when the combination of position uncertainty and FTE exceeds the design limit for total system error. A system may also demonstrate compliance by allocating the requirements to each potential error source and monitor those error sources separately. In this implementation, the caution would be activated when either the position uncertainty or FTE becomes unacceptable. Yet another implementation is to demonstrate through test and analysis that the FTE is inherently bounded, in which case the caution would be activated when the position uncertainty exceeds the allocation design limit. The implementation of this caution, including the allocation of potential error sources and the monitoring concept, is left to the equipment designer.

If, however, FTE is to be substituted for actual cross-track deviation in flight, it is necessary to establish a minimum value (actual cross-track may only be used once it exceeds the minimum FTE), to recognize that the flight control system (pilot and/or autopilot) cannot control to a zero level of FTE.

An annunciation of excessive cross-track deviation is optional for RNP systems. If a system incorporates this type of caution, its intent should be to alert the flight crew that cross-track deviation has become excessive and, if not corrected, could become a problem. If this annunciation is implemented and is a factor in causing system non-compliance, the annunciation should become active early enough to give the flight crew the opportunity to correct the situation prior to receiving the RNP alert.

For any alert (warning, caution or advisory) that uses actual cross-track deviation as one of its components, the number of nuisance alerts (those alerts that activate when a problem does not exist) should be minimized such that the flight crew will recognize and react appropriately to the alert when required.

Note 3: It is desirable that aircraft equipped with an inertial reference system (IRS) have a predictive IRS coast capability that provides an alert when the navigation guidance reverts to the IRS and the drift rate will preclude completion of the planned procedure. In addition, when coasting, the system should display the estimated amount of time remaining before the current RNP will be exceeded. Equipment manufacturers are encouraged to consider extending the predictive IRS coast capability to address the RNP of intended future procedures loaded in the flight plan.

2.2.1.4.13 Response Time

If the RNP equipment includes an external control/display device, or has an integral control/display capability, the control/display function shall provide the dynamic response necessary to support the applications in Table 2-6.

The tasks shown in Table 2-6 shall be capable of being accomplished within the indicated time (as a bench test without distraction). The specified times apply regardless of where the functions are initiated (i.e., the pilot may be in the middle of doing something else before initiating the function).

Note: Where the RNP equipment does not provide the control and display function intended for flight crew use, the equipment designer should verify by analysis or bench test that the response time requirements of Table 2-6 will be achievable on installation.

Table 2-6: Response Time

Function	Maximum time to Accomplish
En route/terminal-related functions	
Access primary navigation information	2 sec.
Direct-to any named waypoint in a published departure, arrival, or approach procedure already in the active flight plan (including selecting the waypoint)	10 sec.
Direct-to any waypoint in the database, but not in the active flight plan (including selecting a five character waypoint)	20 sec.
Select a course to or from an active waypoint	10 sec.
Approach-related functions	
Select and activate an approach at the departure airport, which may be pre-programmed as an alternate flight plan	10 sec.
Select and activate an approach at an airport, given that the airport is the active destination	13 sec.
Runway change after an approach has been selected and activated	10 sec.

2.2.1.4.14 Runway Position Monitoring

If the runway position monitoring function is implemented in the RNP equipment, the equipment shall have the capability to detect a discrepancy between the aircraft position/orientation and the runway entered into the equipment for departure. When the discrepancy is detected an alert shall be annunciated to the flight crew early enough for the takeoff to be safely discontinued, but implemented such that nuisance alerts are minimized.

Note 1: The function may be implemented in the RNP equipment or other aircraft systems (such as aural alerting systems, surface map displays, etc., with its associated alerting methodology) to provide flight crew alerting to the potential for an incorrect initial departure position.

Note 2: In addition to the safety implications of departing on the incorrect runway or a taxiway, an accurate aircraft initial position (departing on the correct runway) is critical to executing an RNP departure clearance.

2.2.1.5 2D Accuracy, Containment, and Continuity Requirements

RTCA/DO-236C (EUROCAE/ED-75D) defines the aircraft level navigation system requirements for accuracy, containment integrity, and containment continuity. The following requirements define the equipment-specific requirements to facilitate the evaluation of an aircraft installation to the requirements of DO-236C.

Note: These requirements are based on the navigation infrastructure assumptions in Appendix C.

2.2.1.5.1 Lateral Accuracy

As defined in Section 1.7.2, total system error (TSE) is composed of three separate components: position estimation error (PEE), path definition error (PDE), and path steering error (PSE). If PDE is significant, then the errors allocated to it need to be considered in the PEE and resulting TSE analysis. TSE in both along-track and across-track directions shall remain smaller than the RNP for 95% of the flight time. The along-track component of TSE consists only of the along-track component of position estimation error.

The equipment designer should allocate the components of TSE as required to meet the expected equipment design, aircraft installation, and operational constraints. This section provides an example of the allocation of these components considering existing industry standards for equipment and aircraft performance. This example allocation is based on a containment integrity allocation of 5×10^{-6} each for faulted and non-faulted effects. Alternative allocations are equally acceptable if demonstrated to meet overall integrity and performance requirements. It also may be necessary to show the alternatives are achievable within the State's infrastructure assumptions in Section 1.5.1 and Appendix C. Allocations also may be made between the equipment and other elements of the installation.

The PEE allocation can be determined based on fixed allocations for PSE found in Table 2-7 and based on the following assumptions:

- FTE analysis provided in RTCA/DO-208, Appendix E for flight director or autopilot operation on straight line path segments.
- The RTCA/DO-208 values for FTE capability for flight director or autopilot operation are also applicable to curved paths.
- The CDI display requirements in Section 2.2.1.4.1 constrain the manual operation FTE so that it is equivalent to flight director operation FTE for:
  - Straight line path segments for RNP 0.3 and higher.
  - Curved path segments for RNP 1 and higher when the aircraft is equipped with a moving map depicting the curved path and flown at 200 knots indicated or less.

    Note: Approval for manual flight operation on straight line or curved path segments under other conditions will require separate evaluation of PSE.
- PDE and CDI centering errors are zero
- Normal (Gaussian) distribution for PEE and PSE

2.2.1.5.1.1 Position Estimation Error

The horizontal position estimation error of the equipment can be allocated based on the following values for the associated RNP:

Table 2-7: Example Position Estimation Error Requirements

RNP	Budgeted TSE (non-faulted) ($5x10^{-6}$)	PEE Allocation (95%) (Horizontal)	PSE Allocation (95%)	PSE Basis
0.3	0.6	0.28	0.125	Autopilot coupled (Note 2)
		0.08	0.25	Flight Director or Manual CDI
1.0	2.0	0.87	0.50	Autopilot, Flight Director or Manual CDI Operation
2.0	4.0	1.75	1.00	Autopilot, Flight Director, or Manual CDI
4.0	8.0	4.00	1.00	Autopilot, Flight Director or Manual CDI Operation

Note 1: The PEE requirements include or are based upon:

- *The associated system TSE containment not exceeding 2*RNP. The statistical containment requirement assumes a probability of 10^{-5} is allocated for TSE exceedance of 2*RNP without an alert, at the system level.*
- *An associated error allocation for PSE, and an allocation of zero for PDE.*
- *The airborne equipment accounts for data and computational latencies, equipment response time, and sensor error characteristics, for its interfaces.*

Note 2: The PSE value assumes autopilot operation and reflects an allocation to PEE that allows the use of either GPS or DME as positioning sources. Where GPS is the only intended source, the assumed maximum PSE can be increased to 0.25 NM. This is consistent with the assumed PSE for flight director operation or manual operation, and would allow a maximum horizontal PEE of 0.08 NM.

Note 3: Consistent with the Gaussian error distribution assumption, lateral accuracy is converted to horizontal accuracy based on a Rayleigh distribution (factored by 1.25). The accuracy requirements for each sensor combination are defined for the radial error, since the desired track is not always known.

2.2.1.5.1.1.1 Navigation Facility Assumptions

The PEE allocation for the design trade-off (*a priori*) analysis of the TSE accuracy and integrity requirements may be obtained by using the error distributions described in Appendix C with equipment meeting the appropriate standard.

Integrity of the infrastructure is not considered as part of the airborne PEE; the Signal-in-Space (SIS) is assumed to have the error distributions described in Appendix C. The only exception is GNSS, which has a SIS failure rate that must be compensated by an augmentation (See Section C.2.4). For this case, the effect of a SIS failure will be accounted for in the containment integrity requirements of Section 2.2.1.5.2.2.1. This applies to in-flight (*a posteriori*) alerting only, the *a priori* analysis still uses the error distributions described in Appendix C.

2.2.1.5.1.2 Path Steering Error

Path steering error consists of two components, flight technical error (FTE) and display error. The display error is assumed to be negligible. The lateral deviation scaling, sensitivity and path steering commands provided by the equipment as specified in this document are intended to enable the installed equipment to meet the maximum PSE values stated in Table 2-7. Appendix M provides guidelines for the collection and analysis of the FTE component of PSE in the event that the equipment designer wishes to demonstrate better performance than shown in Table 2-7.

Note: The CDI display requirements in Section 2.2.1.4 constrain the PSE that will occur for the installed equipment.

2.2.1.5.2 Integrity

2.2.1.5.2.1 Containment Limit

The RNP equipment shall be capable of supporting the aircraft level requirement that the probability that the total system error of each aircraft operating in RNP airspace exceeds the specified cross track containment limit without annunciation is required to be less than 10^{-5} per flight hour. The cross track containment limit is twice the RNP. This system containment integrity requirement shall be partially allocated to the RNP equipment as specified in Section 2.2.1.5.2.2.

2.2.1.5.2.2 Equipment

An acceptable allocation of the system containment integrity requirement to the non-faulted statistical TSE containment in the RNP equipment is $5x10^{-6}$ per hour. Alternative allocations are equally acceptable if demonstrated to meet overall integrity and performance requirements. Allocations may also be made between the equipment and other elements of the installation.

Note 1: The containment integrity limit is allocated to PEE, PSE and PDE, as appropriate. As described in 2.2.1.5.1, the PDE can be assumed to be zero under normal conditions. In the example allocation, one half of the system containment integrity requirement ($5x10^{-6}$ per hour) has been allocated to the RNP equipment non-faulted statistical TSE containment.

Note 2: The PEE and PSE data of Section 2.2.1.5.1.1 Table 2-7, along with the CDI display requirements of Section 2.2.1.4.1, should be utilized by the equipment to derive for display an EPU value consistent with the alert provided when the equipment fails to comply with the containment integrity. The displayed EPU must be scaled such that the containment alert occurs no later than when the displayed EPU value exceeds the RNP in effect. The margin between EPU and the required RNP should be an indication of the flight technical error margin available. If the margin is low, the flight crew may decide or be required to couple the autopilot system.

2.2.1.5.2.2.1 Signal-in-Space Integrity

When the integrity of the infrastructure must be considered by the airborne equipment (i.e., when using GNSS sensors), the requirements of this section define the conditions to ensure containment integrity. The requirements herein were established for the GPS constellation augmented according to DO-208 (with the Selective Availability active assumption), DO-229, or DO-316. It is expected that similar requirements will apply for other GNSS constellations when they become approved for RNP procedures.

The equipment designer must allocate the TSE elements during the design phase (*a priori*) analysis as required to meet the accuracy and containment requirements using the PEE data from Appendix C.2.4.

When the integrity of the infrastructure must be considered by the airborne equipment, the cross track component of total system error shall consist of the combination of path definition error and path steering error in the cross track direction during the in-flight (*a posteriori*) evaluation of continued conformance to the accuracy and containment requirements.

The example allocation in Table 2-7 is based on a containment integrity allocation of $5x10^{-6}$ each for faulted and non-faulted effects with respect to twice the RNP. Subtracting from this the $1x10^{-7}$ containment provided by the horizontal integrity limit (HIL) results (after rounding) in a 0.85*RNP allocation to PSE 95% for the purpose of integrity containment. This is consistent with the PSE allocation in Table 2-7.

For GNSS only-based RNP architectures, or when GNSS is the only source of containment integrity, the equipment shall generate an alert prior to HIL exceeding twice the RNP.

Note 1: The HIL can be the HPL_{FD}, the HPL_{SBAS}, or the maximum of the HPL_{FD} and the HUL. The HPL_{FD} cannot be used on its own when the GPS equipment has detected a fault, however the maximum of the HPL_{FD} and the HUL can be used. Refer to DO-229D for a definition of HPL_{FD}, the HPL_{SBAS} and HUL.

Note 2: For RNP systems where the architecture is an integrated, multi-sensor capability and where GNSS signal-in-space integrity is incorporated into a 2×RNP integrity alert consistent with this standard, a separate GNSS integrity alert is not required.

2.2.1.5.3 Containment Continuity

The RNP equipment shall be capable of supporting the aircraft level requirement that the probability of annunciated loss of RNP capability (for a given RNP) is less than 10^{-4} per flight hour.

Note: This requirement for containment continuity may not be adequate for certain operations. It assumes that the loss of RNP capability is a minor failure condition, and that a safe and appropriate alternate navigation method or procedure is available.

2.2.1.6 Lateral Control Performance

The RNP equipment shall be capable of commanding a bank angle of up to 8 degrees below 400 feet AGL, up to 30 degrees between 400 feet AGL and FL195, and 15 degrees in high altitude transitions, subject to aircraft limitations, e.g., aerodynamic limits, structural limits, etc.

Note 1: The ability to "command up to" refers to the equipment ability to generate bank commands up to the stated limit in the region specified. Another way to look at this is that the minimum limit on bank in the stated regions is the number specified. The minimum limit does not prevent systems from having a higher limit, but they cannot have a lower one.

Note 2: The intent of this requirement is to achieve a single standard to support all of the benefits that RNP is expected to deliver. The committee recognizes that some current designs introduce limits that do not meet this standard for various reasons. However, there are newer standards of procedure design in existence at this time that assume designs that are based on up to 25 degrees of bank, which may require 30 degrees of control to achieve the proper maneuver margin, e.g., AC 20-138D, Order 8260.58, ICAO Doc 8168. It is therefore considered a necessary performance standard going forward, particularly to achieve better utilization of the RF leg in the terminal area by reducing the minimum radius that may be used in procedure design.

2.2.1.7 Speed Control Performance

If the RNP equipment provides the means for a speed control function, it shall provide speed command outputs that facilitate compliance with speed restrictions in the flight plan (as defined in Section 2.2.2.2.3). If the speed restriction cannot be met within +/- 10 knots, a timely indication shall be provided to the crew.

Note 1: The indication that a speed restriction will be missed should be provided early enough to allow the crew to use any corrective measures that may be available to them (e.g. deploying speed brakes).

Note 2: The tolerance of +/- 10 knots allows for variations within aircraft systems to control and indicate aircraft speed.

Note 3: This requirement does not apply to equipment-generated target speeds, such as manually entered descent speed, economy speed, long range cruise speed, etc., nor to ATC-generated speeds ("maintain" instructions).

2.2.2 Vertical Navigation (VNAV) Functional and Performance Requirements

The vertical navigation function of RNP equipment provides vertical profile guidance based on specified flight levels/altitudes and/or speeds at waypoints. Basic VNAV capability includes vertical path guidance to a level or descending path and is generally provided as a linear deviation from the desired path. The desired path is defined by a line joining two waypoints with specified altitudes or as a vertical angle from a specified waypoint/altitude. The desired vertical path may be pilot selectable or may be determined by the equipment by computations based on the altitudes associated with successive waypoints. Enhanced system capabilities may include optimized climb performance or descent profiles.

The following functional and performance requirements are those that RNP equipment shall meet, as a minimum, to operate safely and efficiently. These are established to ensure acceptable operation in the vertical plane regardless of RNP equipment type.

2.2.2.1 Vertical Position Estimation

The vertical position source associated with vertical position estimation in the VNAV function described in this standard is the barometric altimetry system interfaced with or integrated into the RNP equipment.

This standard does not directly address the vertical flight capability of augmented GNSS (SBAS) systems but recognizes that such systems can support VNAV approach operations.

2.2.2.2 Vertical Path Definition

The requirements for defining the vertical path are governed by the two general forms of operation; allowance for aircraft performance, and repeatability and predictability in path definition. This operational relationship leads to the specifications in the following sections that are based upon specific phases of flight and flight operations.

2.2.2.2.1 General

The RNP equipment shall provide a means for the flight crew to confirm the validity of input data prior to the utilization of the new data by the system.

All equipment-calculated altitude data shall be referenced to MSL and the International Standard Atmospheric pressure model**.**

It shall be possible to define a vertical path by specifying altitude constraints at two fixes in the flight plan. Systems that specify flight path angles shall be able to define a vertical path by specifying a fix and a defined flight path angle (FPA) from that fix. Flight path angles shall be in accordance with Table 2-10.

It shall be possible to define a vertical path to an along-track fix.

The RNP equipment shall allow flight crew inputs of altitude and/or speed associated with a fix in accordance with the resolution of Table 2-10.

Upon selection of published terminal procedures (SIDs/DPs, STARs, and approaches), associated altitude constraints and speed restrictions shall be extracted from the navigation database.

It shall be possible to override waypoint altitudes and speeds extracted from the navigation database by manual entries in order to comply with ATC instructions.

2.2.2.2.2 Altitude Constraints

The RNP equipment shall support the fix altitude constraints defined below during all phases of flight:

a) “AT or ABOVE” altitude constraint, e.g. 2400A
b) “AT or BELOW” altitude constraint, e.g. 4800B
c) “AT” altitude constraint, e.g. 5200
d) "WINDOW" constraint, e.g. 2400A3400B

The equipment shall support both mean sea level (MSL) and flight level (FL) altitude formats.

Note: Altitude constraints may also be received as part of a datalink message.

2.2.2.2.3 Speed Restrictions

The RNP equipment shall support airspeed restrictions at waypoints during all phases of flight as defined below:

a) "AT or ABOVE" speed restriction
b) "AT" speed restriction
c) "AT or BELOW" speed restriction

Note 1: Speed restrictions may also be received as part of a datalink message.

The speed restriction shall be applied prior to, at, and after the waypoint as a function of flight phase, in accordance with Table 2-8.

Where speed restrictions and altitude constraints both apply at the same waypoint, the speed restrictions and altitude constraints shall be treated independently, such that if the speed restriction or altitude constraint is satisfied prior to the waypoint, the other restriction shall remain active.

Where speed restrictions and altitude constraints conflict during descent, the RNP equipment shall prioritize achieving the altitude constraint, while treating the speed restriction as a secondary priority.

For speed restrictions associated with an altitude, the RNP equipment shall treat the speed restriction as an AT or BELOW speed restriction as long as the aircraft altitude is below the speed restriction altitude.

Table 2-8 and the general requirements below describe the equipment operation and the operational applicability of the respective speed restriction types:

1. For an "AT or ABOVE" speed restriction, the equipment shall provide speed commands that support the aircraft operation to be at or above the restriction when the waypoint is sequenced.
2. For an "AT" speed restriction, the equipment shall provide speed commands that support the aircraft operation to be at the speed restriction when the waypoint is sequenced.
3. For an "AT or BELOW" speed restriction, the equipment shall provide speed commands that support the aircraft operation to be at or below the restriction when the waypoint is sequenced.
4. When the same "AT" speed restriction is applied at any two waypoints (not necessarily consecutive) in the same flight phase, the equipment shall provide speed commands that support the aircraft operation to treat the leg(s) between those waypoints as a constant speed segment at the restriction speed.

Table 2-8: Operational Applicability of Speed Restrictions

Speed Restriction Type	Speed Applicability by Flight Phase	
	Departure / Missed Approach (CLIMB)	Arrival / Approach (DESCENT)
AT or BELOW	Do not exceed PRIOR[2] to and AT	Do not exceed AT and AFTER
AT	Do not exceed PRIOR to, cross AT, do not go below AFTER	Do not go below PRIOR to, cross AT, do not exceed AFTER
AT or ABOVE	Do not go below AT and AFTER	Do not go below PRIOR to and AT

Note 2: PRIOR to, AFTER and AT in this table refer to the fix (waypoint) with the associated speed restriction.

Note 3: Speed restrictions expressed in Mach number are not required.

Note 4: It is anticipated that speed restrictions will conform to accepted FMS speed schedules, aircraft performance limitations and placards, and that speed restrictions will not be included in the final approach segment. Additionally, it is intended that the speed restrictions should produce a speed schedule that is monotonic during a single phase of flight. For example, aircraft speeds will continuously increase to cruise speed during climb and decrease to approach speed during descent.

Note 5: When used by Air Traffic Control (ATC), speed restrictions assigned at waypoints are intended to apply to the equipment in the same manner as procedural speed restrictions from the navigation database or via datalink.

Note 6: ATC-assigned speeds to "Maintain" are intended to be tactical in nature and are not covered by the requirements in this section. If the equipment does not provide additional capabilities to comply with an assigned "Maintain" airspeed, the flight crew may have to use intervention methods to follow the ATC instructions.

2.2.2.2.4 Vertical Direct-To

The RNP equipment shall construct a descent path to facilitate guidance from current position to a vertically constrained fix.

The equipment shall generate guidance cues to allow this path to be flown.

Note 1: The guidance cues may be accomplished in any number of ways, e.g. a vertical "Direct-To" function, a display of vertical speed required, or a display of the computed flight path angle.

Note 2: If there are altitude constraints prior to the vertical direct-to fix, the altitude constraints are deleted.

Note 3: This feature allows the aircraft to proceed from present altitude direct-to a specified altitude along the flight plan path.

2.2.2.2.5 Climb

This standard contains no path definition requirements for climb.

2.2.2.2.6 Descent and Approach

The RNP equipment shall determine a descent/approach path utilizing the vertical and longitudinal elements associated with the defined lateral flight plan. A vertical element in conjunction with an associated latitude/longitude location forms a three dimensional point in space. A descent/approach path “connects” a series of three-dimensional points in space to form a path from the start of the descent from cruise altitude to the runway threshold.

Note: For systems that implement curvilinear “performance-optimized” descent paths, these paths may be flown prior to reaching the first fix in the descent with an altitude constraint that constrains the path or to the extent that they remain within any window-based geometric path boundaries.

The equipment shall support the following path and constraint definitions for establishing the defined vertical path:

1. “Geometric” Point to Point (GPP) paths:
    a) “AT” to an “AT” constraint
    b) System-defined altitude to system-defined altitude, or
    c) Inside the boundaries (as illustrated in Figure 2-6) of:
        (i) "AT" constraint to "WINDOW" constraint
        (ii) "WINDOW" constraint to "WINDOW" constraint
        (iii) "WINDOW" constraint to "AT" constraint
2. “Flight Path Angle” (FPA) paths:
    a) Procedure defined

2.2.2.2.6.1 Descent Path Construction

The following general requirements apply to the descent path:

1. The constructed descent path shall pass through AT altitude constraints.
2. The constructed descent path is not required to pass through “AT or ABOVE” or “AT or BELOW” altitude constraints at the “AT” altitude, but the path shall satisfy the restriction.
3. The constructed descent path shall pass between the "AT or ABOVE" and the "AT or BELOW" portions of the "WINDOW".
4. The constructed descent path shall also stay between the space described by connecting geometrically (constant barometric gradient) the "AT or ABOVE" portions of "WINDOW" and "AT" constraints, followed by connecting geometrically the "AT or BELOW" portions of "WINDOW" and "AT" constraints (as illustrated in Figure 2-6).

    The above requirement assumes that the airspace will be designed such that the geometric path containment boundaries will provide for a deceleration segment prior to any waypoint- or altitude-based speed restriction.

Note 1: The path described in Item 3 above that is defined with "WINDOW" constraints, may include a "Geometric" Point to Point path, a "Curvilinear" optimum path or a path to accommodate decelerations.

Note 2: For curvilinear paths that are primarily within the geometric path boundary, small excursions outside of the boundary may occur depending on aircraft performance and flight conditions. Appendix Q illustrates examples of acceptable small excursions.

5. The defined path shall be referenced to Mean Sea Level altitudes.

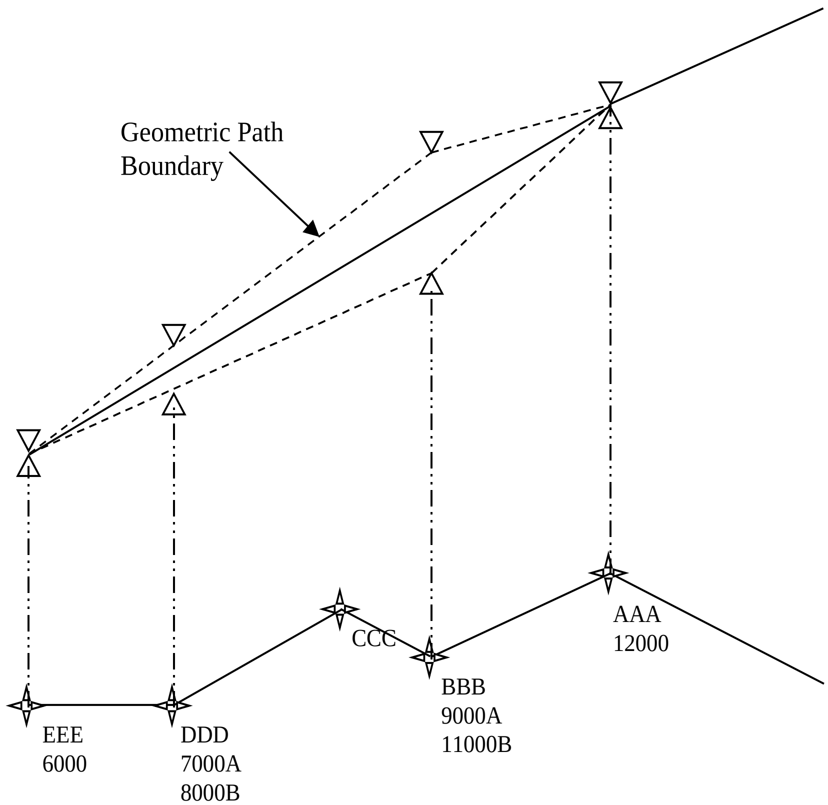


Figure 2-6: Descent Path Permitted by Two "WINDOW" Constraints, Two "AT" Constraints and Cruise Altitude

2.2.2.2.6.1.1 Geometric Point to Point Paths

A geometric point to point (GPP) path shall be defined by a constant barometric altitude gradient between two three-dimensional latitude/longitude/baro-altitude end-points. For this vertical leg type, the latitudes/longitudes and altitudes are established by either the flight plan (e.g. fixes with altitude constraints) or internally within the navigation system (e.g., to sustain a contiguous path). The gradient shall be calculated based upon the distance between the two end points and the altitude difference. Figure 2-7 illustrates a Geometric Point to Point path between fixes AAA and EEE.

Note: The distance between the endpoints can vary from system to system due to the variability in leg distance (as a result of transitioning between *legs). The altitude difference is expected to include the effects of the transition level (FL to MSL altitudes).*

The following requirements and considerations apply to GPP paths:

1. GPP paths may incorporate more than one lateral leg in defining the vertical leg. The distance between the lateral legs, as utilized to determine gradient, shall be along track distance (specifically incorporating the fly-by distance).
2. A GPP path shall support all altitude constraint types listed previously.

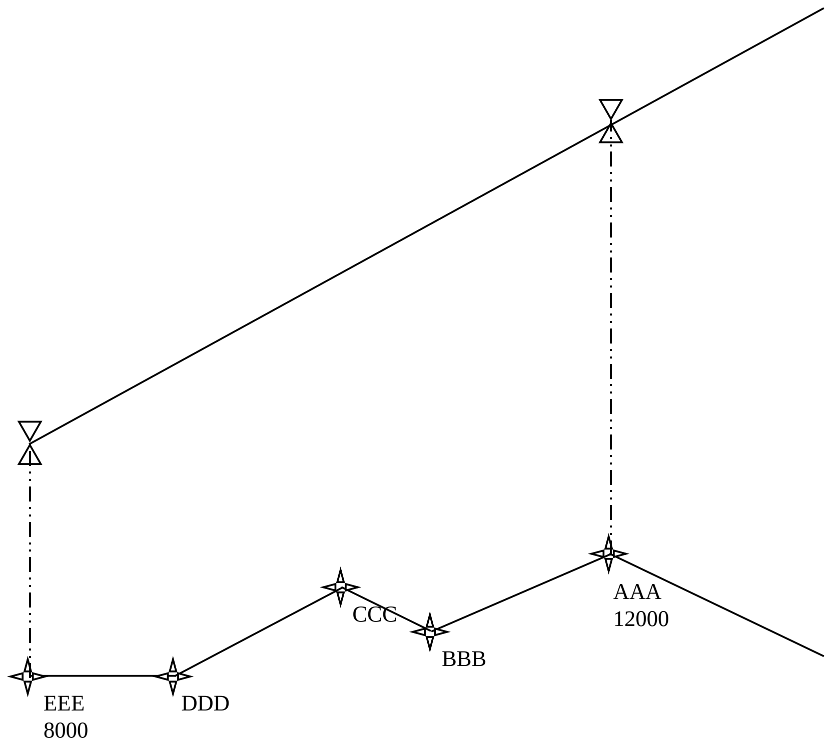


Figure 2-7: Descent Path defined by AT constraints and a Cruise Altitude

Where consecutive AT constraints exist in the descent profile, and there are no altitude constraints on any intervening lateral waypoints (as illustrated in Figure 2-7 and Appendix Q), the RNP equipment shall construct a GPP path between the AT constraints.

2.2.2.2.6.1.2 Flight Path Angle Paths

A flight path angle (FPA) path shall be defined by a three-dimensional fix (latitude, longitude, altitude) and a flight path angle. The path extends rearward from the fix at the specified vertical angle.

Where the flight path angle path is part of a terminal or approach procedure, both the fix and the flight path angle shall be extracted from the navigation database as part of the intended procedure.

If an FPA vertical path intersects the altitude of a preceding three-dimensional (AT, or AT or ABOVE) fix after the constrained fix, the system shall not allow descent below the constraint altitude until intercepting the FPA path (reference Figure 2-8).

Where a FPA vertical path intersects the altitude of a preceding three-dimensional (AT, or AT or ABOVE) fix before the fix, it is acceptable for the RNP equipment to increase the FPA value such that the intersection point coincides with the fix location.

Note: *Procedure design practice should preclude designs where the FPA path intersects the preceding constrained fix altitude before the fix. Systems should be designed to assure that the constraint will be satisfied before the attempt to capture the FPA path.*

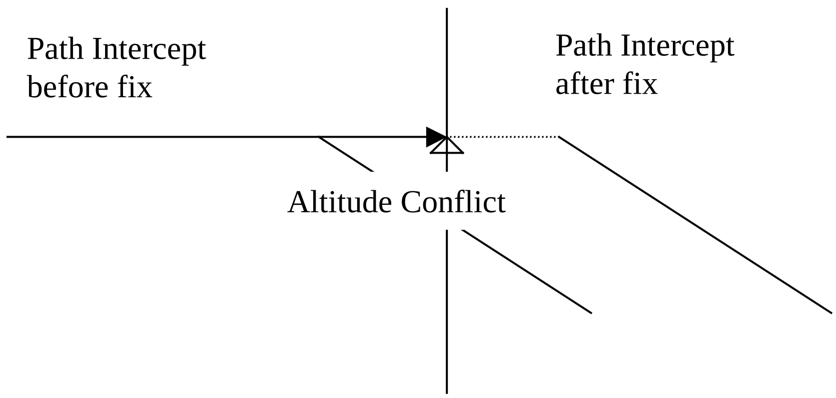


Figure 2-8: Waypoint with Vertical Constraint

2.2.2.2.6.1.3 VNAV Path Transitions

The following describes the desired path for a vertical fly-by transition in descent (reference Figure 2-9). The vertical fly-by is a controlled maneuver between two segments of the vertical path and is not itself a system-defined path. The VPPL limits described in Section 2.2.2.6.1 are not intended to apply to the vertical fly-by path.

When defining the vertical fly-by transition path the system shall use a normal acceleration factor (kg) of not less than 0.03g.

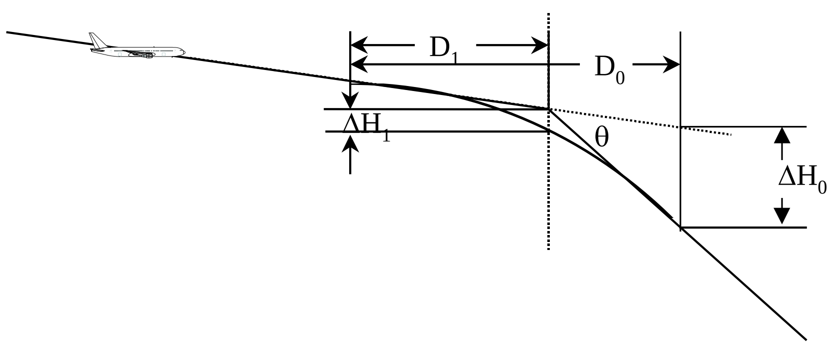


Figure 2-9: Fly-By Transition

D_1: Distance from start of transition to passage of waypoint.

D_0: Distance from start of transition to end of transition.

ΔH_1: Altitude below initial vertical path at passage of waypoint.

ΔH_0: Altitude below initial vertical path at end of transition.

Note 1: The resulting path depends upon the ground speed (GS) of the aircraft, the vertical path angle change (θ), and the reduction in lift (denoted as a fraction of gravity, kg) during the transition. The time to establish the reduced lift is not considered.

Note 2: The requirement that the normal acceleration be not less than 0.03g is intended to limit the vertical displacement (ΔH_1) of the vertical fly-by transition path below the vertical waypoint. When a vertical path angle change of greater than the nominal 3 degrees is encountered, equipment designers may elect to increase the applied normal acceleration, consistent with operational requirements and passenger comfort, in order to avoid excessive height loss (hence airspace protection requirements) at high groundspeeds.

Table 2-9 is an example of height loss for a vertical fly-by, using an angle change of 3 degrees and a 0.03g fly-by, for a range of ground speeds.

Table 2-9: Example of Height Loss for Vertical Fly-By

$\Delta\theta$ = 3 deg	kg = 0.03 g			
GS, Kt	D_1, NM	ΔH_1, Ft	ΔH_0, Ft	Final ΔVS, Ft/min
150	0.29	23	91	797
200	0.51	40	162	1063
250	0.80	63	253	1329
300	1.15	91	364	1594
350	1.56	124	496	1860
400	2.04	162	648	2126
450	2.58	205	820	2391
500	3.19	253	1012	2657
550	3.86	306	1225	2923

Note 1: There is not one unique point over the earth that all systems will fly over when transitioning from one track to another. Variability in VNAV performance (e.g. where the aircraft thinks it is relative to a fix versus the aircraft's actual location, and the degree of positioning confidence with ATC) will be similar to non-VNAV systems.

Note 2: The following is the specific formula used to generate the above table. The user may choose different assumptions for the angle and vertical acceleration to determine the resulting height loss.

The change in vertical acceleration is assumed to be a constant fraction of gravity (kg):

$$\Delta \ddot{H} = kg$$

The change in vertical speed from beginning of maneuver is given by

$$\Delta \dot{H} = kgt$$

where t is time from beginning of maneuver.

The vertical distance from the incoming path is given by a quadratic function

$$\Delta H = \frac{kgt^2}{2}$$

Horizontal velocity is assumed constant (V) so that

$$\dot{D} = V$$

where D is the distance traveled from the beginning of the maneuver.

D is then calculated as

$$D = Vt$$

At end of maneuver the change in vertical flight path angle $\Delta\theta$ *is given by*

$$Tan(\Delta\theta) = \frac{\Delta \dot{H}}{\dot{D}}$$

Time duration t_o *, to end of maneuver is given by*

$$t_o = \frac{V}{kg} Tan(\Delta\theta)$$

At end of maneuver horizontal distance traveled is

$$D_o = \frac{V^2}{kg} Tan(\Delta\theta)$$

At end of maneuver vertical distance traveled is

$$H_o = \frac{V^2}{2kg} Tan^2(\Delta\theta)$$

The vertical waypoint may be considered to be located at the point of intersection of the initial and final vertical paths. The passage of this point occurs at

$$t_o / 2$$

At the passage of the vertical waypoint, the horizontal distance traveled is

$$D_o / 2$$

At the passage of the vertical waypoint, the vertical distance traveled is

$$H_o / 4$$

2.2.2.3 Vertical Path Steering

If a continuous vertical path cannot be generated for any reason, i.e. a vertical discontinuity occurs, the RNP equipment shall provide the capability to transition through the discontinuity, avoiding transient descent or climb maneuvers, and provide continued flight information and guidance during the path transition. An indication that this condition has been detected should be provided in a timely fashion that the flight crew can take action to resolve the situation.

Note: Equipment designers may consider the temporary removal of vertical path guidance in those situations where manual intervention may be essential.

2.2.2.3.1 Transition to Missed Approach

When the RNP equipment has detected that a missed approach has been initiated (by activation of TOGA input or other means):

- the climb flight phase (if provided) should be activated,
- the equipment shall have the means to disregard the remainder of the approach vertical path below the altitude at which the approach was discontinued, and
- the equipment shall comply with the altitude constraints and speed restrictions applicable to the missed approach procedure.

Note. It is recognized that in some installations the flight crew could initiate a missed approach in a manner where the RNP equipment may not be able detect that it has occurred.

2.2.2.4 VNAV Displays and Alerting

2.2.2.4.1 General

Note: For those aircraft meeting the requirements of FAR 25/ EASA CS-25, it is intended that provisions of certification documents such as AC 25-11B, AC 25-1322-1, AMC 25-11 and other applicable documents should be satisfied.

Table 2-10 presents the minimum requirements for display/entry resolution for the vertical navigation function of the RNP equipment (e.g., control display unit or integral display capability).

Note: Where the RNP equipment does not include a control and display function intended for flight crew use, the requirements of Table 2-10 apply to the resolution supported by the data input and output interfaces.

Table 2-10: VNAV Display/Entry Resolution

Parameter	Resolution	
	Display	Entry
Altitude	Flight level or 10 feet	Flight level or 10 feet
Altitude from navigation database	Flight level or 1 foot	Not Applicable
Vertical Speed	100 feet/minute	100 feet/minute
Airspeed	1 knot or 0.01 M	1 knot or 0.01 M
Vertical Path Deviation	10 feet	Not Applicable
Flight Path Angle	0.01 degree	0.01 degree
Temperature	1 degree	1 degree

Note: With all displayed information, it is desired to display computed values rounded rather than truncated.

2.2.2.4.2 Vertical Deviation

The RNP equipment shall provide the means to support the display of non-numeric vertical deviation in the primary field of view during all phases of flight operations where there is a defined path in accordance with the display and electrical output characteristics of Table 2-4 and Table 2-5, respectively.

The equipment shall provide the means to support the numeric display of vertical deviation during all phases of flight operations where there is a defined path in accordance with Table 2-10.

Note: There is no requirement to display vertical deviation during climb, unless the equipment generates a defined path for this flight phase, nor for the cruise phase, where the primary altimeter is considered to provide sufficient altitude deviation information.

2.2.2.4.2.1 Vertical Deviation Scale Sensitivity

Standard non-numeric vertical deviation full scale deflection and scaling is required to enable monitoring and bounding of the vertical FTE along the VNAV descent and approach paths and to support the flight crew's task of maintaining the aircraft on the vertical centerline.

Note 1: For display formats employing the traditional two dots of deviation either side of a centered deviation indication, the vertical deviation display should be scaled to meet the full scale deflection specified below when aligned at the second dot of deviation.

When the RNP equipment provides the means to control the vertical deviation scale sensitivity, the requirements of Section 2.2.2.4.2.1.1 shall apply.

> *Note 2: When the vertical deviation scale sensitivity is controlled by external displays the RNP equipment should have the capability to support such displays.*

2.2.2.4.2.1.1 Final Approach Segment

For the final approach segment, the RNP equipment shall provide the capability for a non-numeric display of vertical deviation with a full scale deflection of +/- 150 feet. In addition, the implementation shall provide the flight crew an easy way to identify a path deviation of 75 feet below path using the vertical deviation display alone.

> *Note: This is the minimum standard for vertical deviation display scaling for final approach operations and does not preclude using a scale of other than +/- 150 feet, provided that the scaling is suitable to control the aircraft on the intended path and the 75 feet deviation can be easily identified by the flight crew. Applicable certification and operational requirements must be satisfactorily met.*

The following requirements apply to RNP equipment using angular vertical deviation scaling:

1) The deviation scaling shall support the FTE monitoring and bounding (75 feet deviation) requirement.

2) The deviation limits shall be equivalent to the operational limits for glideslope deviations during an ILS approach.

> *Note: Angular deviation indications may be unsuitable for VNAV operations for long final approach segments because the angular deviations may no longer support the monitoring and bounding of FTE.*

A scale change for the final approach shall be done in a manner suitable for transitioning onto the final approach segment.

This standard does not address the vertical deviation scaling requirements for SBAS systems. For such systems, refer to RTCA DO-229D.

2.2.2.4.2.1.2 Operations Outside the Final Approach Segment

For operations outside the final approach segment, the RNP equipment shall support the capability for a non-numeric display of vertical deviation with a full scale deflection of not more than +/- 500 feet.

> *Note: This is the minimum standard for vertical deviation display scaling for other than final approach segment operations and does not preclude using a scale other than +/- 500 feet.*

2.2.2.4.3 Altitude and Speed Predictions

The RNP equipment shall provide a means to display altitude and speed predictions for the active fix in accordance with Table 2-10. The capability to display altitude and speed predictions for other fixes in the flight plan is recommended.

> *Note: System-defined vertical flight profiles may include fixes for which an altitude constraint or vertical angle have not been specified. For these fixes, it is desired that the system will provide the capability to estimate the aircraft's altitude and speed at which the fix will be crossed.*

2.2.2.4.4 Level Flight Transition

The RNP equipment shall have a means to support the indication to the flight crew of an impending transition to/from level flight for anticipation of vertical maneuvering.

> *Note 1: For RNP equipment that does not interface with the vertical channel of the flight guidance system, the continuous display of the distance from the associated fix or from the level flight transition point (if not at a fix) may be considered to be sufficient.*

If the RNP equipment interfaces with the vertical channel of the flight guidance system, the equipment shall not cause the aircraft to depart from level flight unless specifically enabled by the flight crew.

> *Note 2: The method used to enable departure from level flight should be consistent with the existing operational philosophy of the airplane's flight guidance system. Typically, the altitude preselector is used to accomplish this.*

2.2.2.4.5 Altitude Constraints

A display of the altitude constraints associated with flight plan waypoints and their type (reference 2.2.2.2.2) shall be available to the pilot in accordance with Table 2-10.

2.2.2.4.6 Speed Restrictions

A display of the speed restrictions associated with flight plan waypoints and their type (reference 2.2.2.2.3) shall be available to the pilot. A display of the speed restrictions associated with altitudes should be displayed in accordance with Table 2-10.

2.2.2.4.7 Flight Path Angles

If there is a flight path angle defined in the navigation database for the final approach segment of an instrument approach procedure, the RNP equipment shall have the means to display the flight path angle for that leg in accordance with Table 2-10.

> *Note: If there is a flight path angle defined in the navigation database for any leg of an arrival procedure, the equipment should display the flight path angle.*

If the RNP equipment provides the capability for manual entry of a flight path angle, the RNP equipment shall have the means to display the flight path angle.

2.2.2.4.8 Vertical Navigation Operations

If the RNP equipment provides the capability for VNAV operations other than exclusively for instrument approach procedures, the equipment shall have the means to distinguish between the vertical phases of flight (i.e., climb, cruise, descent and approach) to facilitate compliance with the flight phase-specific requirements of this standard.

The RNP equipment shall compute and display a top-of-descent (TOD). The RNP equipment may also compute and display a top-of-climb (TOC). The vertical path guidance provided by the equipment shall be valid for all groundspeeds up to a maximum value to be set by the equipment designer and for all ascent and descent rates up to a maximum value determined by the equipment designer.

If the RNP equipment supports only approach operations, the TOD need not be displayed.

> *Note: Performance-based systems should consider the utility of climb phase operations such as maximum performance and step-climb, cruise phase*

operations such as long-range cruise and cruise-climb, and descent phase operations such as cruise-descent, early/late descent, as well as time-of-arrival. The ability to account for acceleration and deceleration segments due to altitude- and fix-based speed restrictions is also desirable.

2.2.2.4.9 Vertical Alerting

If a planned departure from level flight has not been enabled in a timely manner, the RNP equipment shall provide an annunciation to the flight crew.

Note 1: The indication that the planned departure from level flight has not been enabled should be provided early enough to allow the crew to perform the necessary action, such that a smooth transition to the intended climb/descent path is always possible.

If the equipment can determine from a performance standpoint that it will not be possible to fly the defined vertical path an indication should be provided to the flight crew.

Note 2: The above requirement ensures crew awareness of the aircraft performance required to fly the vertical profile. Equipment designers may consider the display of vertical speed required, vertical path angle required, and/or an alert for extreme flight path angles. Any alert should be consistent with the overall flight deck alerting scheme. This could range from a simple status indication to a message and aural warning

2.2.2.5 Temperature Compensation

It is recommended that the RNP equipment should correct for temperature effects to the barometric altitude. Equipment that provides temperature compensation shall meet the requirements of Appendix H.

2.2.2.6 VNAV Accuracy, Integrity and Continuity Requirements

2.2.2.6.1 VNAV Accuracy Requirements - Standard Conditions

RNP equipment shall have system error components in the vertical direction that are less than the accuracy requirements, 99.7% of the flying time. The minimum accuracy requirements for vertical guidance, including static source pressure altimetry error, shall meet the requirements stated in Table 2-11 under normal descent flight profiles.

Table 2-11: Vertical Path Performance Limit (VPPL) (Feet, 99.7% Probability)

Altitude Region (MSL)	Level Flight Segments	Flight Along Specified Vertical Descent Profile
At or below 5,000 ft	150	160
5,000 ft to 10,000 ft	200	210
10,000 ft to 29,000 ft	200	210
29,000 ft to 41,000 ft	200 (See Note 2)	260

Note 1: These requirements are based upon airborne altimetry and avionics systems that provide performance consistent with Required Vertical Separation Minimum (RVSM) requirements. Credit is taken for the

systems qualification for RVSM as this provides improved altimetry performance that benefits the entire aircraft flight envelope.

Note 2: For aircraft type designs prior to January 1, 1997, the value is 200 feet in the cruise flight envelope and is not to exceed 250 feet over the full aircraft operating envelope. Basic height keeping parameters for 1000 feet Vertical Separation Minimum between Flight Level 290 and Flight Level 410 are in ICAO Document 9574, Manual on the Implementation of 1000 Ft Vertical Separation Minimum Between FL290-FL410 Inclusive.

Note 3: The various segment limits are treated as bounds that reflect a number of factors including better or changing resolution vertical deviation scaling for approach, continuous increase/decrease of altimetry system error depending on ascent/descent, applicability of horizontal coupling error (HCE) and vertical angle error (VAE), and flight levels where RVSM criteria are applied.

Note 4: The altitudes where steps occur (Figure 2-10) follow the typical conventions in criteria, and are intended to be used in conjunction with specific path fixes so as to determine what flight performance must be confirmed or demonstrated when flying a path to a fix with constraints as defined in Section 2.2.2.2.6.

Note 5: The limits are not intended for performance aspects associated with path captures or level-offs and the vertical fly-by transition, nor are they directly applicable to operational criteria such as obstacle clearance.

Note 6: In the event that a fix is located in close proximity to a step change in limit, and depending on which side of the step the fix or procedure may be located, a performance limit at or less than the Table 2-11 limit should be acceptable (e.g. at 5,100 feet, a limit might be greater than 160 but less than 210 based upon the underlying vertical error root sum squared (RSS) methodology corresponding to the operation, procedure and applicable error characteristics).

Note 7: The determination of the error terms other than ASE, including lateral position estimation error (PEE), path steering error (PSE_Z) and path definition error (PDE_Z) are expected to reflect the systems architecture, functional design and applicable navigation positioning technology

Note 8: For operations to airports and runways at higher altitudes, the vertical performance limit for the associated altitude region in Table 2-11 is assumed to apply. These linear limits, while resulting in some simplification for performance evaluation and demonstration, will introduce conservatism in the performance margins at the lower altitudes in the altitude region for a procedure (i.e. the limits at the lower altitudes may be much larger than the 3-sigma sum of ASE, PSE, PDE, and HCE).

Note 9: For performance evaluation and demonstration of the horizontal coupling error (HCE), the coupling effect of PEE into HCE is not directly tied to the RNP. How it is determined for the RNP equipment will require consideration of the effect of any computational and data latencies, the positioning technologies available and used, how they may be used (e.g. mixed) together, and the effect on horizontal along track position estimation error.

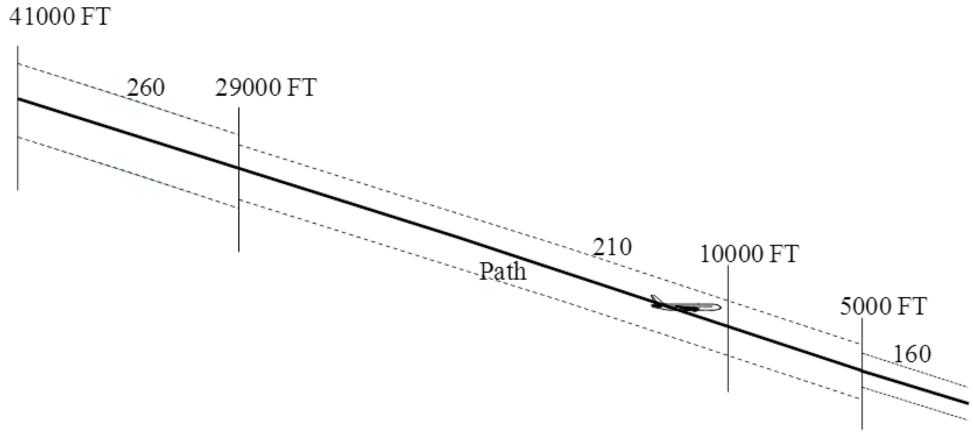


Figure 2-10: Illustration of VPPL Along Vertical Profile

2.2.2.6.2 VNAV Path Steering Error

Vertical path steering error consists of two components, flight technical error (FTE) and display error. The display error is assumed to be negligible. This MOPS does not contain specific performance requirements for vertical FTE. However, the vertical deviation scaling, sensitivity and vertical path steering commands provided by the equipment are intended to enable the installed equipment to bound the vertical deviation as defined in Section 2.2.2.4.2.

Note: The vertical deviation display requirements in Section 2.2.2.4.2.1 constrain the vertical path steering error that will occur for the installed equipment.

2.2.2.6.3 VNAV Integrity and Continuity Requirements

There are no vertical containment integrity and continuity requirements associated with VNAV operations**.**

Note 1: In the vertical dimension, the integrity of the vertical path and operation is addressed by traditional means of limiting the possibility of display of misleading information under existing certification guidelines. Additionally, increased integrity assurance is provided by path definition, through repeatable path performance and known bounds for path following.

Where the RNP equipment provides a VNAV capability that is intended to be used for the conduct of VNAV operations, the probability of annunciated loss of VNAV capability shall be less than 10^{-3} per flight hour.

Note 2: In the vertical dimension, the continuity of the vertical solution is addressed by traditional means of limiting the probability of loss of function under existing certification guidelines, e.g. this would allow for consideration of manual, assisted or automatic systems capability and any associated operational limitation.

2.2.3 Estimated Time of Arrival

The RNP equipment shall be capable of providing an estimated time of arrival (ETA) for every flight plan fix.

Note 1: It is expected that when the next generation of datalink services is implemented, the datalink interface of the RNP equipment will have the capability that supports ground requests for estimated time of arrival.

Note 2: The ETA should be periodically recomputed in the absence of flight plan or forecast changes to continuously support meeting the ETA performance requirement.

Note 3: Flight crews may need to periodically update the entered forecast winds and temperatures (if the RNP equipment provides this capability), and update any flight plan changes as soon as possible in order to meet operational requirements.

Note 4: Crossing time - when a fix/waypoint crossing occurs at a course change with a fly-by *transition, the ETA is associated with the lateral bisector of the turn.*

The equipment shall be synchronized to UTC to keep all time references the same for ETA functions.

2.2.3.1 ETA Accuracy

The maximum error in the ETA at a fix shall be either 1% of the time of flight remaining to that fix or 10 seconds, whichever is greater, for the entered conditions and flight plan, in the absence of environmental uncertainties.

Note 1: As the flight time to the fix decreases, a lower limit to the accuracy requirement was thought sensible rather than allowing it to decrease to zero. So a limit of 15 minutes to go to the fix was chosen as reasonable, which translates (at 1%) into a 9 second tolerance, which was rounded to ten seconds as the lower limit required.

Note 2: The 1% ETA accuracy requirement applies to a stabilized prediction, not for the prediction that must be provided immediately following a flight plan change affecting the defined flight path.

Note 3: ETA calculations are based on estimated position, the ground speeds for each flight plan leg, vertical profile, and the expected curved ground track.

Note 4: For the purposes of showing compliance with the ETA accuracy requirement, time of flight remaining to the fix is defined as the difference between the actual time of arrival (ATA) and the flight time at which the ETA was calculated.

2.2.3.2 ETA Response Time

The ETA for each point in a flight plan shall be available within 30 seconds of completion of the flight plan entries necessary to perform the calculations. This requirement applies to flight plans of a reasonable size, distance, and complexity (e.g., 25 waypoints, 500 NM, with no optimum step).

2.2.4 Time of Arrival Control

If the RNP equipment provides a Time of Arrival Control (TOAC) capability, the requirements of Appendix N shall apply.

2.3 Equipment Performance – Environmental Conditions

The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual operations.

Some of the environmental tests contained in this subsection need not be performed unless the manufacturer wishes to qualify the equipment for the particular environmental condition. These tests are identified by the phrase "When Required." If the manufacturer wishes to qualify the equipment to these additional environmental conditions, then these "When Required" tests shall be performed.

Unless otherwise specified, the test procedures applicable to a determination of equipment performance under environmental test conditions are set forth in RTCA document DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment, and as listed in Table 2-12.

Note: Information on the relationship between DO-160G and earlier versions of that document can be found in FAA Advisory Circular, AC 21-16G.

While the equipment is subjected to the test conditions specified in RTCA/DO-160G, the following requirements of this document shall be met:

2.2.1.4.1 Cross Track Deviation Display

2.2.1.4.12 Failure/Status Indications & Alerting

2.2.1.5.1 Lateral Accuracy

2.2.2.4.2 Vertical Deviation Display

Additionally, for each test, all system controls, displays, inputs and outputs shall perform their intended functions.

The rest of the performance requirements in Sections 2.1 and 2.2 need not be tested to all of the conditions contained in RTCA/DO-160G. Judgment and experience have indicated that these particular performance parameters are not susceptible to certain environmental conditions and that the level of performance specified in Sections 2.1 and 2.2 will not be measurably degraded by exposure to these particular environmental conditions.

Alternative methods that use comprehensive hardware test programs may be used to satisfy the environmental testing required by this section. If such methods are used, the test programs utilized shall test all of the associated hardware utilized in the derivation and computation of the output parameters.

Table 2-12: Environment Test Conditions

DO-160G		Special Requirements or Conditions:
Section	Section Title	
4.5.1	Temperature and Altitude: Operating Low Temperature Test	Test applicable categories of DO-160G Section 4.3

DO-160G		Special Requirements or Conditions:
Section	Section Title	
4.5.2	Temperature and Altitude: Short-Time High Operating Temperature Test	Test applicable categories of DO-160G Section 4.3
4.5.3	Temperature and Altitude: Operating High Temperature Test	Test applicable categories of DO-160G Section 4.3
4.5.4	Temperature and Altitude: In-Flight Loss of Cooling Test (when required)	Test applicable categories of DO-160G Section 4.3
4.6.1	Temperature and Altitude: Altitude Test	Test applicable categories of DO-160G Section 4.3
4.6.2	Temperature and Altitude: Decompression Test (when required)	Test applicable categories of DO-160G Section 4.3
4.6.3	Temperature and Altitude: Overpressure Test (when required)	Test applicable categories of DO-160G Section 4.3
5	Temperature Variation	Test applicable categories of DO-160G Section 5.2
6	Humidity	Test applicable categories of DO-160G Section 6.2
7.2	Operational Shocks and Crash Safety: Operational Shocks	Test applicable categories of DO-160G Section 7.1.1
7.3	Operational Shocks and Crash Safety: Crash Safety	Test applicable categories of DO-160G Section 7.1.1.
8	Vibration	Test applicable categories of DO-160G Section 8.2.2
9	Explosion Proofness (when required)	Test applicable categories of DO-160G Section 9.3. During these tests, the equipment shall not cause detonation of the explosive mixture within the test chamber.
10.3.1	Waterproofness: Drip Proof Test (when required)	Test applicable categories of DO-160G Section 10.2

DO-160G		Special Requirements or Conditions:
Section	Section Title	
10.3.2	Waterproofness: Spray Proof Test (when required)	Test applicable categories of DO-160G Section 10.2. This test shall be conducted with the spray directed perpendicular to the most vulnerable area(s) as determined by the equipment manufacturer.
10.3.3	Waterproofness: continuous Stream Proof Test (when required)	Test applicable categories of DO-160G Section 10.2
11.4.1	Fluids Susceptibility: Spray Test (when required)	Equipment is tested after being subjected to test conditions (instead of while being subjected to test conditions). At the end of 24-hour exposure period, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the requirements of this section shall be met (see table column header).
11.4.2	Fluids Susceptibility: Immersion Test (when required)	Equipment is tested after being subjected to test conditions (instead of while being subjected to test conditions).At the end of the 24-hour immersion period specified in DO-160G, Paragraph 11.4.2, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred. Following the two-hour operational period at ambient temperature after the 160-hour exposure period at elevated temperature, the requirements of this section shall be met (see table column header).
12	Sand and Dust (when required)	-
13	Fungus Resistance (when required)	-

DO-160G		Special Requirements or Conditions:
Section	Section Title	
14	Salt Spray (when required)	-
15	Magnetic Effect	Test applicable categories of DO-160G Section 15.1
16.5.1	Power Input: Normal Operating Conditions (as appropriate)	Test applicable categories of DO-160G Section 16.2
16.5.2	Power Input: Normal Operating Conditions (as appropriate)	Test applicable categories of DO-160G Section 16.2
16.5.3	Power Input: Abnormal Operating Conditions (as appropriate)	Test applicable categories of DO-160G Section 16.2
16.5.4	Power Input: Abnormal Operating Conditions (as appropriate)	Test applicable categories of DO-160G Section 16.2
17	Voltage Spike (as appropriate)	Test applicable categories of DO-160G Section 17.2
18	Audio Frequency Conducted Susceptibility — Power Inputs	Test applicable categories of DO-160F Section 18.2
19	Induced Signal Susceptibility	Test applicable categories of DO-160G Section 19.2
20	Radio Frequency Susceptibility (Radiated and Conducted)	Test applicable categories of DO-160G Section 20.2
21	Emission of Radio Frequency Energy	Test applicable categories of DO-160G Section 21.2
22	Lightning Induced Transient Susceptibility	Test applicable categories of DO-160G Section 22.3
23	Lightning Direct Effects	Test applicable categories of DO-160G Section 23.3
24	Icing	Test applicable categories of DO-160G Section 24.3
25	Electrostatic Discharge (ESD)	Test category A of DO-160G

DO-160G		Special Requirements or Conditions:
Section	Section Title	
26	Flammability	Test applicable categories of DO-160G Section 26.

2.4 Equipment Test Requirements

The test procedures specified in this section are intended to be used as recommended means of demonstrating compliance with the minimum acceptable performance parameters specified herein.

If the manufacturer has implemented additional functions that are not addressed in this MOPS, these functions shall be tested in accordance with the manufacturers defined testing requirements.

2.4.1 Definitions of Terms and Conditions of Tests

The following definitions of terms and conditions of test are applicable to the equipment tests specified herein:

a. Power Input Voltage

Unless otherwise specified, all tests shall be conducted with the power input voltage adjusted to design voltage +/- 2%. The input voltage shall be measured at the input terminals of the equipment under test.

b. Power Input Frequency

1. In the case of equipment designed for operation from an AC power source of essentially constant frequency (e.g. 400 Hz), the input frequency shall be adjusted to design frequency +/- 2%.
2. In the case of equipment designed for operation from an AC power source of variable frequency (e.g. 300 to 1000 Hz), unless otherwise specified, the test shall be conducted with the input frequency adjusted to within 5% of a selected frequency and within the range for which the equipment is designed.

c. Adjustment of Equipment

The equipment shall be properly aligned and otherwise adjusted in accordance with the manufacturer’s recommended practices prior to the application of the specified tests.

d. Test Instrument Precautions

During the tests, due precautions shall be taken to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes, and other test instruments across the input and output impedances of the equipment under test.

e. Ambient Conditions

Unless otherwise specified, all tests shall be conducted under conditions of ambient room temperature, pressure, and humidity. However, the room temperature shall not be lower than 10 degrees C.

f. Warm-up Period

Unless otherwise specified, all tests shall be conducted after the manufacturer’s specified warm up period.

g. Connected Loads

Unless otherwise specified, all tests shall be performed with the equipment connected to loads having the impedance values for which it is designed.

2.4.2 Types of Tests and Cross Reference

2.4.2.1 Bench Testing

Two distinct types of bench testing should be performed. These are referred to as static and dynamic tests.

Static tests comprise precise inputs to verify that input signal and data processing is accomplished so that outputs are within specified range, resolution and scale factor limits. Static bench tests should be designed such that the equipment performance and operation are compatible with the initial conditions of the test (e.g. the system should allow for state conditions which lack a dynamic history).

Dynamic tests provide quantitative data regarding RNP equipment performance using a simplified simulation of flight conditions. This testing, when properly performed and documented, will minimize the flight test requirements.

It is the responsibility of the equipment manufacturer to demonstrate that the fidelity of the dynamic simulation of navigation sensor performance is sufficient to meet the test requirement.

For dynamic testing, the equipment manufacturer has the option to select aircraft type and aircraft speeds, but they should be appropriate for the intended equipment market and application. The fidelity of the response of the simulated aircraft to guidance commands generated by the equipment is left up to the equipment manufacturer.

2.4.2.2 Equipment Class Requirements and Test Cross Reference

Table 2-13 provides a cross reference of the requirements of Section 2.2, the RNP equipment classes, and the tests contained in this section and in Section 3.0. The compliance method is indicated as follows:

A Analysis of equipment performance

D Demonstration of functional capability, including display characteristics, in static or dynamic environment. No numeric results.

I Inspection of equipment hardware, specifications or design drawings. Dynamic operation of the equipment is not usually required

T Physical test in static or dynamic environment, with numeric results.

Where more than one compliance method is shown, use of the specific methods are suggested for the individual requirements in the referenced paragraph.

The application of the functional and performance requirements and associated tests of this MOPS to each equipment class is indicated as follows:

R Required

O Optional

Table 2-13: Requirement/Test Cross Reference

Requirement Paragraph	Subject	Equipment Class		Compliance Method	Test Paragraph(s)
		A	B		
2.2.1.1.1	Estimate of Present Position	R	R	D	2.4.2.3
2.2.1.1.2	Estimate of Position Uncertainty (EPU)	R	R	D, A, T	2.4.2.3
2.2.1.1.3	Containment Radius	R	R	I	
2.2.1.1.4	Position Initialization	R	R	D	2.4.2.3
2.2.1.1.5	Navigation Aid Selection	R	R	D, T	2.4.2.3
2.2.1.1.5.1	Equipment	R	R	D, T	2.4.2.3
2.2.1.1.5.2	Ground-Based Navaids	R	R	D, T	2.4.2.3
2.2.1.1.5.3	Space-Based Navaids	R	R	D, T	2.4.2.3
2.2.1.1.6	Navigation Sensors	R	R	D	2.4.2.3
2.2.1.2.1	Leg Types	R	R	D	2.4.2.3, 2.4.3.4, 2.4.3.14
2.2.1.2.2	Flight Planning	R	R	D	2.4.2.3
2.2.1.2.3	Direct-to Function	R	R	D	2.4.2.3
2.2.1.2.4	Entry of User-defined Fixes	R	R	D, T	2.4.2.3
2.2.1.2.5	User-Defined Course-to-a-Fix	R	R	D, T	2.4.2.3
2.2.1.2.6	Holding	O	O	D, T	2.4.2.3
2.2.1.2.6.1	RNP Holding Area Dimensions	O	O	D, T	2.4.2.3
2.2.1.2.6.2	RNP Holding Area Entry Procedures	O	O	D	2.4.2.3
2.2.1.2.6.3	RNP Holding Area Exit Procedures	O	O	D	2.4.2.3
2.2.1.2.7	Parallel Offsets (except as below)	R	R	D, T	2.4.2.3
2.2.1.2.7 3) a.	- Fixed Radius Transition	R	O	D, T	2.4.2.3
2.2.1.2.7 3) b.	- Radius-to-Fix	O	O	D, T	2.4.2.3 2.4.3.14
2.2.1.2.7 5)	- Pre-Planned Offset	R	O	D, T	2.4.2.3
2.2.1.2.8	Magnetic Variation	R	R	D, A	2.4.2.3
2.2.1.2.9	Transitions Between Legs	R	R	D	2.4.2.3
2.2.1.2.9.1	Fly-By Transitions	R	R	A, T	2.4.2.3, 2.4.3.5
2.2.1.2.9.2	Fixed-Radius Transitions	R	O	D, A, T	2.4.2.3, 2.4.3.5
2.2.1.2.9.3	Application of Waypoint Constraints During Leg Transitions	R	R	D, A	2.4.2.3

Requirement Paragraph	Subject	Equipment Class		Compliance Method	Test Paragraph(s)
		A	B		
2.2.1.2.10	Data Resolution	R	R	A	2.4.3.6
2.2.1.2.10.1	Coordinate Resolution	R	R	A	2.4.3.6
2.2.1.2.10.2	Turn Radius Resolution	R	R	A	2.4.3.6
2.2.1.2.10.3	Course Resolution	R	R	A	2.4.3.6
2.2.1.2.10.4	Magnetic Variation Resolution	R	R	A	2.4.3.6
2.2.1.2.11.1	Database Standard	R	R	I	2.4.3.7
2.2.1.2.11.2	Database Interface	R	R	D	2.4.2.3
2.2.1.2.11.3	Database Version and Operating Period	R	R	D	2.4.2.3
2.2.1.2.12.1	Automatic Selection of RNP	R	R	D	2.4.2.3
2.2.1.2.12.2	RNP Associated with a Flight Plan Leg	R	R	D	2.4.2.3
2.2.1.2.12.3	RNP Associated with a Transition	R	R	D	2.4.2.3
2.2.1.2.13	Earth Reference Model	R	R	A	2.4.3.8
2.2.1.3.1	Fix/Leg Sequencing	R	R	D	2.4.2.3
2.2.1.3.2.1	Takeoff	R	O	D	2.4.2.3
2.2.1.3.2.2	Approach	R	O	D	2.4.2.3
2.2.1.4.1.1	Numeric Display Information	R	R	D, T	2.4.2.3, 2.4.3.9, 2.4.3.10
2.2.1.4.1.2	Non-Numeric Display/Output Requirements	R	R	D, T	2.4.2.3, 2.4.3.9, 2.4.3.10
2.2.1.4.1.2.1	Display Output	R	R	D, T	2.4.2.3, 2.4.3.9, 2.4.3.10
2.2.1.4.1.2.2	Electrical Output	R	R	D, T	2.4.2.3, 2.4.3.9, 2.4.3.10
2.2.1.4.2	Fix Distance Display	R	R	D, T	2.4.2.3, 2.4.3.3
2.2.1.4.3	TO-FROM Indication	R	R	D	2.4.2.3
2.2.1.4.4	Bearing and Distance to Fix	R	R	D, T	2.4.2.3, 2.4.3.3,
2.2.1.4.5	Display of Fix Identifier	R	R	D	2.4.2.3
2.2.1.4.6	Display of Fix Latitude/Longitude	R	R	D, T	2.4.2.3, 2.4.3.3
2.2.1.4.7	Desired Track	R	R	D, T	2.4.2.3, 2.4.3.3
2.2.1.4.8	Groundspeed	R	R	D, T	2.4.2.3, 2.4.3.3
2.2.1.4.9	Track Angle and Track Angle Error	R	R	D, T	2.4.2.3, 2.4.3.3

Requirement Paragraph	Subject	Equipment Class		Compliance Method	Test Paragraph(s)
		A	B		
2.2.1.4.10	Selection of RNP	R	R	D	2.4.2.3
2.2.1.4.11	Navigation Sensor Indication	R	R	D	2.4.2.3
2.2.1.4.12	Failure/Status Indications and Alerting	R	R	D, T	2.4.2.3, 2.4.3.11, 2.4.3.12
2.2.1.4.13	Response Time	R	R	T	2.4.3.13
2.2.1.4.14	Electronic Map Display	R	R	D	2.4.2.3
2.2.1.4.15	Runway Position Monitoring	O	O	D, A	2.4.2.3 2.4.3.15
2.2.1.5.1	Lateral Accuracy	R	R	A, T	2.4.3.3
2.2.1.5.1.1	Position Estimation Error	R	R	A, T	2.4.3.3
2.2.1.5.2.1	Containment Limit	R	R	D, A	2.4.2.3
2.2.1.5.2.2.1	Signal-in-Space Integrity	R	R	D, A	2.4.2.3
2.2.1.5.3	Containment Continuity	R	R	A	
2.2.1.6	Lateral Control Performance	R	R	D	2.4.2.3
2.2.1.7	Speed Control Performance	R	O	D	2.4.2.3
2.2.2	Vertical Navigation (VNAV) Functional and Performance Requirements	R	O	D, A, T	2.4.2.3 2.4.3.16
2.2.2.2.1	General	R	O	D	2.4.2.3 2.4.3.16.2
2.2.2.2.2	Altitude Constraints	R	O	D	2.4.2.3 2.4.3.16.2
2.2.2.2.3	Speed Restrictions	R	O	D	2.4.2.3 2.4.3.16.2
2.2.2.2.4	Vertical Direct-To	R	O	D	2.4.2.3 2.4.3.16.2
2.2.2.2.6	Descent and Approach	R	O	D	2.4.2.3 2.4.3.16.2
2.2.2.2.6.1	Descent Path Construction	R	O	D	2.4.2.3 2.4.3.16.1 2.4.3.16.2
2.2.2.2.6.1.1	Geometric Point to Point Paths	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.2.6.1.2	Flight Path Angle Paths	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.2.6.1.3	VNAV Path Transitions	R	O	D, A	2.4.2.3, 2.4.3.16.2
2.2.2.3	Vertical Path Steering	R	O	D	2.4.2.3, 2.4.3.16.2

Requirement Paragraph	Subject	Equipment Class		Compliance Method	Test Paragraph(s)
		A	B		
2.2.2.3.1	Transition to Missed Approach	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.4.1	General	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.4.2	Vertical Deviation	R	O	D, T	2.4.2.3, 2.4.3.10, 2.4.3.16.2
2.2.2.4.2.1	Vertical Deviation Scale Sensitivity	R	O	D, T	2.4.2.3, 2.4.3.10, 2.4.3.16.2
2.2.2.4.2.1.1	Final Approach Segment	R	O	D, T	2.4.2.3, 2.4.3.10, 2.4.3.16.2
2.2.2.4.2.1.2	Operations Outside the Final Approach Segment	R	O	D, T	2.4.2.3, 2.4.3.10, 2.4.3.16.2
2.2.2.4.3	Crossing Altitude and Speed Predictions	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.4.4	Level Flight Transition	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.4.5	Altitude Constraints	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.4.6	Speed Restrictions	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.4.7	Flight Path Angles	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.4.8	Vertical Navigation Operations	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.4.9	Vertical Alerting	R	O	D	2.4.2.3, 2.4.3.16.2
2.2.2.5	Temperature Compensation	O	O	D, A, T	2.4.2.3, Appendix H.3
2.2.2.6.1	VNAV Accuracy Requirements - Standard Conditions	R	O	A, T	2..4.3.16.1, Appendix P
2.2.2.6.3	VNAV Integrity and Continuity Requirements	R	O	A	
2.2.3	Estimated Time of Arrival	R	R	D	2.4.2.3 2.4.3.17
2.2.3.1	ETA Accuracy	R	O	A, T	2.4.2.3 2.4.3.17 Appendix O
2.2.3.2	ETA Response Time	R	R	D, T	2.4.2.3

Requirement Paragraph	Subject	Equipment Class		Compliance Method	Test Paragraph(s)
		A	B		
2.2.4	Time of Arrival Control	O	O	D, A, T	Appendix N

2.4.2.3 Verification by Demonstration

Where compliance by demonstration (D) is indicated in Table 2-13, each of the identified functional requirements shall be demonstrated.

2.4.3 Functional and Accuracy Test Requirements - Standard Conditions

Specifying a single test procedure for RNP equipment using multi-sensors is impractical due to the multiplicity of position sensor configurations and position fixing methods. In some cases, it is more suitable to specify the tests in terms of general test conditions and requirements. In these cases, the general test conditions and requirements specified shall form the basis for specific test procedures to be prepared by the equipment manufacturer. These procedures shall specify the tests necessary to show equipment compliance with both functional and accuracy requirements in all modes of position fixing and functional operation. It is the responsibility of the equipment manufacturer to demonstrate that the scope and intent of proposed test procedures accomplish the same objectives as the tests described herein.

System characteristics that cannot be evaluated by physical tests must be substantiated by analysis, demonstration, and/or inspection.

2.4.3.1 Test Scenario(s)

Static and dynamic bench testing of RNP equipment requires the use of multiple test scenarios (flight plans) to create different operational test conditions. The equipment manufacturer shall develop flight plan(s) as required to perform the test procedures of this document.

In lieu of generating new flight plans specific to this document, the equipment manufacturer may wish to use existing flight plans developed to meet the test requirements of other RTCA documents, such as RTCA/DO-187, DO-208, DO-229 and others.

Where a test procedure requires waypoints with specific coordinates, these waypoints should be defined in latitude/longitude. The equipment manufacturer is cautioned not to rely on the location of waypoints contained in named navigation database procedures since these may change with time, thus invalidating the test.

Where specific waypoint coordinates are not required, the flight plan may include references to current navaids, named intersections or waypoint names. These may then be adjusted to accommodate changes in the navigation database.

Depending on the capability of the manufacturer’s equipment, flight plans may be generated either by manual entry of individual waypoints and leg types, or by selection of a pre-stored route. Certain leg types may only be available as part of a DP/SID, STAR or approach/missed approach procedure.

Where a test procedure requires a specific navigation database characteristic that is not available from the service provider, it may be necessary for the manufacturer to create a dedicated test database.

As a minimum, flight plan(s) should have the characteristics listed below, and contain at least one (1) example of each of the following:

(a) ARINC 424 leg types: CF, DF, FA, IF, (HM, HA, HF, if implemented), RF and TF

(b) All valid transitions between the leg types listed in (a)

(c) Fly-by waypoint transition

(d) Fixed radius waypoint transition

(e) Waypoints located so as to create flight plan leg lengths of more than 10 NM, 100 NM, 1,000 NM and 9999 NM respectively

(f) Flight plan discontinuity

(g) Waypoints located so as to create track changes of less and greater than 70º (high altitude) and 120º (low altitude).

(h) Waypoints located so as to create unflyable parallel offset paths under certain combinations of aircraft speed and offset value

(i) Waypoints, procedures and geographical areas with the assigned RNPs for which approval is sought

2.4.3.2 Test Set-Up

The equipment required to perform these tests shall be defined by the equipment manufacturer as a function of the specific sensor configuration of the equipment. Since these tests may be accomplished in more than one fashion, alternative test equipment setups may be used where an equivalent test function can be accomplished.

Combinations of tests may be used whenever appropriate. The test equipment signal sources shall provide the appropriate signal format to the specific system under test without contributing to the error values being measured. Tests need only be performed once unless otherwise indicated.

It shall be the responsibility of the equipment manufacturer to determine that the sensor inputs, when presented to the RNP equipment, will perform commensurate with the assumptions of the navaid infrastructure (reference Appendix C) in order to validate the accuracy requirements.

Additional sensor inputs may be optionally provided to enhance RNP capability and/or performance. If the equipment is designed to operate with aircraft data inputs that are necessary to its proper performance (e.g., airspeed, heading, altitude), then these inputs shall be simulated during the appropriate tests.

2.4.3.3 Accuracy

For each combination of sensors and position fixing method, a set of test conditions shall be provided which specify the required sensor inputs, the geometry of the fixes, aircraft position, and desired track. The test conditions shall consider those factors listed in Section 2.2.1.5 and/or others which influence system accuracy. The specified test conditions shall include expected results which consider allowable values for equipment error if all error sources except FTE are integrated in the bench test set-up. If all error sources are not integrated into the bench test set-up, new allowable error criteria shall be determined which apply to the specific RNP system configuration being tested. See Appendix B for guidance in determining allowable errors.

The accuracy of all computed navigation parameters displayed by the equipment shall be tested as part of this test procedure, including fix distance (Section 2.2.1.4.2), bearing and distance to a fix (Section 2.2.1.4.4), user-defined fix latitude and longitude (Section 2.2.1.4.6), desired track (Section 2.2.1.4.7), groundspeed (Section 2.2.1.4.8), and track angle and track angle error (Section 2.2.1.4.9).

2.4.3.4 Ground Navaid Reasonableness and Integrity Evaluation

Reasonableness testing is the process of comparing observed (measured) ranges or bearings to their predicted counterparts based on estimated system position and navaid location. It should be shown that when the difference between predicted and measured values exceeds a limit determined by the equipment designer the measurement is rejected and not used for navigation. Appendix C contains information to assist in the determination of appropriate limits. Various geometries of aircraft/navaid location should be used to establish the system performance under a range of normal conditions.

Appendix B describes one way of determining the integrity of the solution.

Note: *Additional guidance on radio navigation reasonableness and integrity checks can be found in FAA AC 20-138D, Chapter 6.*

One method of achieving integrity requires the addition of a third source for cross checking multiple solutions and rejecting a navaid that contributes to one of the solutions disagreeing with the others, even when the range error to the navaid itself may not appear to be out of allowable range. For instance, using three DMEs, one can compute three position solutions which can be statistically compared to detect one solution that may contain a “bad” navaid.

In particular, testing should cover a range of geometries that demonstrate that the system can detect an error using integrity tests even if reasonableness tests do not. Further, integrity testing should show that the system can detect a bad navaid when the navigation solution has been corrupted such that all the navaids pass reasonableness.

The specific method for evaluating the integrity of the RNP equipment navigation solution is left to the designer.

2.4.3.5 Waypoint Transitions

Configure the equipment for dynamic bench tests as defined in paragraph 2.4.2.1. Position the simulated aircraft such that it is approaching from a suitable distance the active waypoint which has a fly-by transition. Verify that the aircraft remains within the transition area throughout the waypoint transition. Perform this test for combinations of test conditions comprising track changes of less than and greater than 70º or 120º (as applicable to high or low altitude operations respectively), and the operating speed and altitude ranges for the aircraft types for which equipment approval is sought.

Where the active waypoint is defined in the navigation database as having a fixed radius transition, verify by demonstration and/or analysis that the equipment generates a circular waypoint transition path of the required radius from the navigation database.

2.4.3.6 Data Resolution

Verify by analysis that the path definition error accounts for the error contributions arising from the data resolution of waypoint coordinates, turn radius, course and magnetic variation as applicable to the path being generated.

2.4.3.7 Database Standard

Verify by inspection that the navigation database used for testing meets the requirements of the DQR.

2.4.3.8 Earth Reference Model

If the WGS-84 earth model is not used as the reference earth model, verify by analysis that the total system error (TSE) accounts for the difference between WGS-84 and the selected earth model (path definition error). If the path definition is not based on geodesic computations as defined in Appendix D, verify by analysis that the TSE accounts for the difference between the chosen path computation method and the WGS-84 geodesic computations defined in Appendix E. Perform these analyses and tests over the geographical area for which aircraft operational approval is sought and for the worst case leg lengths and orientations.

2.4.3.9 Cross Track Deviation Display

This bench test verifies the requirements for display and electrical output (if provided) of cross track deviation in both analog and digital formats with the equipment operating with a range of RNP. For each RNP, and for representative combinations of aircraft position, desired track, fix geometry, and leg type, a set of test conditions shall be provided to verify the display and electrical output of cross track deviation. For each test condition, the allowable error shall be defined considering the requirements of the referenced requirements subparagraphs.

Configure the equipment for static bench tests. Positioning of the aircraft for this test shall be performed by adjustment of the simulated navigation sensor input(s). This test shall be performed for each navigation sensor and combination of navigation sensors for which the manufacturer seeks approval. Where the equipment has the capability to interface with navigation sensors with analog and digital outputs, both interface types shall be tested.

2.4.3.10 Vertical Deviation Display

This bench test verifies the requirements for the display and electrical output (if provided) of vertical deviation in both numeric and non-numeric formats for operations in both the final approach segment and outside the final approach segment.

Configure the equipment for static bench tests. Positioning of the aircraft for this test shall be performed by adjustment of the simulated navigation sensor input(s).

2.4.3.11 Failure/Status Indications and Alerting

This bench test is intended to verify all the requirements associated with the display of failure and status indications and alerts listed in Sections 2.2.1.4.12 and 2.2.2.4.9. For tests involving equipment and sensor failures or degraded performance, the test involves simulating the conditions of equipment and sensor failure and sensor degraded performance and demonstrating that the appropriate failure/status indications are generated, and equally important, the conditions under which the failure/status indications are not displayed.

These tests shall be performed for all navigation sensors and combinations of navigation sensors for which the manufacturer seeks approval.

Configure the equipment for static bench tests.

1) Configure the sensor interfaces to the RNP equipment to provide simulated, valid sensor signals from all appropriate sensors (e.g., DME, IRS, GPS, etc) and establish the navigation of the aircraft on a course or track, as appropriate, to an active fix. Set the RNP to a value close to the level of performance, such as 0.3 for GPS and 1 for DME-DME, etc.

2) Remove the sensor inputs one at a time. Verify that the equipment provides indications reflecting the sensor removal. Also, note that when the navigation performance accuracy degrades consistent with the available sensor inputs, an indication/alert is provided when the RNP containment integrity requirements are not satisfied.

Note: The order of sensor removal will need to consider the equipment integration of the inputs into the navigation computation. For example, if the order of precedence is GPS, DME-DME, IRS, etc then removal should be in an order to evaluate that the correct mode changes occur. For example, the removal of DME when GPS is the sensor input of choice could have no effect on equipment mode.

3) Configure the sensor simulator(s) to provide degraded performance. Repeat Step 2 above while simulating a progressive degradation of the navigation performance of the sensor under test. Verify that the equipment provides correct indications of degraded sensor performance. Verify that the system provides an alert when the system reverts to a navigation sensor(s) that is not authorized for the active procedure.

2.4.3.12 Time to Integrity Alert

This static bench test verifies the requirements associated with the display of the alert indicating the loss of containment integrity. The test involves simulating the loss of integrity by any and all navigation sensors and combination of navigation sensors for which approval is sought, and measuring the time delay before the alert is displayed.

A *loss of integrity* failure is defined to exist when the total system error is outside the specified alarm limit for the RNP in use, without issuance of the appropriate alarm. Conversely, no failure exists when the error is within the specified bound. Time to alarm is defined to be the maximum allowable elapsed time from the onset of the failure, as defined above, until the time that the *loss of integrity* alarm is annunciated.

2.4.3.13 Response Time

Configure the equipment for dynamic bench tests. Perform the flight planning scenarios defined in Table 2-6, and record the time required for the equipment to accomplish the specified actions. To minimize variability due to operator performance, each scenario may be executed multiple times to determine average equipment performance. Where a series of keystrokes are required, operators should be adequately trained in the required procedure to eliminate inadvertent errors.

2.4.3.14 Radius to Fix Legs

This dynamic bench test verifies the requirements for RNP equipment performance on radius to fix (RF) legs for the respective RNP and over the range of ground speeds for which equipment approval is sought.

The functional performance is evaluated by verification that the RF legs extracted from the navigation database have been correctly constructed and inserted correctly into the lateral flight plan and displayed as intended to the flight crew. The navigation performance is evaluated by analysis and demonstration that the equipment can support the maximum bank angles required to ensure compliance with the path steering error (PSE) requirements of Table 2-7 under all RF leg test conditions.

Equipment designers are encouraged to base the RF leg test scenarios to be used for this test on the templates provided in Appendix L of this standard.

Configure the RNP equipment and test set up for dynamic bench testing as defined in Sections 2.4.2.1 and 2.4.3.2 respectively. The test set up shall include a simulated aircraft with roll axis autopilot-coupling. The simulated navigation sensor input(s) can be error-free, provided that navigation sensor input data latencies and RNP equipment computational latencies are accurately taken into account.

Dynamic positioning of the aircraft for this test shall be performed by adjustment of the simulated navigation sensor input(s).

2.4.3.15 Runway Position Monitoring Test Requirements

If the runway position monitoring function is resident in the RNP equipment, the purpose of this bench test is to demonstrate that an incorrect aircraft position/orientation has been detected in a timely manner and an appropriate alert is generated.

The bench test setup for this evaluation and the specifics of the test scenario are left to the equipment designer. Positioning of the aircraft can be performed by adjustment of the simulated navigation sensor input(s). The navigation sensor(s) can be external or internal to the simulation, and can be error-free.

This test may be performed statically or dynamically depending on the functional implementation in the RNP equipment. If the test is performed dynamically, verify by analysis or demonstration that the alert is generated such that any associated takeoff can be safely discontinued.

The test shall include the following conditions as a minimum:

a. Verify that the alert is not generated when the aircraft position is on the correct runway and in the correct orientation, including locations along the runway that simulate an intersection takeoff.
b. Verify that the alert is generated when the aircraft position error exceeds the allowable error bound.
c. Verify that the alert is generated when the aircraft heading error exceeds the allowable error bound.

The position/orientation error bounds of the runway position monitoring function shall be specified in the equipment documentation, and should take into account the intended navigation system architecture.

Note 1: The simulated errors in aircraft position and/or orientation to be used in this test are left to the equipment designer, provided that compliance with the intent of detecting the potentially unsafe use of an incorrect runway is demonstrated.

Note 2: The equipment designer should also consider providing the capability to define the position/orientation error bounds on initial installation.

2.4.3.16 VNAV Test Requirements

2.4.3.16.1 VNAV Performance Test

The equipment designer shall demonstrate by analysis, and if appropriate, a bench test, that the effects of various equipment-related errors and data resolution contribute not more than 10 feet to the total vertical system error, under any reasonable combination of flight path angle and groundspeed.

Note: The intent of the VNAV accuracy analysis and/or bench test is to demonstrate that VNAV equipment error is effectively negligible for modern computational systems.

An example of an analysis of equipment-related VNAV errors and a discussion of total vertical system errors can be found in Appendix P.

2.4.3.16.2 VNAV Functional Test

The purpose of the VNAV functional test described in this section is to demonstrate that the vertical trajectory has been correctly generated. The vertical trajectory elements applicable to each phase of flight are shown in Table 2-14. This is not an exhaustive list, but represents a checklist for the key VNAV functions.

While the specific test scenarios are left to the equipment designer, and can be combined with other equipment test scenarios, Table 2-14 lists the elements that should be demonstrated as applicable to the intended VNAV function, the planned equipment class, and the type of testing to be performed. The test is intended to demonstrate that geometric point-to-point and flight path angle paths are correctly generated, with all altitude constraints and window-based path boundaries respected. For segments of the vertical profile where a defined path is not generated, such as in climb, or for RNP equipment that does not support a full vertical profile, the minimum requirement is to demonstrate that all waypoint altitude constraints and waypoint and altitude-based speed restrictions are correctly displayed.

The test can be performed either statically or dynamically. Positioning of the aircraft laterally and vertically can be done by adjustment of the simulated navigation sensors.

Verify that the defined vertical path has been correctly generated by the aircraft's vertical position relative to the path. The correct generation of the vertical descent path should be verified at least once on each vertical segment.

If a dynamic test is performed, a specific aircraft performance model is not required. The simulated aircraft behavior on any performance path segments of the profile is left to the equipment designer. Simulated navigation sensors can be error-free, and lateral and vertical channels of any simulated flight guidance system can be assumed perfect. If the wind environment is simulated, it should reflect ICAO winds in the worst case along track directions.

Table 2-14: Vertical Trajectory Elements

Vertical Trajectory Element	Phase of Flight			
	Climb (Note 1)	Cruise	Descent (Note 2)	Final Approach Segment
Waypoint altitude constraint	- AT or ABOVE - AT - AT or BELOW - WINDOW	N/A	- AT or ABOVE - AT - AT or BELOW - WINDOW - AT followed by WINDOW - WINDOW followed by WINDOW - WINDOW followed by AT	- AT or ABOVE - AT
Altitude-based speed restriction	Climb speed/altitude	N/A	Descent speed/altitude	N/A
Waypoint speed restriction	- AT or ABOVE - AT - AT or BELOW	N/A	- AT or ABOVE - AT - AT or BELOW	N/A
Vertical discontinuity	N/A	N/A	As applicable	N/A
Altitude prediction	Active fix	Active fix	Active fix	N/A
Speed prediction	Active fix	Active fix	Active fix	N/A
Vertical path transition	N/A	N/A	Fly-by performance	Fly-by performance at FAF
GPP paths	N/A	N/A	Between AT constraints	N/A
FPA paths	N/A	N/A	N/A	Final approach
Vertical direct-to	N/A	N/A	Descent waypoint	N/A
Vertical profile modification	- Altitude constraints - Speed restrictions - Lateral path modification	N/A	- Altitude constraints - Speed restrictions - Lateral path modification	N/A
VDEV display and scaling	N/A (Note 3)	N/A (Note 3)	All segments	As applicable
Vertical alerting	All segments	All segments	All segments	As applicable
Temperature compensation	N/A	N/A	As applicable (if provided)	As applicable (if provided)

Note 1: Climb column includes departure procedures and the missed approach segment.

Note 2: Descent column includes initial and intermediate approach segments.

Note 3: If VDEV is displayed relative to climb waypoint altitude constraints, or the cruise altitude, this function should be demonstrated.

2.4.3.17 Estimated Time of Arrival

This section presents an acceptable means of showing compliance with the ETA accuracy requirements of Section 2.2.3.1.

Note 1: This is an a priori analysis done by simulation. The actual crossing time for a fix (ATA) is only defined when the fix is crossed, therefore, like PEE in the lateral navigation, it can only be estimated a priori using adequate assumptions.

A combination of performance analysis and simulation shall be performed to substantiate compliance. The chosen method(s) shall evaluate system performance considering all system elements which can contribute to it. It is an evaluation of system error only: i.e. the evaluation excludes wind/temperature errors that are not generated by the system, e.g., forecast errors and performance modeling errors.

Note 2: Given that the ETA performance requirement is stated as a maximum value, statistical analysis is not necessary in this evaluation. The cause of any exceedance should be identified and explained or corrected.

Appendix O provides examples of acceptable methods of ETA performance accuracy analysis. Development of detailed test procedures is left to the equipment designer.

The following list provides some (but not all) of the items that should be considered:

- System operating configurations (e.g. architecture, sensor mix, manual/coupled system, etc., which impact performance);
- Non-faulted performance;
- Display resolution;
- Non-zero forecast winds;
- Planned (constrained) speed profiles over the length of the lateral and vertical path;
- Planned lateral trajectory including curved ground track;
- Planned vertical profile

Note 3: Flight scenarios in excess of two hours duration are not considered necessary to show compliance based upon the intended use.

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3. INSTALLED EQUIPMENT PERFORMANCE

3.1 Equipment Installation

Installation guidance material for RNP equipment can be found in FAA Advisory Circular AC 20-138D, Airworthiness Approval of Positioning and Navigation Systems.

Related guidance material for installation includes the following Advisory Circulars:

- AC 25.1302-1, Installed Systems and Equipment for Use by the Flight Crew
- AC 23-.1309-1E Equipment, Systems, and Installations in Part 23 Aircraft
- AC 25-.1309-1A Equipment, System Design and Analysis
- AC 25.1322-1, Flight Crew Alerting
- AC 43.13-1B Acceptable Methods, Techniques, and Practices – Aircraft Inspection and Repair, and
- AC 43.13-2B Acceptable Methods, Techniques, and Practices – Aircraft Alterations
- EASA AMC 25-.1302 Installed Systems and Equipment for Use by the Flight Crew
- EASA AMC 25.1309 System Design and Analysis

3.2 Alert Limits

The time to alert must provide the flight crew the opportunity to minimize any correctable error (i.e. PSE) and execute any appropriate actions for the RNP procedure or operation, with the expectation that the navigation performance safety margins (i.e. containment limits) have not been exceeded and sufficient margin remains. The starting point for the Total Time to Alert (TTA) is the instant at which a failure occurs in a satellite or ground navigation aid or an airborne sensor or it may be the instant at which the aircraft enters unsatisfactory navigation coverage. The ending point occurs when the RNP alert is issued.

The time remaining from the Maximum TTA, after considering the equipment time interval, may be allocated by the manufacturer/installer between the appropriate sensor(s) and alerting system/annunciation. The total time to alert shall be demonstrated for each RNP and shall not exceed the values listed in Table 3-1.

Table 3-1: Maximum Total Time to Alert

RNP	Maximum Total Time to Alert
0.3	15 sec.
1.0	15 sec.
2.0	30 sec.
4.0	60 sec.

Note: The requirement in this paragraph is an end-to-end requirement, from the instant of failure in the satellite, ground aid or sensor to the moment an alert is issued. Section 2.2.1.4.12 addresses the alerting requirements that must be satisfied by the RNP equipment. The MOPS is intended to enable different equipment designs, system configurations and installations. When consideration is given to the state of the art for RNP equipment as well as the aircraft installations, as well as the variety of operational applications and needs, the maximum TTA may be conservative, such that just meeting it may not be sufficient to obtain operational authorization or *approval for all applications for an RNP (e.g. RNP may differ from those in the table when Advanced RNP and scalable RNP are in effect). Therefore, equipment manufacturers and system integrators are strongly encouraged to optimize (i.e. reduce) the maximum TTA for increased flexibility and use of the equipment and installations for RNP applications.*

3.3 Accuracy Analysis

The equipment manufacturer shall perform an analysis which substantiates the equipment accuracy to the requirements of Section 2.2.1.5.1. The analysis should include the effects of the following and/or other factors as appropriate to the design of the equipment and its intended installations:

a. All sensors and combinations thereof which are used for position determination.

b. The nature and magnitude of sensor errors including factors such as error distributions and time dependence, as appropriate.

c. Limitations of sensor system operation, including signal quality restrictions.

d. Navigation facility selection criteria/methods and geometry considerations.

e. Position fix method(s), frequency of update and filtering techniques.

f. Navigation sensors utilization mode hierarchy for primary and reversionary modes.

g. Sensor data mixing, filtering and/or weighting techniques.

h. Methods by which equipment and sensor errors are combined to substantiate accuracy requirements (Section 2.2.1.5.1).

i. Calculation of cross-track and along-track distance to go for the maximum practical leg length by the equipment.

j. System response time

k. Non-faulted performance

l. Data and computational latencies and resolutions

Appendix B provides sensor characteristic information which should be used in the equipment performance accuracy analysis. Any differences in assumptions should be stated, along with rationale.

3.4 Performance Analysis

The equipment manufacturer shall prepare an analysis which substantiates the equipment capability to meet the requirements of sections 2.2.1.5.2 and 2.2.1.5.3. The analysis shall include the effects of all factors appropriate to the design of the equipment and its intended installations.

4. OPERATIONAL CHARACTERISTICS

4.1 Introduction

The conduct of RNP operations is predicated upon the reliability, repeatability, predictability, and performance assurance of the RNP equipment. RNP airspace operation will be dictated by RNP requirements that are intended to support operational requirements for enhanced safety and efficiency. However, in order to enable RNP operations with qualified systems it is necessary to describe a number of considerations that must be taken into account.

4.2 RNP Capability and Display

The display of navigation data to the flight crew will depend on the system installation. The required information should enable the flight crew to have situational awareness of all RNP total system error (TSE) parameters necessary to understand and conduct an RNP operation. Where the system installation follows the predefined performance allocations of this MOPS, the significant information that will be used by the flight crew will include:

- crosstrack deviation,
- estimated positioning uncertainty on an equipment control display, and
- the allowed operating modes e.g. manual control with CDI, manual control with map, flight director, etc, for the specified RNP type.

Where the installed equipment configuration results in a different allocation of system performance from that in this MOPS, error parameters such as path definition error or display error may be affected. In this case, the required system analysis for the reallocation of the TSE parameters will be required to ensure appropriate information is developed to support flight crew understanding of the relationship of all TSE parameters that are presented to them for display or monitoring, and the allowed operating modes.

For equipment complying with the requirements of the MOPS, the intended use of the indication of Estimate of Position Uncertainty (EPU) is to provide the flight crew a measure of confidence of the system's RNP capability. However, it should be understood that due to implementation choices, what the EPU display represents and how it correlates to other RNP parameters such as FTE or display error may vary between different equipment. The equipment information should make this clear and how EPU relates to the RNP and RNP alerting.

Note: The requirement to provide a TSE caution that indicates the navigation system's inability to comply with current RNP RNAV requirements is not intended to specify a particular implementation. Examples for three possible choices are:

a. A system with real-time estimation of position uncertainty and monitoring of FTE. In this case, a caution may be activated when the combination of position uncertainty and FTE exceeds the budgeted design limit for total system error.

b. A system where the caution would be activated when either the position uncertainty or FTE becomes unacceptable. In this case, system compliance would be demonstrated by the allocation of the requirements of Section 2.2.1.5 to each potential source and monitoring those error sources separately. An installation with a TSO-

C129A navigator, CDI display and alert light is one possible example of this type.

c. *A system where a caution would be activated when the position uncertainty exceeds an allocated design limit. In this case, the system implementation is demonstrated through test and analysis to show that the FTE is inherently bounded, i.e. FTE is not a measured parameter in the monitoring and alerting. An installation with a Flight Management System, Map or CDI display, and Alerting system is one possible example of this type.*

4.3 RNP Selection

In the conduct of operations and procedures with an associated RNP, it is expected that the RNP will be included with the appropriate RNP procedures residing in the equipment navigation database. It is also expected that when the flight crew selects such a procedure, the equipment will recognize and utilize the RNP.

The equipment contains capability not only to use the RNP from the navigation database, but if there is none, to also utilize a manually entered RNP (flight crew) or an uplinked RNP (datalink). If there is a database RNP, it may be manually overridden by the flight crew. The flight crew will receive an annunciation when manually entering an RNP that is larger than the navigation database RNP.

Note: Some equipment may contain an additional capability for default RNP that may be overridden by either the RNP in the database procedure or by flight crew manual entry. This level of flexibility should be considered for normal operations as well as those where there may be a procedural requirement for changing the RNP.

4.4 RNP RNAV Containment Continuity Effect

The following is additional explanatory material related to Section 2.2.1.5.3.

The loss of all airborne navigation capability is classified as major, where the probability of loss is 10^{-5} per hour. Where the airborne navigation system includes a capability for RNP operation, the probability of annunciated loss of RNP RNAV capability for an RNP is 10^{-4} per hour. The result is that there may be instances where the annunciated loss of RNP RNAV capability is followed by the condition where the remaining navigation capability may be insufficient for the initiation or continued conduct of the RNP operation without an alternative basis for aircraft navigation.

In the conduct of RNP operations, specifically terminal and approach, predicated upon an RNP RNAV capability and continuity, the probability of 0.01% may also be inadequate for certain types of operations. What is acceptable and operationally allowable will be based upon consideration of what level of capability and performance is required for the whole flight procedure including the missed approach. Where this issue applies, it could be resolved by increased equipment redundancy/availability or an aircraft limitation precluding the conduct of such procedures.

4.5 Equipment Operating Limitation

To conduct RNP operations safely and reliably, the RNP equipment operating manual, and when installed, the aircraft flight manual (AFM) will include any equipment operating limitation(s) impacting RNP operations. These limitations will include any equipment limitations that help prevent an unexpected loss of containment and a resultant loss of RNP RNAV capability and encompass other known operational restrictions or prohibitions.

Note: RNP RNAV containment requirements will rely on available infrastructure and the associated navigation sensors. The equipment operating limitations in the AFM enable an operator to determine whether or not the aircraft equipment meets or exceeds these requirements. For example, if use of DME/DME is the sole basis of an operator's RNP airworthiness certification, then the AFM must clearly state this basis. Then, if a State prohibits use of DME/DME for RNP operations and bases their RNP operations on use of GPS, the operator should be able to discern that their equipment would not support RNP operations in that State's airspace

4.6 Navigation Facility Selection

The requirement to tune and select navaids should be commensurate with RNP equipment design. RNP equipment designed using only spaced-based navaids are not required to tune and select ground-based navaids. RNP equipment using ground-based navaids or inertial navigation equipment are required to use spaced-based navaids for RNP operations.

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5. MEMBERSHIP

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Tom	Yochum	The Boeing Company
David	Zeitouni	The Boeing Company

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APPENDIX A REFERENCES, GLOSSARY, ACRONYMS AND ABBREVIATIONS

A.1 References

[1] FAA Pilot / Controller Glossary

[2] Bowditch, *American Practical Navigator*, 1981 Defense Mapping Agency Hydrographic / Topographic Center

[3] RTCA Task Force Report on the GNSS Transition and Implementation Strategy

[4] ICAO, Definitions (Document # 9569), First edition, 1991

[5] ICAO, Performance-Based Navigation (PBN) Manual (Document # 9613-AN/937)

[6] ICAO, Report of the Special Communications/Operations Divisional Meeting (Document 9650)

[8] New terms adopted by RTCA SC-181/EUROCAE WG-13

[9] ICAO, Manual on the Implementation of 1000 Ft Vertical Separation Minimum Between FL290 -FL410 Inclusive, Document #9574

[10] RTCA, Standards for Processing Aeronautical Data, DO-200B/ED-76A

[11] RTCA, Standards for Aeronautical Information, DO-201A/ED-77

[12] RTCA, Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment, DO-229D

[13] RTCA, Minimum Operational Performance Standards for Global Positioning System/Aircraft Based Augmentation System Airborne Equipment, DO-316

[14] RTCA, Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps, DO-257A

[15] FAA Advisory Circular AC 20-138D, Airworthiness Approval of Positioning and Navigation Systems.

[16] FAA Advisory Circular AC 21-16G, RTCA Document DO-160 versions D, E, F, and G, 'Environmental Conditions and Test Procedures for Airborne Equipment'

A.2 Glossary

ACCURACY [Derived from ICAO Doc. 9613, RTCA/DO-208]

The degree of conformance between the estimated, measured, or desired position and/or the velocity of a platform at a given time and its true position or velocity. Radio navigation performance accuracy is usually presented as a statistical measure of system error and is specified as:

a) Predictable. The accuracy of a position in relation to the geographic or geodetic coordinates of the earth.

b) Repeatable. The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.

c) Relative. The accuracy with which a user can determine one position relative to another position regardless of any error in their true positions.

Note that this is a general definition of accuracy, and it must be placed in a specific context in order to be applied.

ACTUAL TIME OF ARRIVAL (ATA)

The time at which the RNP equipment estimated position crosses a fix.

Note: Time of arrival error due to the crossing time of the "actual" aircraft is handled through the navigation accuracy requirement.

AIRWAY [ICAO Doc. 9569]

A control area or portion thereof established in the form of a corridor equipped with radio navigation aids.

ALTIMETRY SYSTEM ERROR

The errors attributable to the aircraft altimetry installation including position effects resulting from normal aircraft flight attitudes

ALTITUDE [ICAO Doc. 9569]

The vertical distance of a level, a point or an object considered as a point, measured from mean sea level (MSL).

AREA NAVIGATION (RNAV) [ICAO Doc. 9569]

A method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these. Note that the *desired path* can be designated by any point(s) in a common reference coordinate system.

AVAILABILITY [ICAO PBN Manual, Doc. 9613, derived from RTCA/DO-208]

Availability is an indication of the ability of the system to provide usable service within the specified coverage area and is defined as the portion of time during which the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft. In order to avoid the introduction of a flight duration into its mathematical determination, availability is applied only to the ability of the system to meet all requirements for the RNP prior to initiating an RNP operation.

AVAILABILITY [RTCA GNSS Report]

The availability of a navigation system is the percentage of time that the services of the system are within required performance limits. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that the navigational signals transmitted from external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

BEARING [FAA Glossary]

The horizontal direction to or from any point, usually measured clockwise from true north, magnetic north, or some other reference point. through 360 degrees.

CONTAINMENT [RTCA SC-181/EUROCAE WG-13]

A set of interrelated parameters used to define the performance of an RNP RNAV navigation system. These parameters are *containment integrity*, *containment continuity*, and *containment region*.

CONTAINMENT CONTINUITY [RTCA SC-181/EUROCAE WG-13]

The capability of the total system to satisfy the containment integrity requirement without nonscheduled interruptions during the intended operation. Nonscheduled interruption in operation is defined to be either 1) total loss of navigation capability; 2) a failure of the system which is annunciated as loss of RNP RNAV capability, or 3) a false annunciation of loss of RNP RNAV capability while the system is working properly. Containment continuity is specified by the maximum allowable probability for interruption. That is, P (E3) = P (system not RNP RNAV capable with warning) + P (system RNP RNAV capable with warning), and thus both the true and false alarm rates are bounded.

CONTAINMENT INTEGRITY [RTCA SC-181/EUROCAE WG-13]

A measure of confidence in the estimated position, expressed as the probability that the system will detect and annunciate the condition where TSE is greater than the cross track containment limit. Containment integrity is specified by the maximum allowable probability for the event that TSE is greater than the containment limit and the condition has not been detected. That is, P (E2) = Pr(TSE>containment limit and no warning is given).

CONTAINMENT RADIUS (R_C) [RTCA SC-181/EUROCAE WG-13]

A radius of a circle in the horizontal plane, centered on *estimated position*, such that the probability of the true position lying outside the circle without being detected is 10^{-5}/hour. This uncertainty only includes position estimation uncertainty.

CONTAINMENT REGION [RTCA SC-181/EUROCAE WG-13]

A region, centered on the *desired path*, to which the *containment integrity* and *containment continuity* are referenced. This MOPS only specifies containment requirements in the cross-track dimension, which is defined by a *cross-track containment limit*. It is anticipated that when a horizontal two-dimensional containment region is defined, it will be defined by separate cross-track and along-track containment. Similarly, when a vertical containment region is defined, it is likely to be defined by a vertical containment limit.

CONTAINMENT VALUE [derived from ICAO Doc. 9613]

The distance from the intended position within which flight would be found for at least 95 per cent of the total flying time. [ICAO RNP Manual] Note that the containment value is distinct from the *containment limit*, as currently defined by *the cross-track containment limit*.

CONTINUITY [derived from ICAO Doc. 9650]

The continuity of a system is the *capability* of the total system (comprising all elements necessary to maintain aircraft position within the defined airspace) to perform its function without nonscheduled interruptions during the intended operation. The continuity risk is the probability that the system will be unintentionally interrupted and not provide guidance information for the intended operation. More specifically, continuity is the probability that the system will be available for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation. See the definition of *containment continuity* for how this parameter applies to RNP airspace.

COORDINATES [FAA Glossary]

The intersection of lines of reference, usually expressed in degrees / minutes / seconds of latitude and longitude, used to determine a position or location.

COURSE [FAA Glossary]

1. The intended direction of flight in the horizontal plane measured in degrees from north.

2. The ILS localizer signal pattern usually specified as the front course or the back course.

3. The intended track along a straight, curved, or segmented MLS path.

CROSSING ALTITUDE AND/OR SPEED

The altitude or speed at which the aircraft crosses a designated fix, or is predicted to do so based on the intended vertical profile. For fly-by waypoint transitions and fixed radius transitions, the crossing event occurs at the lateral bisector. For other situations, the crossing event occurs at the abeam point.

CROSS-TRACK CONTAINMENT LIMIT [RTCA SC-181/EUROCAE WG-13]

A distance that defines the one-dimensional containment limit in the cross-track dimension. The resulting *containment region* is centered upon the desired path and is bounded by +/- the cross-track containment limit. There is a required cross-track containment limit associated with a particular RNP.

CROSS-TRACK ERROR [Derived from ICAO PBN Manual, Doc. 9613, derived from RTCA/DO-208]

The perpendicular deviation that the airplane is to the left or right of the desired path. This error is equal to the cross-track component of the *total system error*.

CURVILINEAR OPTIMUM PATH

A vertical flight path composed of multiple straight segments that enable improved flight efficiency through the specification of a path optimized for aircraft performance.

DATA QUALITY [RTCA/DO-200B]
A degree or level of confidence that the navigation data provided meets the requirements of the user. These requirements include levels of accuracy, resolution, assurance level, traceability, timeliness, completeness and format.

DEFINED PATH [RTCA SC-181/EUROCAE WG-13]

The output of the path definition function.

DESIRED PATH [RTCA SC-181/EUROCAE WG-13]

The path that the flight crew and air traffic control can expect the aircraft to fly, given a particular route leg or transition. The desired path for various leg types is described in Section 2.2.1.2.

DIRECT [RTCA SC-181/EUROCAE WG-13]

Geodesic track between two navigational aids, fixes, points or any combination thereof. When used by pilots in describing off-airway routes, points defining direct route segments become compulsory reporting points unless the aircraft is under radar contact.

DISTANCE-TO-GO [RTCA SC-181/EUROCAE WG-13]

The distance between the aircraft present position and the waypoint to which the aircraft is flying. In the case of an aircraft flying a *parallel offset*, the *distance-to-go* is measured to the *offset reference point.*

ESTIMATE OF POSITION UNCERTAINTY (EPU) [RTCA SC-181/EUROCAE WG-13]

A measure based on a defined scale in nautical miles or kilometers which conveys the current position estimation performance.

ESTIMATED POSITION [RTCA SC-181/EUROCAE WG-13]

The output of the position estimation function.

ESTIMATED TIME OF ARRIVAL [ICAO Doc. 9569]

For IFR flights, the time at which it is estimated that the aircraft will arrive over that designated point, defined by reference to navigation aids, from which it is intended that an instrument approach procedure will be commenced, or, if no navigation aid is associated with the aerodrome, the time at which the aircraft will arrive over the aerodrome. For VFR flights, the time at which it is estimated that the aircraft will arrive over the aerodrome.

ESTIMATED TIME OF ARRIVAL [RTCA SC-227/EUROCAE WG-85]

The time at which the RNP equipment predicts that a fix will be crossed.

FINAL APPROACH SEGMENT [FAA AIM]
That segment of an instrument approach procedure in which alignment and descent for landing are accomplished.

FINAL APPROACH [FAA AIM]
The segment between the final approach fix or point and the runway, airport, or missed approach point.

FIX [RTCA SC-181/EUROCAE WG-13]

A fix is a generic name for a geographical position. A fix is referred to as a fix, waypoint, intersection, reporting point, etc.

FLIGHT LEVEL [ICAO Doc. 9569]

A surface of constant atmospheric pressure which is related to a specific pressure datum, 1013.2 hPa and is separated from other surfaces by specific pressure intervals.

FLIGHT PATH ANGLE

The angular displacement of the vertical flight path from a horizontal plane that passes through a reference datum point. The specified angle is from the TO fix or reference datum point.

FLIGHT TECHNICAL ERROR (FTE) [Derived from ICAO PBN Manual, Doc. 9613 and RTCA/DO-208]

The accuracy with which the aircraft is controlled as measured by the indicated aircraft position with respect to the indicated command or desired position. It does not include blunder errors.

FULL SCALE DEFLECTION (FSD) [RTCA SC-227]

For display formats employing the traditional two dots of deviation either side of a centered deviation indication, full scale deflection refers to when the indication is aligned with the second dot of deviation.

GEODESIC LINE [Bowditch]

A line of shortest distance between any two points on a mathematically defined surface. A geodesic line is a line of double curvature and usually lies between the two normal section lines which the two points determine. If the two terminal points are nearly in the same latitude, the geodesic line may cross one of the normal section lines. It should be noted that, except along the equator and along the meridians, the geodesic line is not a plane curve and cannot be sighted over directly.

GEOMETRIC PATH

A vertical flight path defined by a straight line between two points or based upon a specified flight path angle from a reference datum point.

HEADING [ICAO Doc. 9569]

The direction in which the longitudinal axis of an aircraft is pointed, usually expressed in degrees from North (true, magnetic, compass or grid).

HOLDING PROCEDURE [ICAO Doc. 9569]

A predetermined maneuver which keeps an aircraft within specified a airspace while awaiting further clearance.

HORIZONTAL COUPLING ERROR [RTCA SC-181/EUROCAE WG-13]

The vertical error resulting from horizontal along track position estimation error coupling through the desired path.

HOST TRACK/ROUTE [RTCA SC-181/EUROCAE WG-13]

The track or route defined by the waypoints in the active flight plan.

INTEGRITY [ICAO PBN Manual, Doc. 9613, RTCA/DO-208]

The ability of a system to provide timely warnings to users when the system should not be used for navigation. See the definition for containment integrity for how this parameter applies to RNP airspace.

LEG [RTCA SC-181/EUROCAE WG-13]

A leg is a segment of the flight plan consisting of a path type (e.g., Track, Course, Heading) and a termination type (e.g., fix, altitude). In an RNP environment, a leg is typically a path over the earth terminating at a fixed waypoint.

MEAN TIME BETWEEN FAILURES (MTBF) [ICAO Doc. 9569]

The actual operating time of a facility divided by the total number of failures of the facility during that period of time. Note: The operating time should in general be chosen so as to include at least five, and preferably more, facility failures in order to give a reasonable measure of confidence in the figure derived.

NAUTICAL MILE (NM) [ICAO Doc. 9569]

The length equal to 1,852 meters exactly.

NAVIGATION PERFORMANCE ACCURACY [Derived from ICAO PBN Manual, Doc. 9613]

Total navigation accuracy based on the combination of the *navigation sensor error*, airborne receiver error, *path definition error* and *flight technical error*. Also called system use accuracy. This performance accuracy is the uncertainty of the horizontal *total system error*.

NOTAM [ICAO Doc. 9569]

A notice containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.

OFFSET DISTANCE [RTCA SC-181/EUROCAE WG-13]

The lateral distance, measured in nautical miles left or right, that the offset track center line is offset from the host track centerline.

OFFSET TRACK/ROUTE [RTCA SC-181/EUROCAE WG-13]

The track or route that describes a flight path that is offset from the host track as defined by the waypoints in the active flight plan. The offset track/route is defined by the *offset reference point* computed by the navigation system.

OFFSET REFERENCE POINT [RTCA SC-181/EUROCAE WG-13]

The computed offset reference point is located on the line that bisects the track angle between route segments. The location of the offset reference point for each waypoint of the *host track/route* is computed by the navigation system so that it lies on the intersection of the lines drawn parallel to the *host track/route* at the desired *offset distance* and the line that bisects the track change angle.

PARALLEL OFFSET [RTCA SC-181/EUROCAE WG-13]

The parallel offset path is defined by one or more *offset reference points* computed by the navigation system that comprise the active flight plan. The magnitude of the offset is defined by the *offset distance*.

PATH DEFINITION ERROR [RTCA SC-181/EUROCAE WG-13]

The difference between the *defined path* and the *desired path* at a specific point and time.

PATH STEERING ERROR (PSE) [RTCA SC-181/EUROCAE WG-13]

This error is determined by the difference between the *defined path* and the *estimated position*. The PSE includes both FTE and display error (e.g., CDI centering error).

POSITION ESTIMATION ERROR [RTCA SC-181/EUROCAE WG-13]

The difference between true position and *estimated position*

POSITION UNCERTAINTY [RTCA SC-181/EUROCAE WG-13]

A measure that bounds the magnitude of an unknown *position estimation error* at a specific confidence level. A 95% position uncertainty of X can be either one-dimensional (indicating 95% probability true error is less than +/- X error) or two-dimensional (indicating a 95% probability true error is contained within a circle of radius X). Note: This document only addresses the horizontal 95% radial position uncertainty and the horizontal 99.999% radial position uncertainty.

REQUIRED NAVIGATION PERFORMANCE (RNP) [derived from ICAO PBN Manual, Doc. 9613]

A statement of the navigation *accuracy* necessary for operation on a procedure, route or within a defined airspace. The navigation accuracy is one element of Performance Based Navigation's on-board performance monitoring and alerting.

RNP AIRSPACE [RTCA SC-181/EUROCAE WG-13]

Generic term referring to airspace, route(s), leg(s), where minimum navigation performance requirements (RNP) have been established and aircraft must meet or exceed that performance to fly in that airspace.

RNP [RTCA SC-181/EUROCAE WG-13]

A designator used to indicate the minimum navigation system requirements needed to operate in an area, on a route or on a procedure (e.g., RNP 0.3 RNP 1). The designator invokes all of the navigation system requirements specified in this document.

RNP [derived from ICAO PBN Manual, Doc. 9613]

The term RNP is used to refer to a generic RNP navigation accuracy.

RNP RNAV [RTCA SC-181/EUROCAE WG-13]

The term used to describe an area navigation system capability that meets all of the requirements of the MASPS.

TIME-TO-GO [RTCA SC-181/EUROCAE WG-13]

The time required for the aircraft to reach the waypoint to which it is flying, calculated on the basis of the current ground speed. In the case of an aircraft flying a *parallel offset*, the time-to-go is measured to the *offset reference point*.

TOTAL SYSTEM ERROR (TSE) [RTCA SC-181/EUROCAE WG-13]

The difference between true position and desired position. This error is equal to the vector sum of the *path steering error*, *path definition error*, and *position estimation error*.

TRACK [ICAO Doc. 9569]

The projection on the earth's surface of the path of an aircraft, the direction of which is usually expressed in degrees from north (true, magnetic or grid).

TRANSITION ALTITUDE [ICAO Doc 8168]

The altitude at or below which the vertical position of an aircraft is controlled by reference to altitudes.

TRANSITION LEVEL [ICAO Doc 8168]

The lowest flight level available for use above the transition altitude.

VARIATION [Bowditch]

1. The angle between the magnetic and geographic meridians at any place, expressed in degrees and minutes east or west to indicate the direction of magnetic north from true north. The angle between magnetic and grid meridians is called grid magnetic angle, or grivation. Called magnetic variation when a distinction is needed to prevent possible ambiguity. Also called magnetic declination.

2. Change or difference from a given value.

VERTICAL FLIGHT TECHNICAL ERROR

The accuracy with which the aircraft is controlled as measured by the indicated aircraft position with respect to the indicated vertical command or desired vertical position. It does not include blunder errors

VERTICAL PATH DEFINITION ERROR

The vertical difference between the defined path and the desired path at the estimated lateral position. For an approach procedure, this could be the vertical angle error (VAE).

VERTICAL PATH PERFORMANCE LIMIT

The vertical performance limit above and below the defined path.

VERTICAL PATH STEERING ERROR

The distance from the estimated vertical position to the defined path. It includes both FTE and display error (e.g., vertical deviation centering error).

VERTICAL POSITION ESTIMATION ERROR

The same as altimetry system error.

VERTICAL TOTAL SYSTEM ERROR

The difference between true vertical position and desired vertical position at the true lateral position. This error is equal to the sum of the vertical path steering error, path definition error, position estimation error (altimetry system error) and horizontal coupling error.

VNAV [RTCA SC-181/EUROCAE WG-13]

The term used to describe a vertical navigation capability that meets all of the requirements of this document.

WAYPOINT [7100.11a]

A predetermined geographical position used for route definition and/or progress reporting purposes that is defined by latitude/longitude.

A.3 LIST of ACRONYMS and ABBREVIATIONS

2D	Two Dimensional
4D	Four Dimensional
AC	Advisory Circular
ACARS	Aircraft Communicating, Addressing, and Reporting System
ACJ	Advisory Circular Joint
ADS	Automatic Dependent Surveillance
ADS-A	Automatic Dependent Surveillance - Addressed
ADS-B	Automatic Dependent Surveillance - Broadcast
AEEC	Airlines Engineering Electronics Committee
AFM	Aircraft Flight Manual
AMJ	Advisory Material Joint
ARINC	Aeronautical Radio, Inc.
ASE	Altimetry System Error
ATA	Actual Time of Arrival
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
CCA	Common Cause Analysis
CDI	Course Deviation Indicator
CNS	Communication, Navigation, Surveillance
DME	Distance Measuring Equipment
DP	Departure Procedure
DQR	Data Quality Requirements
DTK	Desired Track
EASA	European Aviation Safety Agency
EMD	Electronic Map Display, used to depict navigation information.
EPU	Estimate of Position Uncertainty
ETA	Estimated Time of Arrival
ETE	Estimated Time Enroute
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FAR	Federal Aviation Regulation

FDE	Fault Detection and Exclusion
FHA	Functional Hazard Analysis
FL	Flight Level
FMEA	Fault Mode and Effects Analysis
FMS	Flight Management System
FTE	Flight Technical Error
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HSI	Horizontal Situation Indicator
hPa	Hecto-Pascals
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IGRF	International Geomagnetic Reference Field
IPV	Instrument Procedure with Vertical Guidance
ISA	International Standard Atmosphere
KIAS	Knots Indicated Airspeed
Kts	Knots
LNAV	Lateral Navigation
LOF	Loss Of Function
MAP	Missed Approach Point
MASPS	Minimum Aviation System Performance Standards
MEL	Minimum Equipment List
MI	Misleading Information
MLS	Microwave Landing System
MMEL	Master Minimum Equipment List
MNPS	Minimum Navigation Performance Specifications
MOPS	Minimum Operational Performance Standard
MSL	Mean Sea Level
MTBF	Mean Time Between Failures
NAVAID	Navigation Aid
NDB	Non-Directional Beacon
NM	Nautical Mile

NOTAM	Notice to Airmen
PDE	Path Definition Error
PEE	Position Estimation Error
PSE	Path Steering Error
PSSA	Preliminary System Safety Analysis
RNAV	Area Navigation
RNP	Required Navigation Performance
RSS	Root-Sum-Square
RTA	Required Time of Arrival
SASP	Separation and Airspace Safety Panel
SBAS	Satellite Based Augmentation System
SID	Standard Instrument Departure
SIS	Signal-In-Space
SSA	System Safety Analysis
STAR	Standard Terminal Arrival Routes
TAE	Track Angle Error
TAS	True Airspeed
TOAC	Time Of Arrival Control
TOC	Top Of Climb
TOD	Top of Descent
TSE	Total System Error
TSO	Technical Standard Order
USGS	United States Geodetic Survey
UTC	Universal Time Coordinated
VFR	Visual Flight Rules
VNAV	Vertical Navigation
VOR	VHF Omni-directional Range
VORTAC	VHF Omni-directional Range/TACtical Air Navigation
WG	Working Group
WGS-84	World Geodetic System 1984
XTK	Cross(X) TracK

The following abbreviations should be used for the terms below, including use in checklists, messages, identification, and labels for control functions. These abbreviations should not be used to represent a different term. These standards should be used consistently in the pilot handbook supplements, quick reference checklists, on the equipment controls, displays, and associated labels.

Note: It is not the intent of this list to require upper case abbreviations, as many of these abbreviations may be clearly represented in a combination of upper and lower case type. In all cases the meaning should be easily construed and remain consistent in a given piece of equipment.

Additional acceptable abbreviations can also be found in SAE ARP 4105C, Abbreviations and Acronyms for Use on the Flight Deck.

Table A-1: Recommended Abbreviations

Word(s) To Be Abbreviated	Recommended Abbreviation(s)	ICAO 8400/6 Recommended Abbreviation	ICAO 8400/6 Word(s) To Be Abbreviated
Acknowledge	ACK	ACK	Acknowledge
Active, Activate	ACT, ACTV	ACT	Active Or Activated Or Activity
Airport	APT	AP	Airport
Air Traffic Control	ATC	ATC	Air Traffic Control (In General)
Alert/Alerting	ALRT	ALR	Alerting (Message Type Designator)
Altitude	ALT	ALT	Altitude
Along-Track Distance	ATD		
Along-Track Error	ATE		
Along-Track	ATK		
Approach, Approach Control	APPR, APR	APCH	Approach
Area Navigation	RNAV	RNAV	Area Navigation
Arm, Armed	ARM		
Barometric Setting	BARO		
Bearing	BRG	BRG	Bearing
Cancel	CNCL	CNL	Cancel Or Cancelled
Center Runway	C	C	Center (Runway Identification)
Centigrade	C	C	Celsius (Centigrade), Degrees
Clear	CLR	CLR	Clear(S) Or Cleared To... Or Clearance
Coordinated Universal Time	UTC	UTC	Coordinated Universal Time
Course	CRS		

Word(s) To Be Abbreviated	Recommended Abbreviation(s)	ICAO 8400/6 Recommended Abbreviation	ICAO 8400/6 Word(s) To Be Abbreviated
Course Deviation Indicator	CDI		
Course To Fix	CF		
Cross-Track	XT, XTK		
Cross-Track Error	XTE		
Cursor	CRSR		
Database	DB		
Dead Reckoning	DR	DR	Dead Reckoning
Decision Altitude	DA	DA	Decision Altitude
Delete	DEL		
Departure, Departure Control	DEP	DEP	Depart Or Departure
Desired Track	DK, DTK		
Destination	DEST	DEST	Destination
Dilution Of Precision	DOP		
Direct, Direction	DIR	DCT	Direct (In Relation To Flight Plan Clearances And Type Of Approach)
Direct-To	direct symbol Direct To ( ) D with arrow		
Direct-To Fix	DF		
Distance	DIS, DIST	DIST	Distance
East	E	E	East Or Eastern Longitude
Emergency Safe Altitude	ESA		
En Route	ENR	ENR	En Route
En Route Safe Altitude	ESA		
Enter	ENT		
Estimated Time Of Arrival	ETA	ETA	Estimated Time Of Arrival Or Estimating Time Of Arrival
Estimated Time Of Departure	ETD	ETD	Estimated Time Of Departure Or Estimating Departure
Estimated Time En Route	ETE		
Fahrenheit	F		
Feet, Foot	’, FT	FT	Feet (Dimensional Unit)
Feet Per Minute	FPM	FPM	Feet Per Minute
Final Approach Fix	FAF	FAF	Final Approach Fix

Word(s) To Be Abbreviated	Recommended Abbreviation(s)	ICAO 8400/6 Recommended Abbreviation	ICAO 8400/6 Word(s) To Be Abbreviated
Final Approach Waypoint, for Waypoint Identifiers	f, FA, FAWP	FAP	Final Approach Point
Flight Level	FL	FL	Flight Level
Flight Plan	FPL	PLN	Flight Plan Cancellation (Message Type Designator)
From	FR	FM	From
Full-Scale Deflection	FSD		
Global Positioning System	GPS	GPS	Global Positioning System
Greenwich Mean Time	GMT		
Ground Speed	GS	GS	Ground Speed
Heading	HDG	HDG	Heading
Height Above Threshold	HAT		
		HGT	Height Above
Hold, Holding, Holding Pattern	HLD	HLDG	Holding
Horizontal Alert Limit	HAL		
Horizontal Protection Limit	HPL		
Horizontal Situation Indicator	HSI		
Horizontal Uncertainty Level	HUL		
Initial Approach Waypoint, For Waypoint Identifiers	i, IA, IAWP	IAF	Initial Approach Fix
Instrument Flight Rules	IFR	IFR	Instrument Flight Rules
Intermediate Waypoint	IWP		
Intersection	INT	INT	Intersection
Knots	KT		
Latitude	LAT	LAT	Latitude
Left	L, LFT		
Left Runway	L	L	Left (Runway Identification)
Localizer	LOC	LLZ	Localizer
Localizer-Type Directional Aid	LDA		

Word(s) To Be Abbreviated	Recommended Abbreviation(s)	ICAO 8400/6 Recommended Abbreviation	ICAO 8400/6 Word(s) To Be Abbreviated
Longitude	LON	LONG	Longitude
Magnetic	M, MAG	MAG	Magnetic
		QRD	Magnetic Bearing
Mean Sea Level	MSL	MSL	Mean Sea Level
Message	MSG	MSG	Message
Meters	M	M	Meters (Preceded By Figures)
Military Operating Area	MOA	MOA	Military Operating Area
Millibars	mB		
Minimum Decision Altitude	MDA	MDA	Minimum Descent Altitude
Minimum En Route Altitude	MEA	MEA	Minimum
Minimum Safe Altitude	MSA	MSA	Minimum Sector Altitude
Missed-Approach Holding Waypoint	h, MH, MAHWP		
Missed-Approach Waypoint, For Waypoint Identifiers	m, MA, MAWP	MAPT	Missed Approach Point
Nautical Mile	nm, NM	NM	Nautical Miles
Nautical Miles Per Hour			
Nearest	NRST		
Non-Directional Beacon	NDB	NDB	Non-Directional Radio Beacon
Non-Precision Approach	NPA		
North	N	N	North Or Northern Latitude
Off Route Obstacle Clearance Altitude	OROCA		
Offset	OFST		
Omni-Bearing Selector	OBS		
Outer Marker	OM	OM	Outer Marker
Parallel Track	PTK		
Precision Approach	PA		
Present Position	PPOS, PP	PPSN	Present Position
Procedure	PROC	PROC	Procedure
Procedure Turn	PT	PTN	Procedure Turn
Radial	R, RAD	RDL	Radial

Word(s) To Be Abbreviated	Recommended Abbreviation(s)	ICAO 8400/6 Recommended Abbreviation	ICAO 8400/6 Word(s) To Be Abbreviated
Radial/Distance	R/D		
Radius To Fix	RF		
Range	RNG	RG	Range (Lights)
Receiver Autonomous Integrity Monitoring	RAIM		
Relative Bearing	RB		
Required Navigation Performance	RNP	RNP	Required Navigation Performance
Reverse, Revision, Revise	REV		
Right	R, RT	RITE	Right Turn Of Direction
Right Runway	R	R	Right (Runway Identification)
Route	RTE	RTE	Route
Runway	RWY	RWY	Runway
Selective Availability	SA		
Sequence, Sequencing	SEQ		
Setup	SET		
South	S	S	South Or Southern Latitude
Special Use Airspace	SUA		
Standard Terminal Arrival Route	STAR	STAR	Standard Instrument Arrival
Suspend	SUSP		
Temperature	TEMP	T	Temperature
Test	TST		
Threshold Crossing Height	TCH		
Time To Alert	TTA		
To	TO	TO	To... (Place)
To/From	T/F		
Tower	TWR		
Track	TK, TRK	TR	Track
Track To Fix	TF		
Track Angle Error	TKE		
Transition Altitude	TA	TA	Transition Altitude
Transition Level	TL	TRL	Transition Level
True	T		
True Airspeed	TAS	TAS	True Airspeed

Word(s) To Be Abbreviated	Recommended Abbreviation(s)	ICAO 8400/6 Recommended Abbreviation	ICAO 8400/6 Word(s) To Be Abbreviated
		QTE	True Bearing
True Heading	TH		
Variation	VAR		
Vector	VECT		
Vector To Final	VTF		
Vertical Navigation	VNAV, VNV		
Vertical Protection Level	VPL		
Vertical Speed	VS		
Vertical Track	VTK		
Vertical Track Error	VTE		
Vertical Uncertainty Level	VUL		
VHF Omni-Directional Range	VOR	VOR	VHF Omnidirectional Radio Range
Warning	WARN, WRN	WRNG	Warning
Waypoint	WPT		
West	W	W	West Or Western Longitude
Wide Area Augmentation System	WAAS		
World Geodetic System	WGS		

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APPENDIX B EXAMPLE OF COMPLIANCE ANALYSIS

B.1 Introduction

The example MASPS system level containment analysis from Appendix B of DO-236C has been preserved as part of this appendix to the MOPS for the navigation computer and displays. The Appendix has been amended to specialize the analysis to the navigation computer and displays by adding a summary section (B.1.2) and by adding more detailed material to the sections of the analysis that deal specifically with derivation of the necessary probabilities.

The system level analyses of this appendix provide an example application of the methods of showing compliance outlined in Section 4.0 of DO-236C, as they apply for RNP RNAV systems. The system level example demonstrates the steps necessary to estimate the RNP RNAV capability of a system relative to the containment requirements and illustrates methods of revising the system architecture and operation to improve the RNP RNAV capability.

This example uses a VOR/DME sensor combination to improve the containment continuity of the solution. However, the analysis results in Table B-2 show that use of a VOR/DME mode to aid the containment integrity is only able to support RNP values greater than or equal to 1.0 NM. For this reason, and the general inability of States to guarantee omni-directional signal-in-space for VOR facilities, States do not permit the use of this particular sensor combination for RNP operations. In general, if compliance to the containment requirements rely on a particular navigation sensor combination, limitations may be imposed on the use of the equipment based on factors external to the system itself.

B.1.1 Summary of System Level Analysis

The system chosen for this example performs area navigation using either DME/DME or VOR/DME position fixing. It does not depict a blended multi-sensor system, it has only two independent modes of operation. For the purpose of this example, the VOR/DME mode will be considered only as an acceptable backup navigation mode because of its generally lower accuracy. The analysis also shows that it cannot meet the requirement without redundant display and computing capability. Therefore, a second, redundant system configuration was created by adding a navigation computer and a second navigation display. Both example systems are analyzed in this appendix. The systems have the following hardware components:

- Navigation display (1 or 2); (MOPS applies)
- Navigation computer (1 or 2); (MOPS applies)
- Two DME receivers; and
- One VOR receiver.

The application of the method described to these example systems consists of the following steps, which relate to the failure rate diagrams. Figure B-1 shows the analysis for the single thread system, and Figure B-2 shows it for the redundant system. The analysis steps are:

- Determine the portion of receiver MTBF which represents errors that can affect range/bearing outputs;
- Analyze the receiver internal tests for the above faults to determine detection and miss detection probabilities;

- Obtain (or identify) all of the receiver errors that can cause hazardously misleading information to be displayed and estimate the associated probability;
- Perform similar analysis for the navigation computers and displays;
- Determine the statistical characteristics of the position estimation algorithm;
- Determine the characteristics of any sensor error monitoring algorithms which are part of the position estimation algorithm;
- Combine the failure probabilities according to the system architecture; and
- Compare results to the containment integrity and continuity requirements for various RNP to assess the system's RNP capabilities.

The results of the steps outlined above are summarized in the failure probability diagrams and the numerical results are detailed in the accompanying spread sheet outputs. Section B.2 examines 1) the hardware analysis (common to all elements), 2) the accuracy analysis, and 3) the combination of probabilities per the designs to evaluate the RNP RNAV capabilities.

B.1.2 Summary of Navigation Computer / Display Analysis

There are basically two methods of specializing the analysis to the navigation computer. In the example system level analysis, representative values for hardware reliability and for probable navigation accuracy were assumed. Then the evaluation of compliance was performed using these numbers to evaluate the overall system RNP RNAV performance ability. When performing the analysis of the navigation computer, these numbers will have been derived based on the algorithms to be used for navigation using some type of statistical analysis for the navigation accuracy derivation. Amendments to the sections following will provide further details of the derivation of the probability of TSE>C under normal accuracy conditions and the derivation of the probability of nav sensor error going undetected by the navigation computer algorithms.

B.2 Elements of the Analysis

The analysis examples in this appendix use failure rates and other numerical estimates that are historical and are no longer representative of current hardware. They are used only to exemplify the method.

B.2.1 Hardware Analysis

For each of the hardware components, a Failure Mode and Effects Analysis (FMEA) must be performed in the traditional manner. All component failures must be analyzed to determine if they could lead to the display of erroneous navigation data and, if a failure can do so, it must be determined whether or not the internal tests of the unit can detect the failure. This analysis results in the value of the MTBF shown in the representation of the hardware units. This is the average time from a "no failure" condition to a first failure which would cause erroneous or degraded navigation. The probability of detection and its corollary, missed detection are both shown in the small boxes to the sides of each unit. The product of the probability per hour of this type of failure and the detection or missed detection probability leads to the desired per hour probabilities of undetected or detected failures.

The failure probabilities (per hour) are combined in the diagram according to the configuration of the system being analyzed. For example, both systems have DME and

VOR receivers, the DME receivers were found to have an MTBF of 2000 hours for failures that lead to misleading navigation outputs. For the example, they were assumed to have internal built-in test equipment (BITE) that had a 95% probability of detecting this type of error, allowing 5% to go undetected. The combination of MTBF and BITE detection results in the calculated undetected and detected failure probabilities for the equipment shown in the diagrams. Substantiation of these values will take the usual form of a BITE analysis and an FMEA performed on the components. The VOR receiver was assumed less reliable, with an MTBF of 1400 hours, with the same level of built-in test capability. Similarly, the navigation computer and the navigation display were assumed to have typical failure rates, with the computer having an MTBF of 2300 hours and the display having 3500 hours. These are hardware driven failure probabilities, and do not relate to the TSE or the measurement screening processes in the navigation computer. The levels of built in test were assumed to be better than for the receivers, having a detection capability of 99.5% for failures leading to navigation information errors.

B.2.2 Sensor Error Detection

Most systems which utilize a computer to estimate position from DME/DME or VOR/DME data include some type of reasonableness testing to reject extremely noisy data and/or the occasional “outlier”. The example presented here includes this testing by showing a fault box labeled “Probability of Nav Sensor Error”. The probability represented is the probability of an undetected fault in either in-use receiver. This is shown on both figures as a line from the output “or” gate for the paired receivers. The analysis must then determine the level at which the reasonableness tests can detect sensor data errors. The detection capability will generally be a function of test thresholds and statistics relative to the containment limit specified for the desired RNP. Referring to the table below, a simple relationship is proposed for this example. The assumption is that as the containment limit becomes smaller, the tests become less likely to be able to detect sensor errors which could cause containment violation. This seems reasonable since at some point the size of error which can cause containment violation is below the ability of the test to reliably detect.

The assumed numerical values for these probabilities are given below and shown in the example fault trees as the functions D(C) and V(C). C represents the containment limit, D(C) is the probability that a sensor error not detected in hardware BITE will remain undetected by the DME/DME reasonableness tests and V(C) represents the same for the VOR/DME mode. For this example, both of the functions D(C) and V(C) are dependent on the size of the required containment limit C, which equals two times the RNP. The assumed values are given in the following table.

Table B-2: Assumptions

Assumed Missed Detection Probabilities			
RNP (NM)	C (NM)	D(C)	V(C)
0.3	0.6	0.05	0.10
0.5	1.0	0.01	0.02
1.0	2.0	0.005	0.01
4.0	8.0	0.001	0.002

These assumed values are used in Figures B-1 and B-2 and are multiplied by the probability of an undetected occurrence of a sensor error to provide the rate needed for the analysis. The product of the missed detection and the probability of the error occurring is shown as D_2 (or V_2). The detection probability is one minus the miss probability and is shown as D_3 (or V_3) on the figure. These probabilities feed directly into the computation of total system undetected and detected failure rates to complete the analysis of the system. For this system analysis, the probabilities used in this calculation must be substantiated through an appropriate combination of simulation and test of the hardware and the software involved.

One method of arriving at the probabilities D(C) for a specific navigation algorithm would be to use a Monte Carlo simulation. DME must be characterized for normal errors in some fashion; use of Appendix C material from DO-236C would be one way. Once the sensor normal operation is characterized, its non-normal performance must be characterized, for instance, DME location in navigation data could be in error. Analogously, making an estimate of V(C) must also evaluate normal and non-normal error sources. The model of normal error should not rely on Appendix C, because modeling VOR error should also consider such "normal" errors as beam bending and scalloping associated with the environment in which the VOR operates. This could be done by adding elements to the error model of Appendix C.

Once the values for D(C) and V(C) are estimated, the data rejection algorithms from the navigation computer must be tested against the model of normal and non-normal error occurrence in the simulation.

One method would be to define a path through a region of operation, say Europe (dense navaid coverage), USA western regions (less dense), and Africa or Australia (very sparse coverage). These paths would then be flown repeatedly with different initial navigation errors (statistically drawn). Each navaid tuned would be randomly assigned a data base error initially (position error) and as it is used, the statistics for normal operation would be applied at each sample taken. The program would need to record at least the following relative to the containment or test threshold: the number of false detections (navaid data is ok but algorithm rejects it), the number of missed detections (navaid data is not ok but algorithm accepts it), and the number of correct detections (navaid data is not ok and algorithm rejects it).

Once this data is gathered for sufficient trial flights to make the estimate statistically robust, one can compute the probability D(C), and the same could be done for V(C). The analysis of the entire system can then proceed as described in the diagrams and evaluation sections of this appendix.

B.2.3 Position Error Analysis

The last basic element which must be defined is the total system error including the position estimation error statistics and the path steering error statistics involved in the use of the system. The position estimation error statistics are different for the two modes of operation. For this example, the position estimation error was assumed to be Gaussian with zero mean and variance dependent upon mode of operation. For both modes it was assumed that the position estimation error can be characterized as a bivariate Gaussian probability density function with an approximately equal standard deviation in both principal directions. The standard deviations used for this analysis were 0.2 NM for DME/DME and 0.4 NM for VOR/DME. These errors assume range and reasonableness limits on the use of DME and VOR data. The path steering error was assumed Gaussian in the cross track direction with a standard deviation of 0.05 NM, representative of autopilot coupled flight. Therefore, for the combined density the standard deviations for total system error in the cross track direction are essentially unchanged due to PSE.

For the navigation computer that is defined in this MOPS, the only error sources that apply in this section are the path definition error and the position estimation error. The TSE is representative of normal operations; therefore, the evaluation of both position and path definition errors must be carried out for normal operations. Once again, the sensor errors must be defined, as in B.2.2, and a statistical estimate of horizontal error due to the particular position estimation algorithm used in the navigation computer though use of Monte Carlo simulation. Further, one needs to show that when normal operation does not meet the RNP allocation to the navigation computer, there is an alert compliant with the MASPS.

An analysis of the path definition algorithms must also be carried out globally; with samples measured relative to the exact WGS-84 geodesic computations. An aggregate statistic can be compiled to enter into the analysis, or, if one uses WGS-84 geodesic computations for path, there will be no contribution to TSE from this source.

If a path steering error monitor had been included, for example under an assumption of pilot flying using CDI and monitoring being required, the analysis diagrams would have contained a separate element for the effect of the monitor. This would show that certain levels of path steering error could be detected and their effect eliminated through indications to the crew.

B.2.4 System Level Analysis

Referring now to the figures, the detected and undetected error probabilities for the system must be evaluated by combining appropriately the underlying probabilities found in the previous sections. Both figures are fault tree representations of the system architecture and the underlying failure probabilities. The evaluation of the detected failure rate will be discussed first, followed by a discussion of the undetected failure rate. It is important to note here that the undetected failure cases must be analyzed independently, that is each mode of operation must have sufficient integrity (low enough undetected failure rate) to meet the requirement for the RNP for which it is proposed to qualify. The system continuity, or detected failure rate, is the combination of the two modes, since either one can be used to navigate. Sections B.2.5 and B.2.6 will concentrate in detail both on the single thread system and on the dual system fault diagrams. A numerical RNP analysis of the results will follow, and will point to the need for redundancy of displays and computers for the example based on the desire to meet lower RNP. Both sets of data will be presented and explained.

B.2.5 Detected Failure Rate Analysis

Beginning with the “System Detected Failure Rate” output on Figures B-1 and B-2, one sees that it is composed of two elements, the probability of losing display or computer capability, and the probability of losing both navigation modes. These two elements add, since loss of either will result in total loss of navigation function. This is represented in the diagram by the final “or” element leading to the detected failure rate.

To analyze the relationship between the navigation computers and the displays, begin with the MTBF associated with loss of either. The navigation displays are shown as having an MTBF of 3500 hours relating to errors which can be classed as a failure relative to containment. To a first approximation, the failure rate per hour is the inverse of the MTBF, or (1/3500) per hour. In the single system this result is used directly, however, in the dual system, both have to fail before the entire navigation function is lost, leading to a corresponding probability of loss per hour as the product of the two rates, or (1/3500) * (1/3500). The detection rate assumed for these errors (through hardware BITE) is assumed to be 0.995 as shown, yielding a final probability per hour of 2.84×10^{-4} for the single and 8.06×10^{-8} for the dual as shown.

The same analysis applies to the navigation computers, with similar results shown on the diagrams. For the dual case, if both of the redundant computers or both of the displays fail, the system is lost, thus the two probabilities add, yielding the final combined display/computer result. For the single case, of course, if either the computer or the display fails the system is lost. These variations are shown in the respective diagrams.

In both cases, a similar analysis of the hardware failures of the receivers is performed. The DME receivers are combined (for D/D mode), as are the VOR and DME receivers (for D/V mode). Since both receivers must be working for a mode to work, the probabilities of detected failures are added, and then combined with the probability of detecting an undetected receiver error using the reasonableness tests. The reasonableness tests are peculiar to the navigation computer, and were evaluated in detail in section B.2.2. This combination provides the complete result for the receiver and navigation data related failures which can then be combined with the results for the navigation displays and computers to obtain the total detected failure rate of the DME/DME mode of the system.

A similar analysis yields the results for the VOR/DME mode of operation. The combination of the DME/DME and VOR/DME modes is shown as an “and”, since both must be lost to lose navigation, the “and” results in taking the product of the two probabilities as the final result for the navigation modes of the system. This result combines with the probability of loss of computers and displays as described in the first paragraph of this section to yield the total detected loss of function rate for the system as designed.

B.2.6 Undetected Failure Rate Analysis

The major difference between the analysis of the detected error rate and the analysis of the undetected error rate is that the undetected error rates of the two modes must be considered separately. For any multiple mode system, each independent operating mode must meet the containment integrity requirement for the RNP for which it is to be qualified. This leads to the fault diagram producing two results for the undetected failure rates of this system. The results are shown at the top and the bottom of the diagrams on the right side. This dramatically points out that one cannot directly improve integrity performance by adding backup modes. If one added a cross check between the modes, comparing D/D solutions to D/V solutions, integrity would be affected, but that is not being postulated for this example. However, one must note that if the cross check were necessary to achieve the required containment integrity level, the system would no longer be dual mode, since loss of either mode results in loss of RNP RNAV capability.

A second very important point to the undetected failure analysis is that the “tails” of the position estimation error and path steering error distributions must be included with the fault effects in the hardware in the analysis of compliance with the containment requirements. This is a departure from the normal FMEA, and is one of the distinguishing features of the requirements for RNP qualification. The top box on both diagrams depicts this, where the probability of TSE exceeding the containment limit is added directly to the hardware undetected failure rate, since in this example no independent monitoring of position error has been postulated. The presence of a monitor on the 95th percentile level of position estimation error would change this analysis by perhaps "trimming" the tails of the TSE distribution in much the same way as an FTE monitor would, however, such a monitor is not considered for this example in the interest of simplicity.

Following the diagram for the undetected failure rate of the D/D mode, it combines the undetected excursions due to normal accuracy from above, with the probability that navigation reasonableness tests will miss an error which was also undetected in the hardware, and adds the probability that the display(s) or computer(s) will suffer undetected failures. This generates the total probability per hour of undetected failure for the system.

B.3 RNP RNAV Evaluation

Under the numerical assumptions of the table giving the values for functions D(C) and V(C), and the combination shown in the figure(s) for the fault analysis, the systems have the following results for containment integrity and containment continuity. The containment integrity values are shown for each mode and the containment continuity values are shown for both the single and dual computer/display systems.

Table B-2: Analysis Results Summary

	Containment Integrity		Containment Continuity	
RNP	DME/DME	VOR/DME	Single Nav	Dual Nav
0.3	1.36×10^{-3}	6.68×10^{-2}	7.18×10^{-4}	1.48×10^{-6}
0.5	4.40×10^{-6}	6.21×10^{-3}		
1.0	3.85×10^{-6}	4.50×10^{-6}		
4.0	3.65×10^{-6}	3.72×10^{-6}		

The results of the analysis for this example system can now be stated. Based on the numbers in the table above, a dual navigation computer and dual navigation displays are necessary to meet the containment continuity requirement of 1×10^{-4}. The following summarizes the RNP RNAV capability of the dual system which operates in D/D mode with an independent VOR/DME backup:

- The redundant system is necessary to meet the containment continuity requirement, since the detected failure rate of the single system is greater than the allowable 1×10^{-4}.
- The best RNP RNAV capability for the combined DME/DME with VOR/DME backup is RNP 1, because:
    1. The containment integrity for the DME/DME mode supports RNP 0.5, however,
    2. The containment integrity of the VOR/DME backup mode only supports the requirements for RNP 1 or greater.

B.4 Approval Limitations of Example System

There are approval limitations for this proposed system design. The first is relative to the supporting infrastructure provided by the State. Since this system must have both DME/DME and VOR/DME modes available to meet the containment continuity requirement, it is not suitable for airspace where the navaid infrastructure cannot support the operation.

The second limitation is that it requires LNAV autopilot coupled operation, as that assumption was made in the analysis of the containment capability of the system.

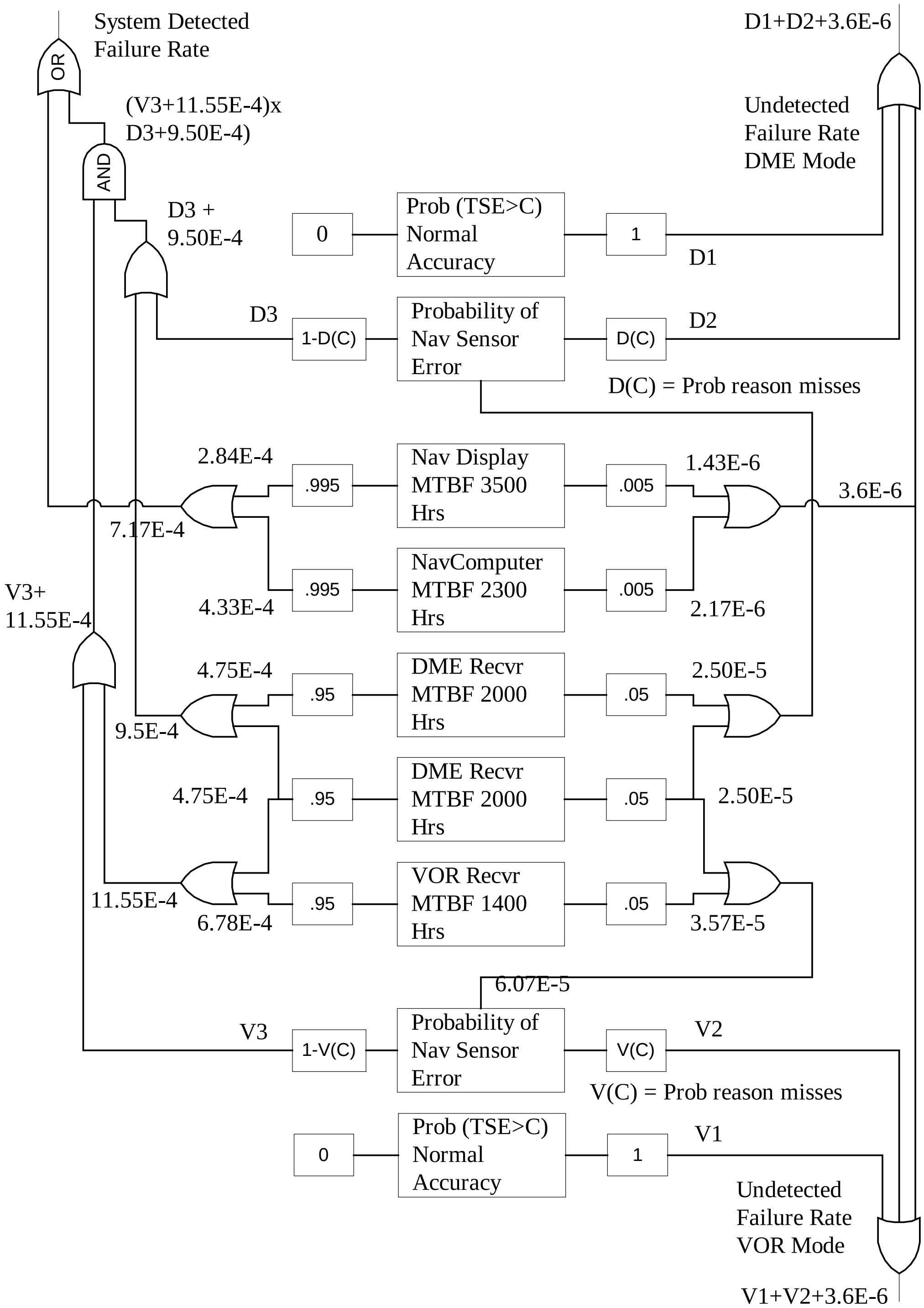

Figure B-1: Single System Fault Diagram

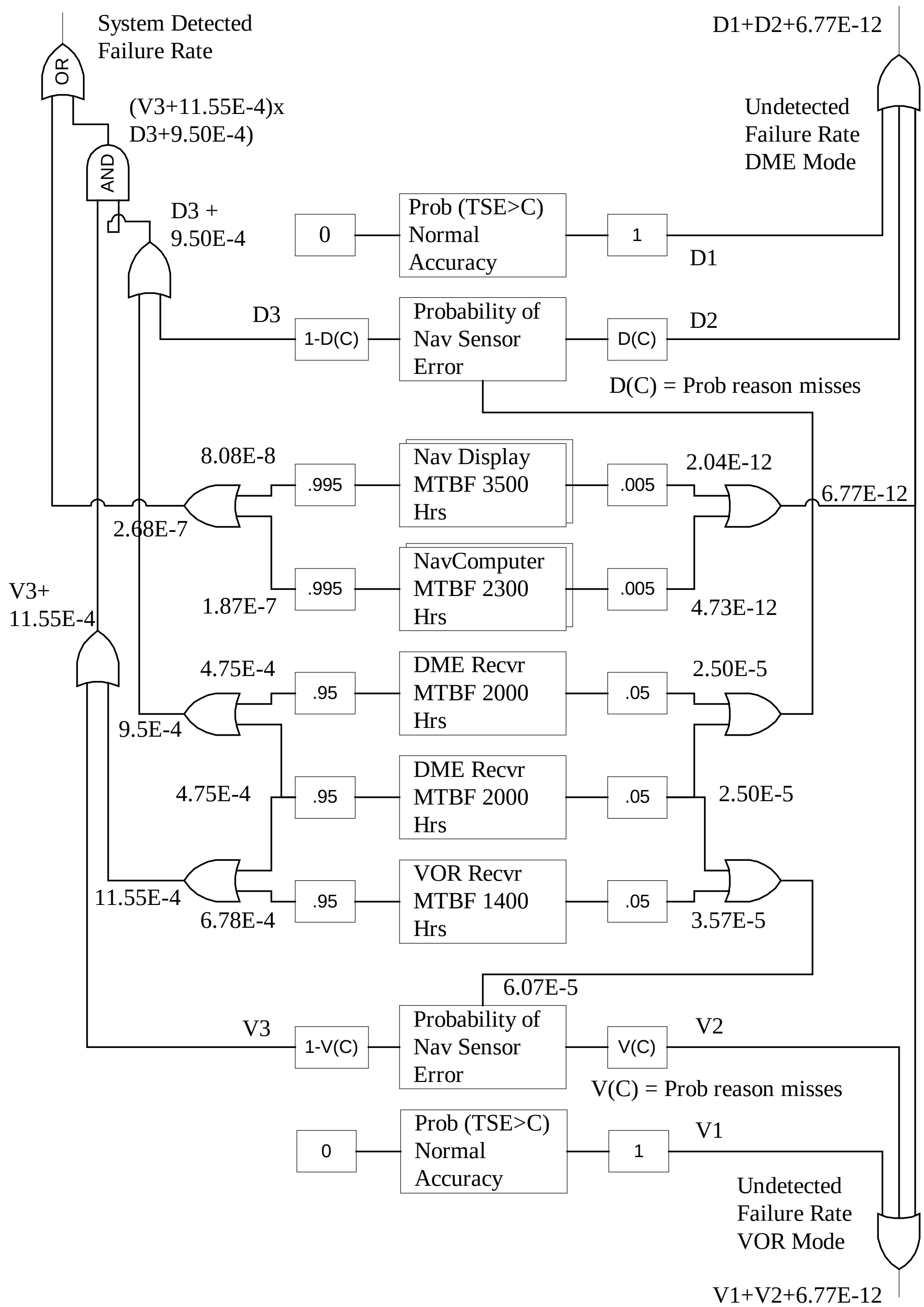

Figure B-2: Dual System Fault Diagram

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APPENDIX C NAVIGATION SYSTEM REQUIREMENTS AND INFRASTRUCTURE CHARACTERISTICS

C.1 Introduction

Section C.2 describes the sensor performance that is assumed to be provided by each type of navigation facility if it is to be used to promulgate a route for RNP, and with Vertical Performance requirements, where appropriate. This performance must be assumed by the aircraft when demonstrating compliance to the system requirements in Section 2.0 of this MOPS. Section C.3 provides information for the airspace planner in assessing what RNP may be supported by a particular navigation infrastructure.

Integrity of the infrastructure is not considered as part of the airborne evaluation; the Signal-in-Space (SIS) is assumed to have the error distributions described below. The only exception is GPS, which has a SIS failure rate that must be compensated by an augmentation (See Section C.2.4).

Infrastructure continuity is not considered as part of the airborne evaluation, but must be considered by the State prior to defining RNP airspace predicated on a particular navigation infrastructure. It is assumed that an RNP operation will not be initiated unless the SIS continuity is sufficient. If the aircraft uses the infrastructure identified by the State, no additional assessment of SIS continuity is required. However, if the aircraft uses components of the infrastructure not identified by the State, an assessment of the SIS continuity must be performed. This Appendix provides the outage rates for different navigation facilities to enable this assessment.

In addition, it is assumed that the State publishes the correct location for each navigation facility, so that any error arising from inaccurate survey of a navigation facility is consistent with the following accuracy assumptions.

Note 1: The guidance contained in this appendix was developed to address three specific aspects of the reliability, repeatability and predictability of equipment navigation performance as specified in this standard. For the manufacturer, use of the service performance characteristics herein is intended to lead to a common and consistent basis in how equipment accuracy is determined, achieved in design, and ensured. For navigation services, provision of navigation infrastructure with the signal characteristics defined ensures that regardless of choices in equipment design implementation, predictable and reliable aircraft navigation performance based upon this standard will be achieved and demonstrated. As States and service providers implement RNP applications, the attendant effect of their services on aircraft performance and capability becomes a factor in the choice to design procedures and designate airspace per the ICAO PBN Manual. The effect of services is also expected to influence the population and location of navaids that are included in a PBN navigation infrastructure.

Note 2: The information in this appendix has been revised from the MASPS information which contains conservative performance numbers that account for both old and new navaid technologies, and differences in equipment standards over time. The committee has concluded that navaids have mostly been modernized, and along with RNP capable aircraft that now contain modern avionics, provide improved availability and *performance. The information contained in this* MOPS reflects the performance of receivers compliant with RTCA/DO-189 and DO-196.

C.2 Navigation Facility Assumptions for the Airborne System

C.2.1 VHF Omni-directional Range (VOR)

The basic expression for VOR accuracy is:

$$\sigma_{VOR}^2 = (\sin(\text{GS error}) * D)^2 + (\sin(\text{airborne error}) * D)^2$$

where

GS error = standard deviation of ground station radial error

D = distance to the VOR, and

airborne error = standard deviation of airborne error

When demonstrating compliance to this MOPS, the airborne system shall assume that the VOR infrastructure will provide a radial signal with a Gaussian angular error that has a mean of zero and an upper limit of 1°, per ICAO Annex 10, Vol 1, paragraph 3.3.7.

VOR signals may not be used as the aircraft passes overhead the VOR facility.

Note 1: The VOR radial alignment is less than 1 degree of the nominal magnetic radial limited by the monitor required by ICAO Annex 10, ICAO Doc. 8071.

When designating RNP airspace based upon a VOR infrastructure, the State may assume that the VOR contribution to error (in the perpendicular direction from the track to the VOR) is less than or equal to:

$$\sigma_{VOR}^2 = (0.0087 * D)^2 + (0.0087 * D)^2$$

Note 2: This assumes that VOR equipment has an airborne error contribution of 1 degree (95%).

VOR facilities are assumed to have a mean time between failures of 10,000 hours.

C.2.2 Distance Measuring Equipment (DME)

The basic expression for DME error is:

$$\sigma_{DME}^2 = (\text{GS Error})^2 + (\text{Air Error})^2$$

where GS Error = ground station timing error

When demonstrating compliance to this MOPS, the airborne system may assume that the DME infrastructure complies with ICAO Annex 10 DME monitoring requirements and will provide a ranging signal with a Gaussian slant range error that has a mean of zero and a standard deviation < 0.04 NM.

Note 1: The DME GS range error will be less than 150 meters, 0.08 NM, (95%) for systems installed after 1 January 1989 (ICAO Annex 10).

Note 2: The DME Air Error will be less than 0.17 NM (95%) per RTCA/DO-189, post 1989 requirements.

When designating RNP airspace based upon a DME infrastructure, the State may assume that the DME contribution to error (slant-range to the DME) is equal to:

$$\sigma_{DME}^2 = (0.04\ \text{NM})^2 + (0.085\ \text{NM})^2$$

or

$$\sigma_{DME} = 0.0939\ \text{NM}$$

Note 3: This assumption is based upon the achievable performance of airborne equipment, as defined in RTCA/DO-189 and EUROCAE/ED-54, post 1989 requirements.

DME facilities are assumed to have a mean time between failures of 10,000 hours.

C.2.3 Inertial Reference System (IRS)

Since an IRS is not dependent upon external signals, no external error allocation is necessary.

C.2.4 Global Positioning System (GPS)

When demonstrating compliance to this standard, the RNP equipment may assume that the GPS infrastructure will provide a signal that results in PEE components in the along and cross track directions with a Gaussian error that has a mean of zero and either a standard deviation of 50 meters or 16 meters (refer to Note 1).

Note 1: The 33 meter GPS range error and corresponding 50 meter PEE is the appropriate assumption for a DO-208 compliant sensor and assumes Selective Availability is active. The 10.5 meter GPS range error and corresponding 16 meter PEE is the appropriate assumption for DO-229 or DO-316 compliant sensors respectively and assumes Selective Availability is not active but does not take credit for the SBAS augmentation.

When establishing compliance to the containment requirements, GPS satellites shall be assumed as having a major service failure rate of 10^{-5}/ hour/satellite. A major service failure is defined to be a pseudorange error greater than 150 meters received from a satellite not designated "unhealthy". The overall failure rate shall also be assumed to be 10^{-5}/ hour/satellite (the failure rates are equivalent because the major service failure rate is conservative). It can be further assumed that for both these failure cases, a failure rate of 10^{-4}/ hour is appropriate to represent the probability that one failed satellite is in view of the equipment.

Note 2: GPS provides a unique signal-in-space in that it is not directly monitored to a level commensurate with aviation requirements (time-to-alarm and probability of missed detection). In order to use GPS for IFR navigation, augmentation is required to provide the monitoring function [airborne augmentation such as fault detection and exclusion (FDE), space-based augmentation, or ground-based augmentation]. The requirements for the augmentation must be based upon the potential effect of a GPS satellite failure on multiple users. These requirements will be determined for each type of augmentation, and will be more stringent than that required to satisfy the containment requirements of a single aircraft. For GPS systems using FDE as the requisite augmentation, the probability of missed detection and failed exclusion have both been established as 10^{-3} (RTCA/DO-229, FAA Notice 8110.60).

C.3 Effect of PEE on Route or Procedure Airspace Design

It is assumed that RNP procedures will not be developed unless the navigation infrastructure supports the procedure. In order to assess whether or not a particular infrastructure supports a specific RNP, the State will identify the desired RNP and assess the feasibility of the desired RNP. The assessment of feasibility involves the following steps:

1) Determine the maximum σ_{PEE} that supports the desired type,

2) Identify the navigation facilities which support the σ_{PEE}, selecting at least one type of airborne integration.

The State should identify the facilities within range of the intended procedure. Because the airborne equipment assumes that the SIS has the characteristics defined in this Appendix, the State must also use these assumptions in assessing the RNP supported by an infrastructure.

Depending on the type of facilities provided and the intended operation, the State may elect to have redundant facilities to ensure that the availability is consistent with air traffic requirements. If multiple facilities are required to satisfy the air traffic service requirements, then the worst-case operational configuration should be used.

For example, an RNP procedure may be created based on a DME/DME environment. Although only two DMEs are required to provide navigation, the State may determine that three DMEs are necessary to achieve the desired availability and account for DME ground station maintenance and failures. In this case, the two DMEs with the worst geometry should be used to perform the assessment (the third DME should be assumed to be out of service).

C.3.1 RNP RNAV System Performance Accuracy Considerations for Airspace Design

C.3.1.1 VOR/DME Positioning

When using a collocated VOR/DME for area navigation, the airborne RNP equipment position estimation accuracy may be assumed to be at least as accurate as:

$$\sigma_{VOR/DME} \leq \sqrt{0.0088 + 2 * (0.0087 * \mathrm{D})^2} \quad \text{(NM)}$$

where D is slant-range distance .

Note 1: This includes the signal-in-space and receiver errors, the slant-to-horizontal conversion and the effects of altitude error in this conversion. The VOR accuracy is based on a receiver accuracy of 0.5 degree (standard deviation).

Note 2: In considering the above position estimation accuracy, the PEE values of section 2.2.1.5.1.1 apply to the determination of the maximum allowable distance for a given RNP. Beyond this, the airborne system will either provide the appropriate alert or will have to utilize another sensor or sensor type to meet the RNP.

C.3.1.2 DME/DME Positioning

When using multiple DMEs for area navigation, the airborne RNP equipment position estimation accuracy may be assumed to be at least as accurate as:

$$\sigma_{DME/DME} \leq \frac{0.133}{\sin(\alpha)} \text{ (NM)}$$

where α is the inclusion angle of the two DMEs.

Note 1: This includes the signal-in-space and receiver errors, the slant-to-horizontal conversion and the effects of altitude error in this conversion.

Note 2: In considering the above position estimation accuracy, the PEE values of Section 2.2.1.5.1.1 apply to the determination of the range of allowable angles for a given RNP. Beyond this, the airborne system will either provide the appropriate alert or will have to utilize another sensor or sensor type to meet the RNP.

C.3.1.3 INS Positioning

Inertial navigation systems may be combined with any of the navigation sensors to improve the continuity and performance of the airborne RNP equipment position estimation function.

When utilizing inertial navigation systems, the integrated RNP RNAV system may be assumed to provide at least the following accuracy after loss of radio updating.

Time Since Radio Updating (T) (hr)	IRS 95% Error (NM)
0.0 to 0.5 hr	8 * T
0.5 to 1.5 hr	4

where T is time since loss of radio updating.

To the extent that better coasting performance is achievable, the equipment manufacturer should document the coasting performance capabilities and limitations (i.e., coasting time while sustaining 95% navigation accuracy at desired RNP performance levels). This documentation must be consistent with the RNP RNAV containment alerting algorithms for the aircraft.

Note 1: This is only intended to address equipment where IRS/INS is an input and base component in a multi-sensor position estimation function. This is known as a loosely coupled capability. For tightly coupled equipment where the IRS/INS instrument errors are adjusted/corrected in real time by another positioning sensor, e.g. GNSS, criteria are provided in RTCA/DO-229D.

Note 2: In considering the above position estimation accuracy, the PEE values of section 2.2.1.5.1.1 apply to the determination of the maximum allowable time for a given RNP. Beyond this, the airborne system will either provide the appropriate alert or will have to utilize another sensor or sensor type to meet the RNP.

C.3.1.4 GNSS Positioning

Position accuracy requirement for GNSS are defined in RTCA/DO-229D and RTCA/DO-316.

Note 1: GNSS position estimation is a special case of position estimation since the Appendix C assumptions do not allow the aircraft to assume that the GNSS satellites are fault-free. These requirements for GNSS-based operations have been coordinated internationally and are defined in ICAO Annex 10, Volume 1.

Note 2: In considering the above position estimation accuracy, the PEE values of section 2.2.1.5.1.1 apply for a given RNP. Beyond this, the airborne system will either provide the appropriate alert or will have to utilize another sensor or sensor type to meet the RNP.

APPENDIX D LEG TYPE DEFINITIONS

As defined in section 2.2.1.2.1, the RNP navigation equipment defined path is composed of a series of ARINC 424 leg types. This appendix provides supplementary detail on the characteristics of each of these allowed leg types.

Note: More information on RNP path terminators, all valid leg transitions, etc can be found in ARINC 424.

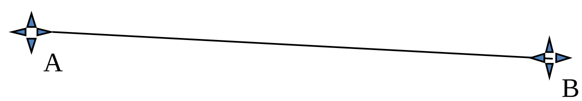
D.1 Initial Fix (IF)

An IF is a fix. An IF leg is used only to define the beginning of a route or procedure.

Note: An IF leg does not define a desired track in and of itself, but is used in conjunction with another leg type (e.g. TF) in order to define the desired path.

D.2 Track to Fix (TF)

A TF leg is defined as a geodesic path between two fixes. The first fix is either the previous leg termination or an IF leg. The termination fix is normally provided by the navigation database, but may also be a user-defined fix.

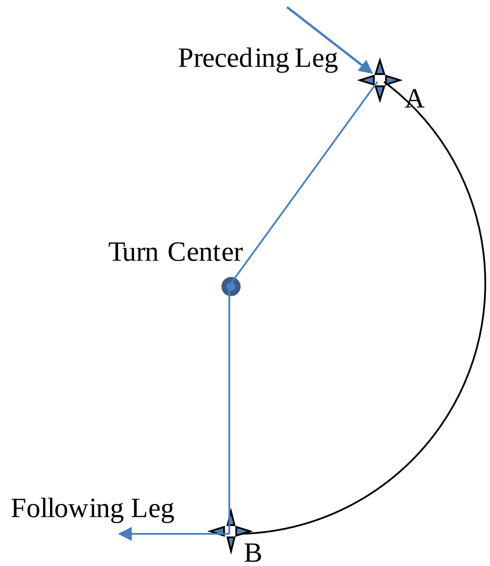


Path: Geodesic Path between A and B
Termination: Fix B

Figure D-1: Track to Fix (TF) Leg

D.3 Radius to Fix (RF)

An RF leg is defined as a constant radius circular path about a defined turn center that terminates at a fix. The termination fix, the turn direction of the leg, and the turn center are provided by the navigation database. The radius is computed as the distance from the turn center to the termination fix by the navigation computer. The beginning of the leg is defined by the termination fix of the previous leg, which also lies on the arc.



Path: Constant Radius Arc to Fix B
Termination: Fix B

Figure D-2: Radius to Fix (RF) Leg

D.4 Hold to Altitude (HA)

An HA leg is a holding pattern which terminates at the next crossing of the hold fix when the aircraft altitude is at or above the specified altitude. The altitude is provided by the navigation database. The source of the magnetic variation needed to convert magnetic courses to true courses is detailed in Section 2.2.1.2.8.

D.5 Hold for Clearance (HM)

An HM leg is a holding pattern which terminates only after flight crew action. The source of the magnetic variation needed to convert magnetic courses to true courses is detailed in Section 2.2.1.2.8. Where required by procedure, a speed restriction will be provided in the navigation database.

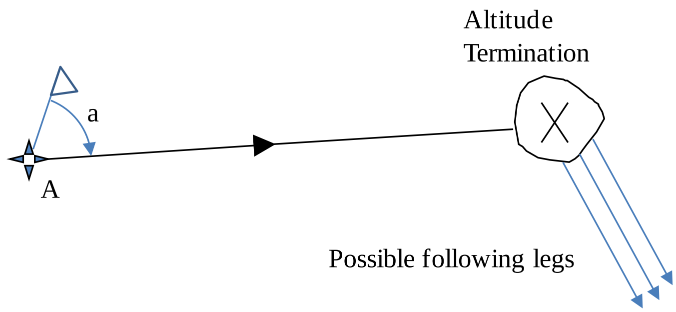
D.6 Hold to Fix (HF)

An HF leg is a holding pattern which terminates at the first crossing of the hold fix after becoming established on the inbound course. This is typically after the entry procedure is performed. The source of the magnetic variation needed to convert magnetic courses to true courses is detailed in Section 2.2.1.2.8. Where required by procedure, a speed restriction will be provided in the navigation database.

D.7 Fix to Altitude (FA)

An FA leg is defined by a geodesic path that starts at a fix, with a specified track at the fix, and terminates at a point where the aircraft altitude is at or above a specified altitude. The outbound course from the fix, the fix, and the terminating altitude are provided by the navigation database. If the outbound course is defined as a magnetic course, the source of the magnetic variation needed to convert magnetic courses to true courses is detailed in Section 2.2.1.2.8.

Note: It must be recognized that an FA leg can be tightly contained only in the cross-track dimension. It is highly variable in the along-track dimension due to the unknown termination point of the FA leg and the resulting following leg in the procedure (typically a DF leg). The FA Leg is intended to be used as the initial segment for specific departure procedures to facilitate more direct courses out of the terminal area for aircraft with a high climb rate.



Path: Geodesic Path from Fix A with Outbound track "a"
Termination: Altitude

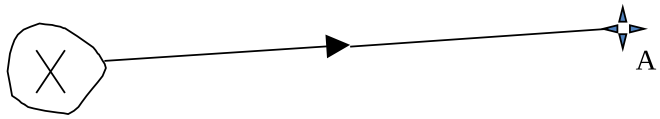
Figure D-3: Fix to Altitude (FA) Leg

D.8 Direct To Fix (DF)

A DF leg is defined as a geodesic path that starts near the area of initiation and terminates at a fix.

Additional path definition requirements associated with the Direct-To operation are given in Section 2.2.1.2.3.

Note: It must be recognized that in terms of a predetermined repeatable flight path, a DF leg is highly variable. This variability is in contrast to the applicability of a DF leg to RNP characteristics once established on the leg. When established on a DF leg, the containment region for that leg can be defined and the RNP may be specified relative to the defined path.



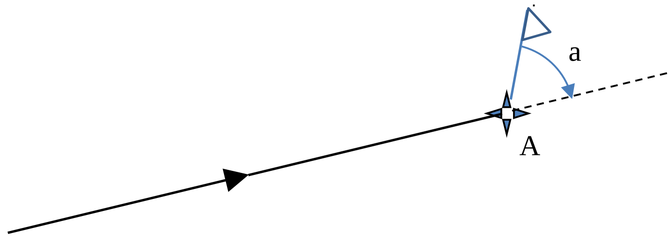
Path: Geodesic Path direct to Fix A
Termination: Fix A

Figure D-4: Direct to Fix (DF) Leg

D.9 Course To Fix (CF)

A CF leg is defined as a geodesic path that terminates at a fix with a specified course at that fix. The inbound course at the termination fix and the fix are provided by the navigation database. If the inbound course is defined as a magnetic course, the source of the magnetic variation needed to convert magnetic courses to true courses is detailed in Section 2.2.1.2.8.

Note: *It must be recognized that in terms of a predetermined repeatable flight path, the applicability of a magnetically-specified CF leg to the definition of an RNP procedure is limited. The CF leg is used in many approach procedures because ARINC 424 previously specified it as the only type of leg to be used for coding the final segment of an approach. This was due to course-based legs being consistent with operational procedures at the time. Supplement 12 of ARINC 424 allows the use of TF legs as an alternative to CF and, as a consequence, it is believed that CF legs will therefore exist in RNP procedures only during a transition period.*



Path: Geodesic Path to Fix A with Inbound Track "a"
Termination: Fix A

Figure D-5: Course to Fix (CF) Leg

APPENDIX E WGS-84 EARTH MODEL

E.1 General

One of the most important considerations as the NAS evolves from a station-referenced navigation system to an earth-referenced navigation system is the earth model (datum) used for Aviation Information Publications (AIPs) and air navigation systems. This appendix describes the geometry of the WGS-84 ellipsoid, and defines the geodetic latitude and longitude of a point on that ellipsoid. An example algorithm is then given for solving the following, which is called the inverse problem of geodesy:

> Given the geodetic latitude and longitude of two points on the WGS-84 ellipsoid, find the range and bearing of the shortest path between them.

This path is called a geodesic.

A related problem is the direct problem of geodesy:

> Given the departure geodetic latitude and longitude, the geodesic path length, and the departure bearing on the WGS-84 ellipsoid, find the arrival latitude, longitude and bearing.

The corresponding problem on the surface of a sphere has the following well-known and elementary solution. Suppose that one is given a pair of distinct, nonantipodal points on the surface of a sphere. (Recall that two (distinct) points on the surface of an ellipsoid are said to be antipodal if they are located symmetrically with respect to the center of the ellipsoid). Then these two points, together with the center of the sphere, determine a plane. This plane intersects the surface of the sphere in two circular arcs which together form a circle called a great circle. The shorter of these two circular arcs is the shortest path on the surface of the sphere which joins the prescribed points.

For two antipodal points on the surface of a sphere, there are infinitely many planes which contain both of those points and which also contain, the center of the sphere. Any of the circular arcs determined by the intersection of one of these planes with the surface of the sphere will be a geodesic. Hence, the problem does not have a unique solution in this case.

On a nonspherical, ellipsoid, the situation is considerably different. (It is therefore inappropriate to refer to geodesics on a nonspherical ellipsoid as "great circles"). In particular, the only geodesics which are plane curves are those which lie along a meridian or along the equator [reference 1]. Furthermore, the geodesic can in general be computed to an arbitrary level of accuracy only iteratively. The iterative algorithms presented here were published in [reference 2], and will yield accuracy to within fractions of a millimeter if the termination criterion ε is taken to be 10^{-12} (unless the two points are antipodal, or nearly antipodal. The geodesic is nonunique or highly sensitive to small changes in the problem data, respectively, in that case). This accuracy is generally obtained in no more than six iterations. Compared to "closed-form" approximate solutions, such as that in [reference 3], the algorithm presented here is simpler to implement in software. Further discussion of various algorithms may be found in [reference 4].

E.2 Definition of Terms

Throughout this appendix, the term ellipsoid will specifically refer to an ellipsoid of revolution, obtained by rotating an ellipse about its minor axis. The points at which the minor axis intersects the surface of the ellipsoid are called the North and South poles. The plane which passes through the center of the ellipsoid and which is normal to the minor axis is called the equatorial plane. The equatorial plane intersects the surface of the ellipsoid in a circle, called the equator.

The geodetic latitude of a point on an ellipsoid is the angle between the equatorial plane and the outward normal vector at that point on the ellipsoid. This angle is taken to be positive in the Northern Hemisphere and negative in the Southern Hemisphere.

Any plane which is orthogonal to the equatorial plane and which passes through the center of the ellipsoid intersects the surface of the ellipsoid in an ellipse, called a meridian. One of these meridians is arbitrarily selected as a reference, and is called the Greenwich meridian. The longitude of a point on the ellipsoid is determined by the angle between the plane that contains the meridian passing through that point, and the plane which contains the Greenwich meridian. (The longitude of either pole is undefined). Longitude is customarily expressed in degrees, measured Eastward from the Greenwich meridian.

A curve that is traversed in a specified direction is said to be oriented. The bearing of an oriented smooth curve on an ellipsoid describes the direction of the tangent vector to that curve, at a particular point on that curve. Bearing is usually expressed in degrees, measured clockwise from local North. (Local (true) North at a point on an ellipsoid is defined as the direction of the tangent vector to the meridian at that point, where the meridian is oriented toward the North Pole. Note that local North is undefined at either pole, so this description of bearing does not apply there).

E.3 Nomenclature

B_1 = Geodetic latitude of departure point, in degrees.

L_1 = Longitude of departure point, in degrees.

B_2 = Geodetic latitude of arrival point, in degrees.

L_2 = Longitude of arrival point, in degrees.

α_1 = Bearing of the geodesic, at the departure point, in radians

α_2 = Bearing of the geodesic, at the arrival point, in radians

s = Range (arclength along the geodesic) from departure point to arrival point, in meters.

E.4 WGS-84 Parameters (from [5])

a = 6378137 m (WGS-84 semimajor axis).

b = 6356752.3142 m (WGS-84 semiminor axis).

e^2 = $6.694379991013 \times 10^{-3}$ (square of WGS-84 first eccentricity)

= $(a^2 - b^2)/a^2$

$(e')^2$ = $6.73949674227 \times 10^{-3}$ (square of WGS-84 second eccentricity)

= $(a^2 - b^2)/b^2$

f = $3.35281066474 \times 10^{-3}$ (WGS-84 flattening)

= $(a - b)/a$

E.5 The Inverse Problem

The inputs are:

B_1 = Departure geodetic latitude in degrees

L_1 = Departure geodetic longitude in degrees

B_2 = Arrival geodetic latitude in degrees

L_2 = Arrival geodetic longitude in degrees

(B_1, L_1) and (B_2, L_2) are with respect to the WGS-84 ellipsoid.

The outputs are:

s = Geodesic path length on the WGS-84 ellipsoid

α_1 = Departure bearing at (B_1, L_1) in radians

α_2 = Arrival bearing at (B_2, L_2) in radians

The algorithm is specified as follows:

1. Convert geodetic latitude from degrees to radians.

$$\Phi_1 = \pi B_1/180$$

$$\Phi_2 = \pi B_2/180$$

2. Compute the difference in longitude, in radians.

$$\Delta L = (\pi/180)\ (L_2 - L_1)$$

3. Compute the "reduced latitudes", in radians.

$$\beta_1 = \tan^{-1}\left[(1 - f)\tan(\Phi_1)\right]$$

$$\beta_2 = \tan^{-1}\left[(1 - f)\tan(\Phi_2)\right]$$

4. Initialize the iteration.

$$\lambda_k = \Delta L$$

5. Perform the following iteration, until

$$|\lambda_{k+1} - \lambda_k| < \varepsilon,$$

where ε is the termination criterion:

$$\sin\sigma = \sqrt{(\cos\beta_2\sin\lambda_k)^2 + (\cos\beta_1\sin\beta_2 - \sin\beta_1\cos\beta_2\cos\lambda_k)^2}$$

$$\cos\sigma = \sin\beta_1\sin\beta_2 + \cos\beta_1\cos\beta_2\cos\lambda_k,$$

$$\sigma = \operatorname{atan2}(\sin\sigma, \cos\sigma),$$

$$\sin\alpha_e = \frac{\cos\beta_1\cos\beta_2\sin\lambda_k}{\sin\sigma}$$

$$\cos^2\alpha_e = 1 - \sin^2\alpha_e$$

$$\cos 2\sigma_m = \begin{cases} \cos\sigma - \dfrac{2\sin\beta_1\beta_2}{\cos^2\alpha_e}, & \text{if } \cos^2\alpha_e \neq 0; \\ 0, & \text{otherwise} \end{cases}$$

$$C = (f/16)\cos^2\alpha_e\left[4 + f\left(4 - 3\cos^2\alpha_e\right)\right],$$

$$\lambda_{k+1} = \Delta L + (1 - C)\, f\sin\alpha_e\left\{\sigma + C\sin\sigma\left[\cos 2\sigma_m + C\cos\sigma\left(-1 + 2\cos^2 2\sigma_m\right)\right]\right\}$$

0

6. The range s, and the bearings α_1 and α_2 at the departure point and arrival point,

$$\operatorname{atan2}(Y,X) = \begin{cases} \tan^{-1}(Y/X), & \text{if } X>0; \\ \tan^{-1}(Y/X)+\pi, & \text{if } X<0; \\ \pi/2, & \text{if } X=0 \text{ and } Y>0; \\ -\pi/2, & \text{if } X=0 \text{ and } Y<0. \end{cases}$$

respectively, may now be computed as follows:

$u^2 = (e')^2 \cos^2\alpha$,

$A = 1 + (u^2/16384)\{4096 + u^2 [-768 + u^2 (320 - 175 u^2)]\}$,

$B = (u^2/1024)\{256 + u^2 [-128 + u^2 (74 - 47 u^2)]\}$,

$\Delta\sigma = B \sin\sigma \{\cos 2\sigma_m + (1/4) B [(-1 + 2 \cos^2 2\sigma_m) \cos \sigma - (1/6) B (-3 + 4 \sin^2 \sigma) (-3 + 4 \cos^2 2\sigma_m) \cos 2\sigma_m]\}$,

$s = bA(\sigma - \Delta\sigma)$,

where the function atan2 has following definition, as in FORTRAN:

Note that some implementations of atan2 (such as Excel) reverse the order

of parameters.

$\alpha_1 = \operatorname{atan2}(\cos\beta_2 \sin\lambda_{k+1}, \cos\beta_1 \sin\beta_2 - \sin\beta_1 \cos\beta_2 \cos\lambda_{k+1})$,

$\alpha_2 = \operatorname{atan2}(\cos\beta_1 \sin\lambda_{k+1}, -\sin\beta_1 \cos\beta_2 + \cos\beta_1 \sin\beta_2 \cos\lambda_{k+1})$,

Note that α_2 is the bearing at the destination point, of the arriving geodesic which originated at the departure point. The so-called back azimuth, or initial bearing of the geodesic that departs from the arrival point and returns to the departure point, is

$\alpha_2 \pm \pi$

E.6 The Direct Problem

The inputs are:

- B_1 Departure geodetic latitude in degrees
- L_1 Departure geodetic longitude in degrees
- s Geodesic path length
- α_1 Departure bearing at (B_1, L_1) in radians

The outputs are:

- B_2 Arrival geodetic latitude in degrees
- L_2 Arrival geodetic longitude in degrees
- α_2 Arrival bearing at (B_2, L_2)

The algorithm is specified as follows:

1. Convert geodetic latitude and longitude to radians

   $\Phi_1 = \pi\ B_1/180$

   $\lambda_1 = \pi\ L_1/180$ positive east, negative west

2. Compute the reduced latitude

   $\beta_1 = \text{atan}\ [(1 - f)\ \tan(\Phi_1)\ ]$ ... 2 quadrant arctan

3. Compute equatorial geodesic angular distance and azimuth

   $\tan\sigma_e = \tan\beta_1 / \cos\alpha_1$

   $\sigma_e = \text{atan}(\tan\beta_1 / \cos\alpha_{1)}$

   $\sin\alpha_e = \cos\beta_1 \sin\alpha_1$

   $\cos^2\alpha_e = 1 - \sin^2\alpha_e$

4. Initialize the iteration

   $u^2 = (e')^2 \cos^2\alpha_e$

   $A = 1 + (u^2/16384)\ \{4096 + u^2\ [- 768 + u^2\ (320 - 175\ u^2)]\},$

   $B\ = (u^2/1024)\ \{256 + u^2\ [-128 + u^2\ (74 - 47\ u^2)]\},$

   $\sigma_i\ = s/(bA)$

5. Perform the following iteration, until

   $|\ \sigma_{i+1} - \sigma_i\ | \leq \varepsilon$

   where ε is the termination criterion:

   $2\sigma_m = 2\sigma_e + \sigma_i$

   $\Delta\sigma = B\ \{\cos2\sigma_m + 1/4\ B\ [(-1 + 2\cos^2 2\sigma_m) \cos\sigma_i – 1/6\ B\ (-3 + 4\ \sin\text{\^{}}2\sigma_i)\ (-3 + 4 \cos^2 2\sigma_m) \cos2\sigma_m]\} \sin\sigma_i$

   $\sigma_{i+1} = s/(bA) + \Delta\sigma$

6. Compute arrival point and arrival azimuth

   $\sigma\ =\ \sigma_{i+1}$

   $Y\ =\ \sin\beta_1 \cos\sigma + \cos\beta_1 \sin\sigma \cos\alpha_1$

   $X\ =\ (1- f)\ [\sin^2\alpha_e + (\sin\beta_1 \sin\sigma - \cos\beta_1 \cos\sigma \cos\alpha_1)^2]^{1/2}$

   $\Phi_2\ =\ \text{atan}\ (Y/X)$... 2 quadrant arctan

   $Y\ =\ \sin\sigma \sin\alpha_1$

   $X\ =\ \cos\beta_1 \cos\sigma - \sin\beta_1 \sin\sigma \cos\alpha_1$

   $Z\ =\ \text{atan2}\ (Y, X)$.... 4 quadrant arctan Z is positive east

   $C\ =\ f/16\ [4 + f(4 - 3\cos^2\alpha_e)]\cos^2\alpha_e$

   $\lambda_2\ =\ \lambda_1 + Z - (1 - C)\ f\{\ \sigma + C\ [\cos2\sigma_m + C\ (-1 + 2\cos^2 2\sigma_m) \cos\sigma] \sin\sigma\} \sin\alpha_e$

   $Y\ =\ \sin\alpha_e$

$$X = -\sin\beta_1 \sin\sigma + \cos\beta_1 \cos\sigma \cos\alpha_1$$

$$\alpha_2 = \text{atan2}(Y, X) \ldots \text{ 4 quadrant arctan}$$

Note that α_2 is the bearing at the arrival point, of the arriving geodesic which originated at the departure point. The so called back azimuth, or initial bearing of the geodesic which departs from the arrival point and returns to the departure point, is

$$\alpha_2 \pm \pi$$

E.7 Validation

The Indirect Problem algorithm described above was tested by computing the range and bearing of the geodesics between all ordered pairs of distinct locations listed in RTCA DO-208 MOPS Section 2.5.2.5.2.1 above. The value of the termination criterion ε used was 10^{-12}. The maximum number of iterations required in any of these 552 cases was 8, with a mean of 4.92 and a median of 5.

Geodesic curves on an ellipsoid may be computed by solving the following system of nonlinear ordinary differential equations, where the unknown quantities are the geodetic latitude B, longitude L, and bearing α, at each point on the geodesic, and where the independent variable t is arclength along the geodesic divided by a:

$$\frac{dB}{dt} = \frac{\left[(1 - e^2 \sin^2 B)^{3/2} \cos\alpha\right]}{(1-e^2)}$$

$$\frac{dL}{dt} = \frac{\left[(1 - e^2 \sin^2 B)^{1/2} \sin\alpha\right]}{\cos B}$$

$$\frac{d\alpha}{dt} = \left[(1 - e^2 \sin^2 B)^{1/2} \sin\alpha\right] \tan B$$

(For a derivation of these equations, see pp. 88-93 of [2]).

For each departure point, range, and bearing (at the departure point), the actual terminal point of the corresponding geodesic curve was computed by numerically integrating these equations, using the Runge-Kutta-Fehlberg algorithm of order (References 4 & 5), and a local truncation error tolerance of 10^{-14}. The distance between the actual terminal point and the desired arrival point was then computed. In every case, this distance was less than two-tenths of one millimeter.

For the convenience of anyone wishing to implement the above algorithm in software, seven test cases are supplied here. (These test cases are suggested in [Reference 4]). Table E-1 below lists the geodetic latitude of the departure points, and the geodetic latitude and longitude of the arrival points. (The departure points are all on the Greenwich meridian).

Table E-1: TEST CASE INPUT

Case	Departure Latitude	Arrival Latitude	Arrival Longitude
1	37.331931575000	26.128566516667	41.476529802778
2	35.269791283333	67.370771216667	137.791198430556
3	1.000000000000	-0.998286322222	179.296674991667
4	1.000000000000	1.020885977778	179.771622900000

5	41.696077777778	41.696166666667	0.000155555556
6	30.000000000000	37.892351622222	116.321302341667
7	37.000000000000	28.260193152778	-2.627646994444

The results for each of these cases are shown in Table E-2 below. (The value of the termination criterion ε used was again 10^{-12}).

Table E-2: TEST CASE OUTPUT

Case	Departure Bearing α_1	Arrival Bearing α_2	Ranges
1	95.4669065012712	118.100037749533	4,085,797.71045745
2	15.7398635998781	144.927624307827	8,084,459.01281178
3	89.0255041313847	90.9762395789926	19,959,214.6261821
4	5.0047450389878	174.995222917504	19,779,362.8384626
5	52.6771685463032	52.6772720198999	16.2833273117916
6	45.0000844826718	129.136526168938	10,002,067.6833720
7	-165.000275690672	-166.421458799296	999,975.508415485

Table E-3 below shows the required number of iterations, and the error (distance between the desired arrival and the actual terminal point), for each test case.

Table E-3: NUMBER OF ITERATIONS

Case	Number of Iterations	Error	Significant Decimals		
			α_1	α_2	s
1	5	$1.38189930304136 \times 10^{-5}$	10	10	5
2	4	$5.62351088062680 \times 10^{-5}$	7	9	4
3	5	$1.42575492953545 \times 10^{-4}$	6	5	4
4	18	$1.41770874909204 \times 10^{-4}$	8	7	4
5	3	$6.87589522482552 \times 10^{-8}$	7	6	7
6	4	$4.84762978049413 \times 10^{-5}$	9	9	4
7	5	$7.19785012259682 \times 10^{-6}$	9	9	5

Note that the data shown in Table E-2 are the literal output obtained by running the algorithm on a particular platform, and that not all of the digits shown are significant. The last three columns of Table E-3 give the number of digits to the right of the decimal point which are considered to be significant, for each of the data shown in Table E-2. These were obtained by rounding, in turn, the departure bearing, arrival bearing, and range for each case, to different levels of precision, and computing the actual terminal point of the corresponding geodesic. For the arrival bearing, the departure point and arrival point were exchanged, and the departure bearing was replaced by the arrival bearing minus 180°). The number of decimals considered to be significant was determined by the minimum level of precision which resulted in the error between the actual terminal point and the desired arrival point being within fifty percent of the value shown in Table E-3.

The Direct Problem algorithm was validated with above data as well, with nearly identical results.

As a final validation, it is recommended that random pairs of (B_1, L_1) and (B_2, L_2) be generated. These pairs may then be fed into the Indirect Problem algorithm to produce α_1, α_2 and s. Then, (B_1, L_1), α_1 and s may be fed into the Direct Problem algorithm to obtain (B_2, L_2) and α_2. The differences (B_2 - B_1), (L_2 - L_1), (α_2- α_1) should be small, $< 10^{-10}$. This is the closed form validity check.

E.8 References

1. Frederick Pearson II, Map projections: theory and applications. CRC Press, Boca Raton-Ann Arbor - London - Tokyo, 1990.
2. T. Vincenty, "Direct and inverse solution of geodesics on the ellipsoid with application of nested equations", Survey Review, No. 176 (1975), pp. 88-93.
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5. Department of Defense World Geodetic System 1984: Its definition and relationships with local geodetic systems, second edition. Defense Mapping Agency Technical Report TR-8350.2, Defense Mapping Agency, Fairfax, Virginia, September 1991.

APPENDIX F HUMAN FACTORS CONSIDERATIONS

F.1 Introduction

Flight deck technology is proliferating and new functions may be proposed beyond what is envisioned in the current document. Nonetheless, consideration of human factors issues early and throughout the design process using established principles can guide the development of the human-equipment interface.

This appendix provides additional context, guidelines and considerations for the RNP equipment designer so that human factors elements can be addressed early in the design process. The recommendations in this section are intended to assist in defining a flight crew interface for functions implemented in the RNP equipment. The recommendations in this section address some common, recurring human factors issues with RNP equipment and are not intended to be a comprehensive human factors guide.

This appendix assumes that if the RNP equipment contains functions that interface with the flight crew for input and output, these aspects of the RNP equipment design are documented in a similar fashion to other equipment design features as part of the equipment development process. In this appendix the flight crew interface elements of the equipment design documentation are collectively referred to as the Flight Crew Interface Guidelines.

The guidelines in this Appendix should be considered in the context of an aircraft or avionics manufacturer's flight deck design philosophy. In general, the design of RNP equipment crew interfaces should be consistent with the overall flight deck design philosophy, including using the same user interface conventions where possible. For example, if a flight deck convention uses large font for manually entered data and small font for automatically generated data, the RNP equipment design should use the same convention. In particular, care should be taken that no aspect of the RNP equipment crew interface conflicts with the design conventions of any other equipment in the same flight deck.

F.2 Flight Crew Interface Guidelines

The RNP equipment manufacturer should develop flight crew interface guidelines for the RNP equipment. The flight crew interface guidelines are intended to be the manufacturer's declared guidelines for designing the interfaces with the flight crew. As such, it is intended to capture changes to the interface as functions are added to the RNP equipment and guide the interface design of these functions in a manner that ensures consistency and compatibility.

Note: The designer/manufacturer may address this requirement in any existing documentation. A new document is not required when available documentation can be revised or expanded to satisfy the requirement.

Deviations from the flight crew interface guidelines, for instance to ensure compliance with the flight deck philosophy requirements of an aircraft manufacturer, can be accommodated by updating the guidelines to identify the changes and their justifications.

The RNP equipment flight crew interface guidelines should contain RNP equipment recommendations that as a minimum address:

- Controls
- Labels and symbology
- Page format/ display layouts

- Data entry fields
- Fonts and highlighting
- Color
- Alerts and Messages
- Crew Workload

The RNP equipment manufacturer should confirm that all elements of their RNP flight crew interface guidelines have been followed.

F.2.1 Controls

The RNP equipment flight crew interface guidelines should establish consistent use of controls.

The equipment controls should be designed to provide feedback when operated. Tactile and visual cues are acceptable forms of feedback. Aural feedback is acceptable but may need to be combined with tactile and/or visual feedback, especially when the noise level is high on the flight deck.

The equipment controls (including soft controls) should be designed to prevent inadvertent activation of adjacent controls.

Note 1: Common and acceptable means of reducing the likelihood of inadvertent operation through key design include the following:

- *A minimum edge-to-edge spacing between buttons of 1/4 inch. Keys should not be spaced so that sequential use is awkward or error prone.*
- *Placing fences between closely spaced adjacent controls.*
- *Concave upper surface of keys to reduce slippage.*
- *Size of control surface sufficient to provide for accurate selection.*

If soft controls are utilized in the RNP equipment, they should be positioned in a consistent location from one page to another, which could enable quick access to activation of controls.

The RNP equipment controls should be operable with the use of only one hand.

Operations that occur with high frequency or in the terminal area should be executable with a minimum number of control operations.

Controls should be operable during vibrations. Vibrations affect not only the ability of pilots to intentionally activate a control, but also can affect inadvertent activation and awareness of activation.

To the extent possible, controls should be organized according to the following principles:

- Collocate the controls with associated displays.
- Partition the controls into functional groups.
- Place the most frequently used controls in the most accessible locations.
- Arrange the controls according to the sequence of use.

There should be a clear indication when any control is not in a designed default position (e.g. if a knob is pulled out and functions differently).

The use of controls should be documented clearly and consistently in the manufacturer's documentation (e.g. systems descriptions, pilot handbook supplements and quick reference checklists).

Note 2: It is expected that airplane and equipment designers will ensure that materials related to the RNP equipment such as pilot handbooks, quick reference checklists or electronic checklists are consistent with respect to the overall system operation.

F.2.1.1 Labels and Symbology

F.2.1.1.1 Controls

Label nomenclature should clearly communicate the control's function to the flight crew.

Label nomenclature for controls should be consistent with established industry nomenclature for identical functions. The RNP equipment labels should use terms, icons, or abbreviations recommended in applicable FAA policy and other standards when available. Otherwise, the RNP equipment labels should use labels that are in general use in aviation.

Note: Recommended abbreviations are listed in Appendix A, Table A-1.

When implemented in the equipment, these abbreviations should not be used to represent a different term or function.

If a control can be used for multiple functions, the current function should be indicated either on the display or on the control.

Unless the control function and method of operation are obvious or indicated through other means (e.g., form, location), the control labeling scheme should clearly and unambiguously convey:

- The current function performed by each control,
- The method for actuating the control when performing the current function.

The RNP equipment should place labels for controls such that:

- The spatial relationships between labels and the objects they reference are clear.
- Labels are on or adjacent to the controls they identify.
- Labels are not obstructed by the associated controls.
- Labels are oriented to facilitate readability. For example, labels associated with symbols such as a runway or airway should continuously maintain an upright orientation or alignment with their associated symbol.

The RNP equipment should unambiguously associate soft control labels with the control they label (e.g., either through location or through an indicator of which control is associated with the label). It is acceptable to remove a soft control label when the associated function is no longer available.

F.2.1.1.2 Data Fields and Other Symbology

The labeling design should avoid hidden functions such as clicking on empty space on a display to make a selection.

Symbols used in the RNP equipment should be compatible in meaning with other established navigation resources (e.g., navigation maps and instrument charts).Where the units or labels for the displayed data are not evident, (due to context of the field on a page format or layout) the RNP equipment should include the units of measurement or label within the data field.

Note: For example, individual weight data fields would not require units if the units were included in the page title.

F.2.2 Displays

F.2.2.1 Page Format and Display Layout

The RNP equipment flight crew interface guidelines should establish consistent use of page formats and display layouts.

The RNP equipment should be designed such that information and data fields are consistently positioned and aligned on the display(s). Consistency in the positioning of information and data fields creates predictability, which could allow information to be found faster.

Note 1: For example, grouping airplane weight fields and aligning them so that the decimal point is placed in the same vertical column could enable the flight crew to determine completeness of information during a visual scan. This organization could reduce the time and mental workload required to locate and process the information in each field.

The RNP equipment should display the most essential information as the most prominent.

Note 2: For example, one way to make data items prominent is to present them at the top of the displayed page.

The RNP equipment should consistently group related information on the display(s). Grouping related information can help the flight crew to identify the context of the displayed information.

Note 3: Consistent grouping of related information across the various displays can facilitate the processing of that information by the flight crew, (e.g., lateral information on the left of the display, while vertical information is on the right of the display).

The RNP equipment should use page layouts that are consistent with the needs of specific flight phases. For example, approach is a unique operational phase of flight that may need to be supported with groups of related functions and associated information.

Note 4: Consistent page layouts can reduce reliance on pilot memory and workload by collecting functions and information related to an operational context.

The RNP equipment should minimize clutter and the density of information. The RNP equipment designer should give highest priority to the presentation of essential information that is required to support the function(s).

Note 5: Minimizing clutter can allow the needed information to be found faster and could reduce the flight crew mental workload to assimilate the information. Excess information or information unrelated to the operation increases the time to find and process information and introduces the potential for misinterpretation.

If a set of related information (e.g., flight plan) cannot be presented on the single page, the RNP equipment should provide a clear indication to the pilot that the information continues on another page. The RNP equipment should break lines of text only at spaces or other natural delimiters.

The RNP equipment should consistently format similar data across pages (e.g., latitude/longitude should be displayed in the same format on all pages where it appears). The manufacturer should identify information presented in multiple locations and show that the information is presented consistently. Where the inconsistent display of an information item is unavoidable, it should not contribute to errors or misinterpretation.

For RNP equipment that uses a menu structure, the following considerations apply:

- The RNP equipment should group pages associated with a particular function together in a single branch of the menu structure.
- The RNP equipment should display pages that contain important manual data entry fields and information that needs to be readily available to the flight crew within the first or second layer of the menu structure. When not feasible, the RNP equipment should dedicate hard or soft buttons to provide direct access to the applicable page (e.g., a "Direct To" button immediately opening the associated page).

If the RNP function is integrated as part of a system that performs other functions that may be in use simultaneously, the RNP equipment should retain the data entry state when a data entry task is interrupted by a higher priority function. This will allow the interrupted task to be resumed when the user returns to the RNP function. The RNP equipment should provide thea means for a direct return to the previous (interrupted) task.

Note 6: An example of an "interruption" is when a flight crew member is prompted to address a datalink message on the same device while flight plan data is being entered (e.g., as on an MCDU). When the datalink message has been addressed, the flight crew member can return to data entry task and find that all the data previously entered is still there.

F.2.2.2 Data Entry Fields

The RNP flight crew interface specification should establish consistent use of data entry fields.

The RNP equipment should distinctly and uniquely identify the following data fields:

- Mandatory data entry
- Optional data entry
- Display only

Where the RNP equipment incorporates toggle/sequential data entry fields, these should be designed to indicate the current selected state (e.g. if there are 3 states sequentially selectable, the selected state can be highlighted while the other states remain displayed).

The RNP equipment should validate flight crew data entries for syntax and range (e.g. speed, altitude, weights outside of established limits or database constraints). It should provide a positive indication that a manual input has been accepted. If a flight crew input is not accepted by the system, the RNP equipment should provide an indication of the invalid data entry to the flight crew within 500 milliseconds of the entry, and should display the reason for the rejection. If the flight crew input is not accepted by the system, the input failure should be clearly and unambiguously indicated.

The RNP equipment should indicate the acceptance of character entry within 250 msec.

Note 1: The method to indicate acceptance of the entry is to be determined by the manufacturer and should be consistent with the respective Flight Crew Interface Guidelines. Simply blanking the scratchpad data field/line without a corresponding indication in the target data field/line may not be considered to be a positive indication of a successful data entry.

If a data entry results in an extended calculation, the RNP equipment should provide feedback to the flight crew that an extended calculation is in progress.

Note 2: This feedback may be in the form of a temporary visual cue or other suitable means. An extended calculation may be considered as one that takes longer than approximately two seconds in modern equipment, such as for vertical profile optimization after a flight plan change. The time interval of two seconds is based on certification experience and is considered a reasonable amount of time to meet the flight crew expectation for feedback.

The RNP equipment should provide a means to allow pilots to quickly recover from input errors (e.g., with a backspace, delete, or clear). If multiple selection options are presented, the RNP equipment should clearly distinguish between those which are applicable to the current operating state of the aircraft and those that are not (e.g., the selection of takeoff flap settings will not be displayed on an Approach page format).

If the RNP equipment uses data entry spaces to indicate the number of characters that can be entered into a data field, the RNP equipment should provide the maximum number of data entry spaces that can be entered (e.g., a mandatory data entry field that accepts up to 5 characters must not display only 4 available data entry spaces).

F.2.2.3 Fonts and Highlighting

The flight crew interface specification should establish consistent use of fonts (type and size) and highlighting.

Font may implicitly convey additional meaning (e.g., a large font may reflect that a manual data entry has been made). The RNP equipment should use fonts consistently on all pages such that the meaning of information is preserved.

Highlighting (e.g., reverse video, shadows, brightness, or color) can be used to bring attention to a field or to convey that an action is required. For example, highlighting may indicate an active mode or that flight crew data entry is expected. If highlighting is used, the RNP equipment should use the same highlighting scheme across all pages.

F.2.2.4 Color

If the RNP equipment makes use of color, the flight crew interface guidelines should establish a consistent use of color throughout the display(s) that is in line with accepted practices and standards (e.g., AC 25-11B, Electronic Flight Displays).

No more than six colors should be used for color-coding on the display.

Note 1: This restriction on the number of colors may not apply to information shared with the Electronic Map Display such as terrain and weather.

The RNP equipment should only use the color red for actions requiring immediate flight crew awareness and immediate flight crew response.

The RNP equipment should only use the colors amber or yellow for actions requiring immediate flight crew awareness and subsequent flight crew response.

Note 2: Consistent use and standardization for red, amber, and yellow is required to retain the effectiveness of flight crew alerts. It is important that the flight crew does not become desensitized to the meaning and importance of color coding for alerts, which could increase the flight crew's processing time, add to their workload, and increase the potential for flight crew confusion or errors.

Note 3: It is recognized that some existing implementations have used red, amber, and yellow on graphical displays to communicate levels of flight crew awareness required for the respective event or condition. Although this approach could be generalized to the same intent as an alert, it is essential that the RNP equipment conform to the use of red as requiring immediate flight crew action and amber/yellow requiring immediate awareness and potential future action.

Colors should be discernable throughout the declared viewing envelope under day and night (full range of operational light) conditions. Yellow and white may be indistinguishable in some conditions when used to code text or small symbols.

Pure (e.g., "royal") blue should be avoided for text, small symbols, other fine detail, or as a background color. Blue should be avoided because it is difficult for the human eye to bring blue symbols into focus and to distinguish the color from yellow when the symbols are small.

Note 4: The following color pairs/combinations should also be avoided:

- *Saturated red and green,*
- *Saturated blue and green,*
- *Saturated yellow and green,*
- *Yellow on purple,*
- *Yellow on green,*
- *Yellow on white,*
- *Magenta on green,*
- *Magenta on black (although this may be acceptable for lower criticality items),*
- *Green on white,*
- *Blue on black, and*
- *Red on black.*

Color-coded information should be accompanied by another distinguishing characteristic such as shape, location, or text.

F.2.2.5 RNP Equipment Alerts and Messages

The RNP flight crew interface guidelines should establish consistent use of RNP equipment alerts and advisory/status messages. The RNP equipment should establish the display priority of alerts and advisory/status messages that provide information to the crew. Alerts requiring flight crew awareness or action should be given the highest priority for display.

The RNP equipment message nomenclature should be easily understood by the flight crew. The RNP equipment should display the entire text of the message within the available space on a single display page.

Note: The above recommendation may not apply to self-formatting external systems such as datalink or surveillance systems, where messages may extend beyond a single display page.

For a single event/failure, the RNP equipment should provide only one message with the key information for flightcrew action.

The RNP equipment should alert the flight crew that an action is required when the equipment detects a state having more than one operational choice that may be in conflict (e.g. manual entry of a waypoint altitude constraint that would result in a climb during descent).

F.3 Readability

The RNP equipment controls and displays should be readable throughout the declared viewing envelope under day and night (full range of operational light) conditions.

The RNP equipment manufacturer should determine the limiting lateral and vertical viewing angles (off axis) that ensure readability for those displays that are part of the RNP equipment. The RNP equipment manufacturer should document the angle limitations in the installation instructions for the equipment.

Note 1: In the above requirements, readability refers to the ability to distinguish a character and its color or the shape and color of a symbol/icon.

Note 2: The RNP equipment designer should take into consideration the lateral viewing angle required for cross-cockpit viewing of the displays.

The RNP equipment controls and displays should have the capability to manually control the luminance.

Note 3: An automated luminance function may be implemented but that does not relieve the requirement for a manual control capability.

The RNP equipment controls should be designed to facilitate nighttime usability (i.e., illuminated).

Note 4: Control illumination may be achieved by either illuminating the control itself or providing flight deck (external) illumination. This will need to be evaluated on an installation specific basis.

F.4 Crew Workload Considerations

The RNP equipment should be designed to maximize operational suitability and minimize pilot workload. Reliance on pilot memory for operational procedures should be minimized.

Workload can be defined as the relationship between the physical and/or mental demand needed to perform a task and the pilot’s capacity to perform that task relative to other tasks on the flight deck. Workload can be thought of as a U-shaped curve, such that workload that is too high or too low can negatively impact pilot performance.

Workload is dependent on task complexity and may be increased by steps or actions that rely on pilot memory for sequencing the actions. Workload can be measured objectively by evaluating task performance (e.g., the number of errors made, the consequences of the error, the error recovery time) or gathering physiological measures. Note that workload cannot be completely measured by the number of keystrokes or pilot actions required for a specific task and focusing on these variables alone can lead to false conclusions. There are also subjective measures of workload that have been found to be effective in measuring pilot workload, such as questionnaires, that may be used.

Page flow should be ordered to support the steps to be accomplished. Establishing consistent page sequencing or leading the pilot through page sequences with cues can further reduce workload (e.g., implement shortcut prompts for commonly used pages/functions to bypass menu pages).

Note: Manufacturers should consider the need for flexibility in sequencing of flight crew actions to allow adaptation to different flight deck philosophies.

F.5 Validating Operational Suitability

Evaluations of operational suitability include an assessment of crew workload. There are established methods for doing such evaluations.

It is recommended that evaluations be done in a reasonably representative operational environment using a flight simulator and operationally relevant scenarios.

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APPENDIX G CNS-ATM SYSTEM CONSIDERATIONS

The development of aircraft systems for CNS-ATM operations has resulted in the need to extend the navigation system capability to support an expanded CNS-ATM feature set. What follows are some considerations for CNS-ATM operations that the RNP equipment installation may need to support.

When establishing air traffic route spacing and aircraft separation minima, in addition to the navigation element, one also must consider the supporting airspace infrastructure, including surveillance and communications (CNS). Additionally, the parameters of Air Traffic Management (ATM), such as intervention capability, capacity, airspace structure, and occupancy or passing frequency (exposure) must be evaluated. A general methodology for determining separation minima has been developed by the ICAO (see Document 9689). The general methodology is to conduct an operational safety assessment that considers all CNS/ATM elements.

Note: See RTCA DO-264 for a description of the OSA and an example of a specific element (Communications). Separation minima associated with a given RNP may therefore vary, dependent upon other factors considered during the operational safety analysis.

G.1 CNS-ATM Functions using ARINC 622

G.1.1 Air Traffic Control Data Link

The navigation system may require the capability to support downlink requests to ATC for route changes, lateral offset, and speed and vertical clearances. Its features should support the receipt and display of corresponding clearances, plus crossing constraints, transfer of control and frequency change messages. The system should support the processing of pre-departure clearances, lateral route clearances and offset clearances, contained in uplink messages, for flight plan modification. This is also known as Controller Pilot Data Link Communications (CPDLC).

The system should support the capability for receipt and display of uplink requests for report or confirmation.

The system should solicit an appropriate flight crew decision for each uplink message as appropriate.

The system should support the capability to store and access uplink and downlink messages. Stored messages will be tagged with time of receipt/sending and type of response, if any. The system should support the capability for storing a minimum of 5 uplink and 5 downlink messages.

The system should provide appropriate annunciations and alerts for the uplink messages.

G.1.2 Surveillance

G.1.2.1 ADS-A

The navigation system should support the capability for ADS-A functionality for position/intent broadcast including periodic reporting, event reporting and on-demand reporting, where the type and content of a given report is defined by the uplink message. The system should support a periodic contract, an event contract, and on-demand requests for each of up to four ATC facilities and for one airline center. The capability for flight crew disabling of the function should be provided.

G.1.2.2 ADS-B

The navigation system should support the capability for ADS-B functionality for the broadcast of aircraft state and trajectory intent information. The specific data formats will follow the conventions and criteria set forth by ARINC 429 and ARINC 702A.

The aircraft state data should include flight identification, a time stamp, barometric altitude, PVT, and trend data. Trajectory intent status data should be included for output based on determination if the aircraft is following its defined flight path. Selected altitude should be included as to support determination of tactical intervention of the vertical trajectory. Total system error should be provided as a measure of current containment integrity.

In addition to the aircraft state data defined above, the system should provide data for active and modified flight path trajectory intent. The data should consist of a string of four-dimensional points that describe the predicted trajectory of the aircraft along with the point type and turn radius associated with the flight path transition. This data should be updated under the following events:

a. Whenever an active flight plan change occurs

b. When a lateral fix is sequenced

c. Whenever there has been a significant change to the predicted trajectory caused by tactical operations or unforecast environmental conditions

d. When a defined period has elapsed (on the order of one minute) since the last transmission

A modified flight plan will be transmitted only by pilot command.

> *Note: In some line operations it is not uncommon for pilots to modify an active flight plan as a tactical move. During this time, back-up means of navigation are used. This process would affect items a, b and c, as well as the statement concerning pilot transmission of modified flight plans. Considerations must be given to how this will affect data overload, misinformation, etc., in Air Traffic operations.*

G.1.2.3 Enhanced Surveillance

The navigation system should support the capability for the broadcast of the aircraft state and trajectory intent information consistent with EASA CS ACNS sub-part D

G.1.3 ATS Facilities Notification

The system should support a means of notifying ATC that the aircraft is ready for data link communications. The capability will include initiation manually by the flight crew and automatically by uplink. The system should support the capability to exchange data link application names, versions and addresses.

G.2 CNS-ATM Functions using ACARS

The system should support CNS-ATM functions that are character encoded and transmitted over ACARS as specified in ARINC 623. The functions that may be included are:

- Predeparture Clearance (PDC)
- Oceanic Clearance Message (OCM)
- Automatic Terminal Information Service (ATIS)

G.3 Aeronautical Telecommunications Network (ATN)

The system should support CNS-ATM functions that are defined in the ICAO CNS/ATM-1 Standards and Recommended Practices (SARPS), including:

- Data Link Initiation of Communications (DLIC)
- CPDLC
- ADS
- Flight Information Services (FIS)

G.4 Global Navigation Satellite Systems

The system should support the capability to include GNSS data as one input into the systems navigation solution.

Note: While it is intended that RNP forms the basis for airspace design and operation, it is also recognized that it may not realize benefits to some segments of the aircraft population. These segments may rely on navigation systems that are less capable, providing a degree of navigation capability but will be primarily a GNSS based area navigator. In order to maximize the utility for all, it is expected that the airspace and procedures will converge to common standard. However, until that occurs, a systems integrator may need to consider implementations for RNP that fit the broadest applications.

G.5 Printer Interface

The system may need to support an interface with a printer to allow printing of log messages and certain portions of messages not displayed on cockpit displays. This may be viewed as a flight crew convenience feature since the printer is non-essential to the conduct of CNS-ATM operations.

G.6 Displays and Alerts

The need for clear and unambiguous situational awareness for the integration of the CNS-ATM features along with the basic features and displays for the navigation system may warrant consideration for any new capabilities that support navigation displays.

G.7 Interval Management Operations

Interval Management (IM) is a future CNS-ATM operation leveraging flight-deck tools to provide speed commands to the flight crew and aircraft to achieve and/or maintain a relative spacing interval from another aircraft designated by ATC (referred to as Designated Traffic).

The committee acknowledges that the concept of operations and requirements for IM are in development as of the date of publication of this MOPS. The committee recognizes that the final IM concept of operations may impact the design of future RNP equipment. The committee's intent in establishing this Appendix is to communicate information about the IM concept in development. The following considerations for IM operations are presented for planning and information only, based on present knowledge of the concept. The committee also acknowledges that the DO-236C MASPS will need to be updated with IM requirements first before this Appendix can be considered finalized.

G.7.1 Loading IM Clearance Information from ATN

The ATM system may provide the flight crew and aircraft the IM Clearance Information necessary to execute an IM Operation by voice or through the aircraft's participation in the ATM system (i.e., through datalink communications, as applicable).

G.7.2 Information to Enable IM

To enable the IM operation, the RNP equipment may need to provide the following information to enable IM as part of a data exchange:

- Information about the aircraft's 4D trajectory (e.g., turn centers and radii; predicted altitudes and speeds at waypoints; and trajectory-change points, such as top of descent, bottom of descent, and Mach/CAS transition altitude);
- Estimated Times of Arrival (ETAs) at downstream waypoints;
- Active waypoint from the aircraft's active flight plan;
- The RNP equipment's predicted wind speeds and directions;
- The aircraft's planned Final Approach Airspeed.

APPENDIX H TEMPERATURE COMPENSATION

H.1 Introduction

RNP equipment that provides the means to correct for the effects of temperature on the barometric altitude shall meet the requirements of this appendix.

> *Note: For additional information on temperature compensation, associated installation and operational issues, and other considerations, see RTCA/DO-236C Appendix H and ED-75D Appendix H.*

H.1.1 Background

The barometric altimeter indication is influenced by temperature variations. During cold temperature operations (below ISA), the airplane's true altitude is lower than the indicated altitude. Similarly, during hot temperature operations (above ISA), the airplane's true altitude is higher than the indicated altitude. This results in an aircraft flying a vertical path angle shallower than (or steeper than for hot temperature) the designed vertical path angle (or gradient) without an indication in the flight deck (Figure H-1). Temperature compensation corrects the vertical approach path to the one intended by the procedure designer. When the aircraft flies the compensated altitudes, the aircraft is actually flying the published approach as designed. However, the indicated altitude will be different than the charted value.

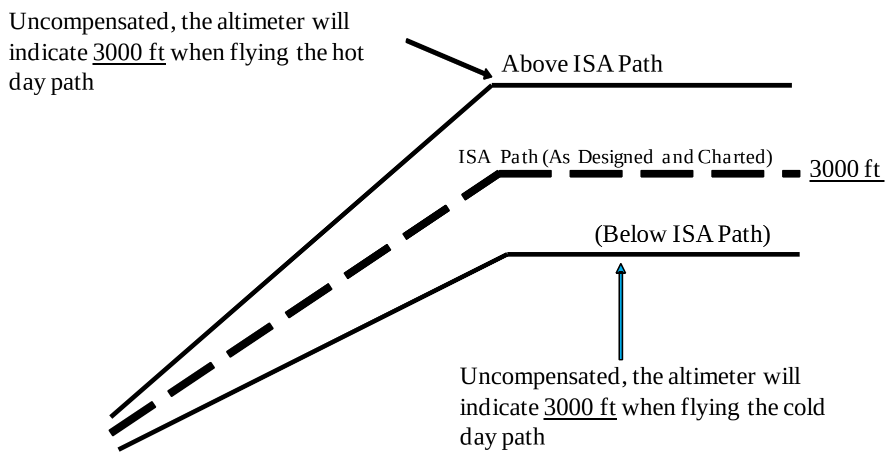


Figure H-1: Temperature Effects on Altimetry

Without the application of temperature compensation, in below-ISA conditions (cold temperatures) the aircraft's true altitude is always below the procedure design's charted barometric altitudes. When this occurs the aircraft will follow a lower angle path with reduced obstacle clearance margin such that, in some circumstances, terrain and obstacle clearance may not be assured.

Likewise, for above-ISA conditions (hot temperatures), particularly at higher elevation airports, the aircraft will follow a much steeper baro-VNAV final approach path angle than the procedure design intended. These steeper angles can sometimes exceed the flight path angle capability of an aircraft's design and create an unstable final approach with excessive descent rates. Meanwhile, operations at high density altitudes (above ISA temperatures and higher elevation airports) may require the use of alternate aircraft configurations (i.e.

flap settings) with associated higher minimum maneuvering airspeeds, creating additional difficulties.

H.2 System Performance

H.2.1 Relationship between Temperature and Vertical Path Performance

The RNP equipment derives the final approach vertical path performance through reference to vertical total system error, which includes PDE, PSE, ASE and HCE (reference Appendix P). Temperature compensation then corrects for the bias in the barometric altimetry system indications caused by deviations from ISA at the aerodrome's field elevation.

H.2.2 Path Definition

H.2.2.1 Path Definition Accuracy

The RNP equipment shall use a flight crew-entered temperature and standard temperature lapse rate to compute altitude and flight path angle corrections for the temperature compensation function. The RNP equipment should use the accurate method (reference H.2.4). Alternate methods shall result in altitude corrections within 10% tolerance of a solution generated from the accurate method.

A waypoint altitude correction that results from a flight path angle correction shall be within 10% tolerance of a solution generated from the accurate method.

Any amount by which the altitude correction exceeds the allowable tolerance from that of the accurate method shall be accounted for in vertical path definition error (PDE_Z) as a bias term.

> *Note: The use of non-standard lapse rates based on current air temperature, as provided by an air data computer during the procedure, and a reported field temperature, while not precluded, is not a minimum requirement. The added complexities of addressing non-standard lapse rates and temperature inversions dynamically while on the flight path are not expected to give significant benefit, as variations in path angle will not be significant in affecting the stabilized path of the aircraft. Effects from temperature inversions are not deemed an issue since the warmer temperature resulting from the inversion would result in the aircraft being higher than what is accounted for by the standard lapse rate correction. Temperature effects diminish as the aircraft approaches the airport elevation.*

H.2.2.2 Temperature Compensation to Defined Path

When temperature compensation capability is provided in the RNP equipment, corrections shall be applied to the altitudes and flight path angles contained in any approach procedure selected from the navigation database (Figure H-2**)** from the initial approach fix (IAF) through the missed approach procedure including the missed approach holding point (MAHP), and including altitude-terminated legs in the missed approach segment.

> *Note 1: This does not exclude the capability to temperature compensate altitudes that are not part of an approach procedure.*

For all approach types (including SBAS, GLS, ILS, MLS) temperature compensation shall be applied to all segments where vertical guidance is dependent on barometric altimetry, including the FAF altitude.

Note 2: Only the vertical path of the final approach segment of an SBAS, GLS, ILS or MLS approach is independent of temperature; however the FAF altitude must be compensated in order to provide a smooth transition from the barometric path to the final approach geometric path.

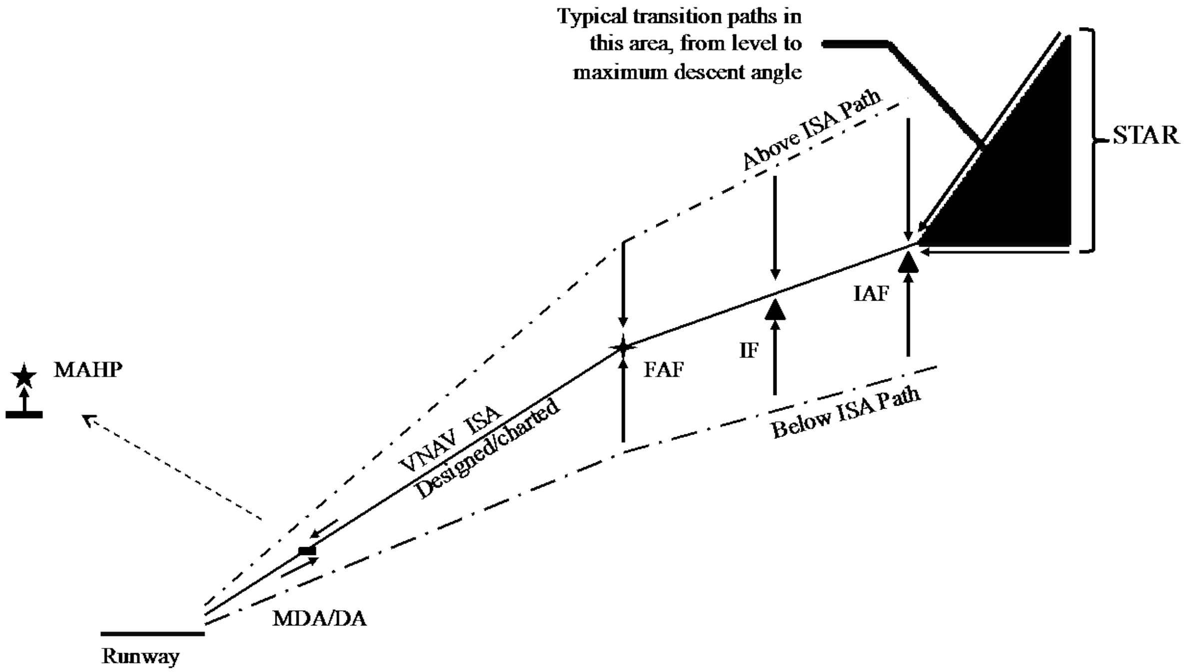


Figure H-2: General Example of Temperature Compensation

The RNP equipment shall provide a means for the flight crew to enable/disable the temperature compensation function**.**

Note 3: As an example, not entering destination airport temperature is an acceptable means of disabling the temperature compensation function.

The RNP equipment shall provide a means for flight crew entry of temperature and the review, prior to their acceptance, of the resulting altitude corrections from temperature compensation.

Where it is necessary to remove the effect of temperature compensation on the altitude of an individual waypoint of an approach procedure, an acceptable means would be the manual entry of the original uncompensated altitude.

Note 4: This situation may arise as a result of an ATC clearance. An annunciation should be generated (reference Section H.2.5) for crew action to resolve any altitude conflict caused by the removal of temperature compensation from the altitude of an individual waypoint.

The RNP equipment shall provide for the entry and display of temperature to a resolution of at least 1 degree (reference Table 2-10).

Note 5: In the above requirement, temperature refers to both absolute temperature and ISA deviations, as applicable.

All types of database-defined altitude constraints (AT, AT or ABOVE, AT or BELOW, WINDOW) shall be compensated for temperature.

Altitudes that are manually entered into a procedure by the flight crew shall not be compensated for temperature with the exception of the MDA/DA.

Note 6: ATC does not expect a flight crew to temperature compensate an ATC-assigned altitude. For this reason, the RNP equipment should not apply temperature compensation to altitudes that have been manually entered by the flight crew.

Note 7: If the RNP equipment provides functionality related to aircraft-specific altitudes, such as thrust reduction or acceleration heights/altitudes, these heights/altitudes may also be candidates for temperature compensation.

H.2.2.2.1 Transition Level Considerations

If the temperature-compensated altitude of a waypoint altitude constraint is above the transition level (Figure H-3), the RNP equipment shall provide an indication to the flight crew that the situation has been detected. The indication shall be provided in a sufficiently timely fashion that the crew can take action to resolve the situation.

Note 1: This situation may occur in regions of the world where the transition level is below FL180.

Note 2: Since temperature compensation is to be applied to all approach procedure waypoint altitudes, the above requirement applies regardless of whether the waypoint altitude constraint is above or below the transition level prior to temperature compensation.

Note 3: Complex operational situations can arise involving temperature compensation that may be inappropriate for the RNP equipment to handle automatically. Since the crew has direct control over the activation of the temperature compensation function, they are best-equipped to determine when to do so.

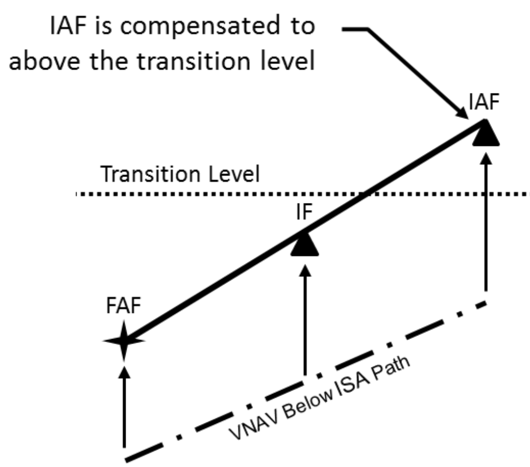


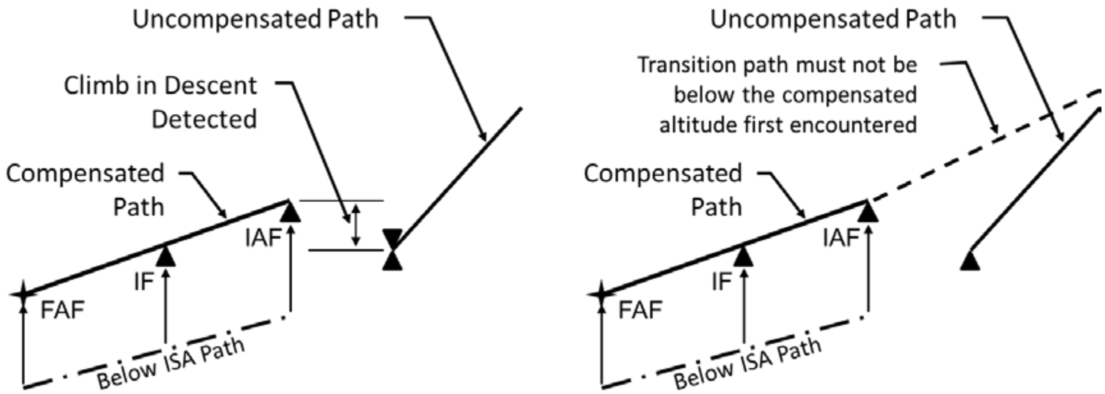
Figure H-3: Transition Level Considerations

H.2.2.2.2 Vertical Path Transitions

When temperature compensation adjusts the vertical path, the RNP equipment shall ensure the path construction precludes the insertion of a climb path segment in a descent path. This will typically apply when transitioning from a path segment based upon uncompensated fix altitudes to a path segment whose altitudes have been compensated for temperature. Examples of typical situations where an altitude conflict may occur involving transitions from uncompensated to compensated descent paths in below-ISA and above-ISA conditions are shown in Figure H-4 and Figure H-5 respectively for constrained and unconstrained uncompensated descent paths.

Note 1: In above-ISA conditions the equipment designer should also consider providing an appropriate indication to the crew when the situation is detected where the transition path is steeper than normal (ref: Figure H-5).

Note 2: A situation similar to that of H.2.2.2.1 Note 2 can exist during transitions between uncompensated and compensated vertical paths where the RNP equipment should maintain the altitude of the constrained descent path waypoint (ref: Figure H-4(a)) until the compensated descent path is intercepted.



(a) Constrained Descent (b) Unconstrained Descent

Figure H-4: Examples of Vertical Path Transitions From Constrained and Unconstrained Descent Paths (Below-ISA Conditions)

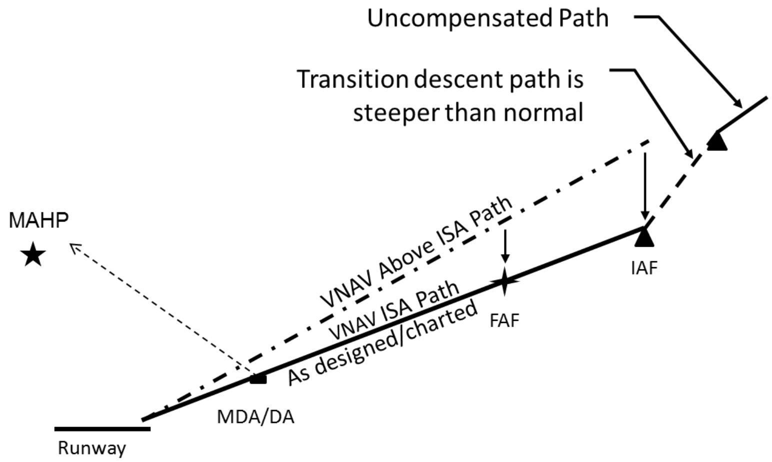


Figure H-5: Vertical Path Transition From Constrained Descent Path (Above-ISA Conditions)

H.2.3 Temperature Compensation to MDA/DA

When the RNP equipment loads the uncompensated MDA/DA from the database or the flight crew enters it, the RNP equipment should provide a means to determine and display the temperature-compensated MDA/DA.

When the RNP equipment computes a temperature compensated altitude for the MDA/DA, the resulting altitude shall be within +/-10% of the value provided by the accurate method (reference Section H.2.4)**.**

Note: Reasonableness checks can mitigate the potential effect of erroneous temperature compensation to the MDA/DA (see section H.2.6).

H.2.4 Accurate Method

The accurate method is not solved directly but must be solved with an iterative solution. Typically the solution converges to 1 foot after four iterations. This method is valid to 36,000 ft (11000 m).

Correction = $\Delta h_{Paircraft} - \Delta h_{Gaircraft} = (-\Delta T_{std}/L_0) * Ln[1 + L_0 * \Delta h_{Paircraft}/(T_0 + L_0 * h_{Paerodrome})]$			
Where:			
$\Delta h_{Paircraft}$	=	Aircraft height above aerodrome (pressure)	ft
$\Delta h_{Gaircraft}$	=	Aircraft height above aerodrome (geopotential)	ft
ΔT_{std}	=	Temperature deviation from the ISA temperature	°K
L_o	=	Standard temperature lapse rate with pressure altitude in the first layer (sea level to tropopause) of the ISA.	°K/ft
T_o	=	Standard temperature at sea level	°K
$h_{Paerodrome}$	=	Aerodrome height (pressure)	ft

Note: Lapse rate (L_o) is defined as a negative number in order to be consistent with the ICAO equations. As an example a lapse rate of 2º K per 1000 ft = -0.002.

H.2.5 Displays and Alerting

The RNP equipment shall clearly differentiate the display of temperature compensated altitudes from uncompensated altitudes. The RNP equipment shall also clearly indicate the altitudes being used to define the path, and shall provide the means to support their display.

Note 1: One acceptable means to meet this requirement is to display both the uncompensated altitude and the compensated altitude to the flight crew, or make the uncompensated altitude readily available to the crew. The flight crew may also benefit from a display of the difference between the uncompensated altitude and the compensated altitude. Meeting this requirement can create clarity between the charted, procedural altitudes or manually entered altitudes (i.e. ATC-assigned altitudes) vs. the temperature compensated altitudes.

If the RNP equipment provides the capability to automatically set the altitude select window on a flight guidance system, and temperature compensation is in use, the compensated altitude shall be displayed in the altitude select window.

If the RNP equipment displays the flight path angle, the displayed angle shall match the angle extracted from the navigation database.

Note 2: The FPA extracted from the navigation database is a geometric angle, and is the FPA the procedure designer intends the aircraft to fly regardless of the temperature. The application of temperature compensation has therefore no impact on the display of that angle.

When temperature compensation results in an altitude conflict (e.g. commanded climb while in descent phase of an instrument approach procedure), the RNP equipment shall provide an annunciation suitable to prompt flight crew action.

If the display of predicted waypoint altitudes is implemented, the predicted altitudes shall be on the temperature compensated path.

H.2.6 Reasonableness Checks

The RNP equipment shall provide a means to check the reasonableness of the temperature entry.

Note 1: The RNP equipment may use air data from other independent systems to support this type of function.

Note 2: The reasonableness check may be a function of the worst case ISA deviations at the altimeter source for the altitudes the RNP equipment corrects. For example, the RNP equipment may assume worst case ISA deviations of ± 50º C. Thus, for a manually entered MDA/DA of 250 feet, the error bound on the compensation would nominally be no greater than ± 53 feet.

H.2.7 System Interface Data and Output Considerations

Since the temperature compensation function of the RNP equipment provides compensation solely for the instrument approach procedure, the temperature entered for this temperature compensation function may not be appropriate for other aircraft functions using temperature.

However, when the RNP equipment enables temperature compensation during an instrument approach procedure, the compensation effects on the flight path angle and altitude constraints may be appropriate for use by other systems as intent information (e.g. ADS-C).

The design requirements for terrain awareness systems (TAWS) account for temperature effects; consequently the application of the RNP equipment's temperature compensation function to the TAWS function may not be appropriate.

H.2.8 Temperature Compensation and QFE

QFE operations are not addressed by this MOPS. However, if the RNP equipment supports both temperature compensation and QFE operations, the requirements of this Appendix shall also apply to QFE operations.

Note: QFE is the barometric altimeter setting that will cause the aircraft's altimeter to read the height above a specific airport or ground level, and therefore read zero on landing. QNH is the barometric altimeter setting that will cause the aircraft's altimeter to read altitude above mean sea level within a certain defined region. With respect to temperature compensation, the only difference between instrument approach operations using QNH altimeter setting and QFE operations is the altimeter reference setting. Similar to QNH, QFE operations base minimum IFR altitudes on terrain and obstacle clearance. Thus, QFE operations encounter the same effects from ISA deviations and will encounter the same effects on an RNP equipment's use of barometric altitude. As a result, aircraft conducting QFE operations can benefit from the RNP equipment's application of temperature compensation.

H.3 Temperature Compensation Test Requirements

This section defines the test procedures required to substantiate the minimum operational performance required for the temperature compensation function of the RNP equipment.

The general test requirements of Sections 2.4.2.1 and 2.4.3.1 shall apply as appropriate.

The development of test scenarios for the demonstration of temperature compensation functionality and performance is left to the equipment designer.

H.3.1 Test Cross Reference

Table H-1 provides a cross reference between the requirements of Section H.2 and the tests contained in this section. The compliance method is indicated as follows:

A Analysis of equipment performance

D Demonstration of functional capability, including display characteristics, in static or dynamic environment. No numeric results.

I Inspection of equipment hardware, specifications or design drawings. Dynamic operation of the equipment is not usually required

T Physical test in static or dynamic environment, with numeric results.

n/a No test required

Where more than one compliance method is shown, the specific methods to be used are suggested for the individual requirements in the referenced paragraph.

Table H-1: Temperature Compensation Test Cross Reference

Requirement Paragraph	Subject	Compliance Method	Test Paragraph(s)
H.2.2.1	Path Definition Accuracy	T	H.3.3
H.2.2.2	Temperature Compensation to Defined Path	D	H.3.4
H.2.2.2.1	Transition Level Considerations	D	H.3.4
H.2.2.2.2	Vertical Path Transitions	D	H.3.4
H.2.3	Temperature Compensation to MDA/DA	D, T	H.3.3, H.3.4
H.2.4	Accurate Method	T	H.3.3
H.2.5	Displays and Alerting	D	H.3.4
H.2.6	Reasonableness Checks	D	H.3.4
H.2.7	System Interface Data and Output Considerations	I	n/a
H.2.8	Temperature Compensation and QFE	D, T	H.3.3, H.3.4

H.3.2 Test Setup and Scenario(s)

The bench test setup for the evaluation of the temperature compensation function is left to the RNP equipment designer.

The equipment designer shall develop flight plan(s) suitable for testing the temperature compensation functionality and performance of this appendix. In lieu of generating new flight scenarios, the equipment designer may wish to use existing flight plans developed to meet the other test requirements of this standard or may use suitable published procedures.

The flight plan(s) shall comprise a typical lateral and vertical profile for a terminal arrival procedure and instrument approach procedure. The missed approach segment should be followed by a number of additional waypoints representing either the initial waypoints of departure procedure to an alternate airport, or the return to the current airport to conduct another approach.

The flight plan(s) shall contain at least one example of each of the following altitude constraint types:

a) AT or BELOW
b) AT
c) AT or ABOVE
d) WINDOW

At least one approach procedure shall include both an intermediate fix (IF) and an initial approach fix (IAF). In addition, the missed approach segment shall include an altitude-terminated leg.

H.3.3 Path Definition Accuracy

The flight plan scenario(s) of Section H.3.2 shall enable the evaluation of the computed altitude corrections for the combinations of airport elevation, height above the airport and reported airport temperature (Taero column) in Table H-2 below. A minimum of ten (10) test conditions shall be selected from Table H-2, covering the full range of altitude correction values including the extremes.

For each selected test condition, verify by test that the altitude correction is within +/-10% of the value shown in Table H-2 for that condition.

> *Note: A negative correction implies that the compensated altitude is lower than the uncompensated altitude.*

H.3.4 Verification by Demonstration

Where compliance by demonstration (D) is indicated in Table H-1, each of the identified functional requirements shall be demonstrated.

Table H-2: Altitude Correction Values

Taero	Airport Elevation Above Sea Level (feet)																	
	Sea Level						5,000						15,000					
	ΔISA	Height Above Airport (feet)					ΔISA	Height Above Airport (feet)					ΔISA	Height Above Airport (feet)				
		250	1,500	2,500	5,000	10,000		250	1,500	2,500	5,000	10,000		250	1,500	2,500	5,000	10,000
40	25	-20	-120	-201	-405	-822	34.9	-28	-168	-281	-565	-1147	54.7	-44	-263	-440	-885	-1,794
25	10	-8	-51	-85	-170	-347	19.9	-17	-101	-168	-339	-689	39.7	-33	-201	-335	-676	1,371
15	0	0	0	0	0	0	9.9	-9	-52	-87	-175	-355	29.7	-26	-155	-260	-523	1,064
0	-15	14	83	139	280	571	-0.1	5	28	47	95	194	14.7	-13	-81	-136	-274	-557
-15	-30	29	175	294	594	1,215	-20.1	19	118	197	398	813	-0.3	0	2	3	6	12
-30	-45	46	279	468	948	1,947	-35.1	36	218	365	739	1,516	-15.3	16	95	159	322	658
-45	-60	66	398	667	1,352	2,787	-50.1	55	332	556	739	2,322	-30.3	33	201	336	681	1,398
-60	-75	n/a	n/a	n/a	n/a	n/a	-65.1	n/a	n/a	n/a	n/a	n/a	-45.3	53	321	539	1094	2,256

Note: The values in the above table are generated from the accurate method equation in section H.2.4.

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APPENDIX I

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APPENDIX J HOLDING PATTERN ENTRY EXAMPLE

J.1 Introduction

Conventional holding pattern entry procedures are based on overflying the station or fix upon which the holding pattern is based. A consequence is the need for additional protection for entry procedures, particularly on the non-holding side of the holding pattern. With the advent of more capable RNAV systems, it is no longer necessary to overfly the station or holding waypoint and less space consuming holding patterns can be developed.

J.2 Entry Procedures

There is no required entry pattern, however the entry procedures described below can be considered as acceptable. These examples of entry procedures satisfy the characteristic that the flight plan leg preceding the hold fix is maintained until the aircraft is within the holding area.

J.2.1 Entry Sectors

The holding pattern is composed of two half circles and two straight segments as shown in Figure J-1. The example shown includes the requirement that, for entry, the inbound leg length is greater than or equal to the width of the holding pattern. Using the center of the two half circles, complete C1 and C2. The center of C1 is located on a line perpendicular to the inbound holding course and passing through the holding waypoint (point A in Figure J-1). The straight segments are drawn tangent to the two circles. Entry sectors are constructed by drawing a line making an angle of 70° with the inbound leg passing through the holding waypoint. The holding pattern is now divided into four sectors labeled 1, 2, 3 and 4 in Figure J-1.

J.2.2 Sector 1 Entry

Turn along the arc of the circle centered on the line between the centers (line BC in Figure 2), to intercept the reverse of the inbound course of the holding pattern. Intercept and follow circle C2 until reaching the tangent between C2 and C1. Intercept and follow circle C1 until reaching the holding waypoint (point A in Figure J-2).

J.2.3 Sector 2 Entry

After overflying the holding waypoint (point A in Figure J-3), tangentially intercept circle C2. Follow C2 until intercepting the inbound holding course.

J.2.4 Sector 3 Entry

Overfly the holding waypoint and continue on the same course as was used to approach the holding waypoint. Intercept C1 or a circle centered on the line between the centers of C1 and C2. Follow this circle until intercepting the outbound straight segment. (see Figure J-4).

J.2.5 Sector 4 Entry

Continue on the course flown to the holding waypoint. Tangentially intercept a circle centered on the extended line between the centers of C1 and C2. Follow this circle until intercepting the outbound straight segment. (see Figure J-5).

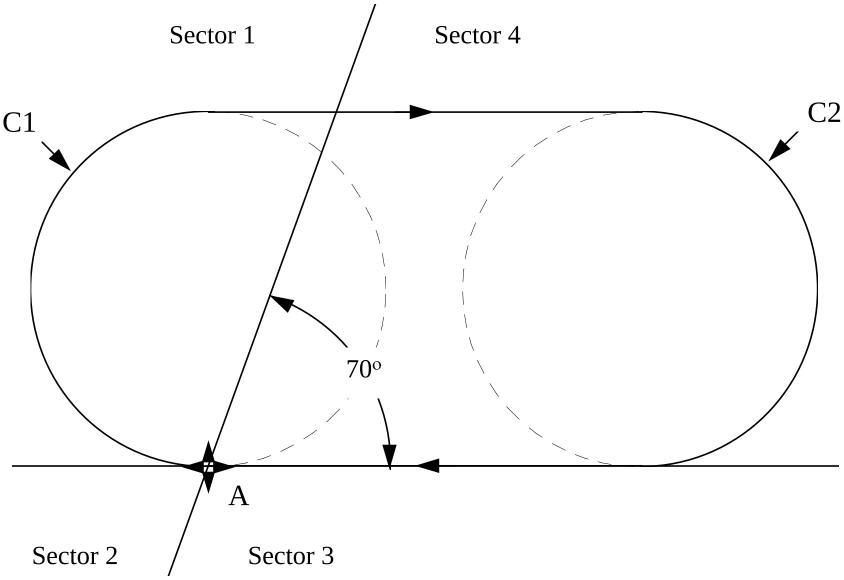

Figure J-1: Holding Entry Sectors

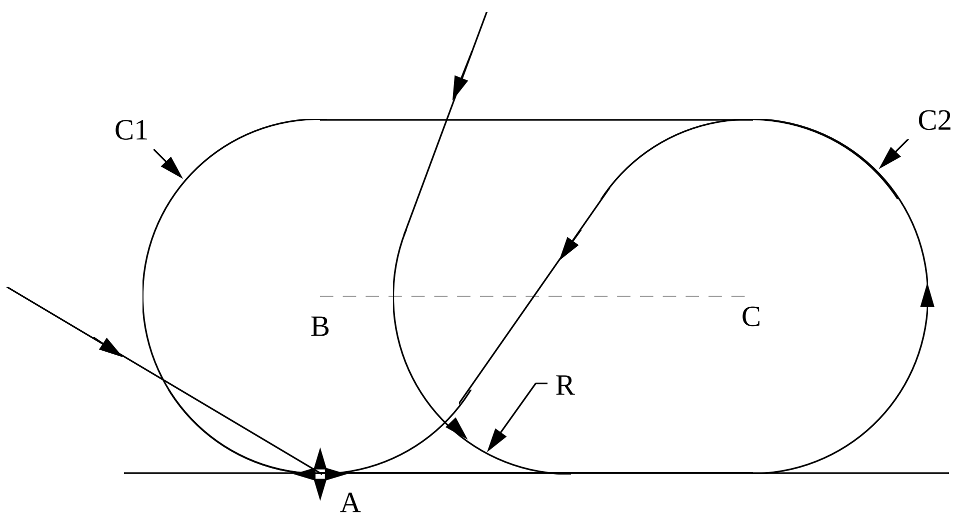

Figure J-2: Sector 1 Entry Procedure

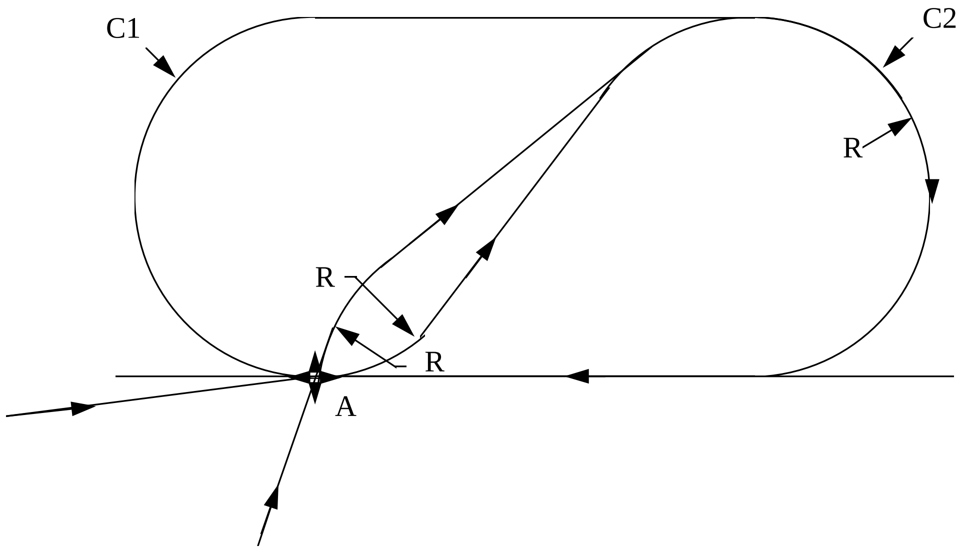

Figure J-3: Sector 2 Entry Procedure

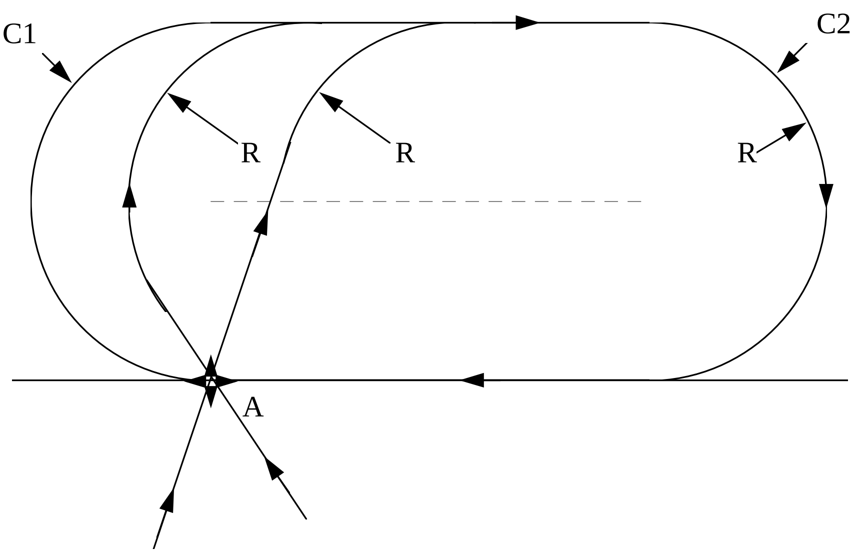

Figure J-4: Sector 3 Entry Procedure

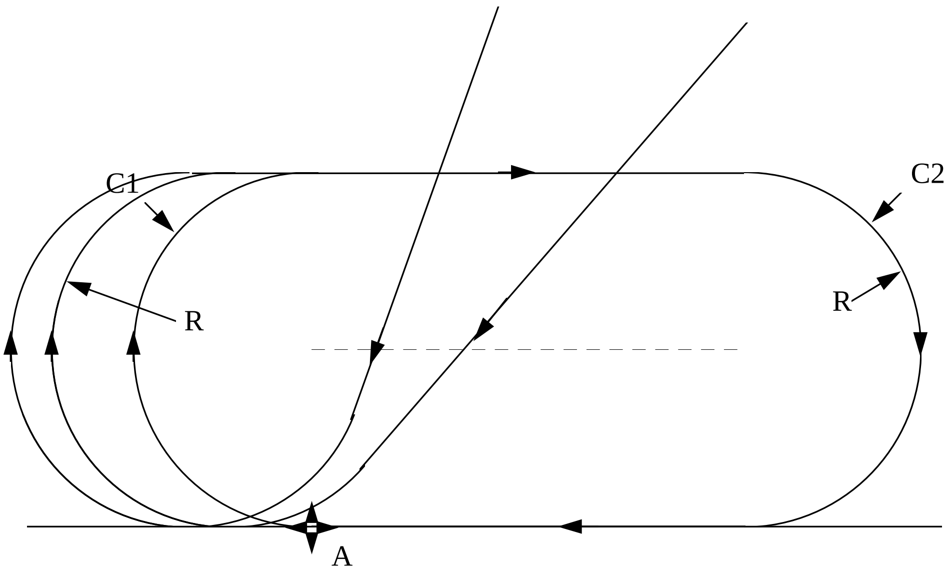

Figure J-5: Sector 4 Entry Procedure

APPENDIX K

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APPENDIX L RF LEG SCENARIOS

L.1 Introduction

This appendix provides templates that may be used as an acceptable method to demonstrate, by dynamic bench test, the capability of the RNP equipment to enable the conduct of procedures containing RF legs. The templates depict the various RF legs that procedure designers might use when constructing actual initial, intermediate, or missed approach segments for RNAV (GPS) or RNAV (RNP) approaches along with SIDs and STARs.

Note 1: The intent of these RF Leg tests is to demonstrate the capability of the RNP equipment lateral navigation function only.

Note 2: The vertical information included in the approach scenarios is intended for information purposes only and to facilitate building the example procedure. The vertical error budget (VEB) is a means of performance based design using data and error source information as a basis. Originally it was used to establish obstacle clearance criteria for VNAV procedure design then was enhanced for use in RNP AR applications.

The bench test procedures to be created by the equipment designer need to include the depicted RF leg types shown in section L.2 and it is acceptable for the individual RF legs depicted in the figures to be linked using straight segments to create “mega procedures” for demonstrating RNP equipment capability. However, the reflex curve legs (‘S’ turns) and decreasing radius turns must not have a straight segment between the path terminators (see Figure L-1 for an example). The tests are intended to demonstrate that the RNP equipment is capable of providing the required guidance in the various types of turns including turns of minimum radius.

Note 3: Figure L-1 is only an example and is not intended as the only possible combination for creating efficient flight profiles.

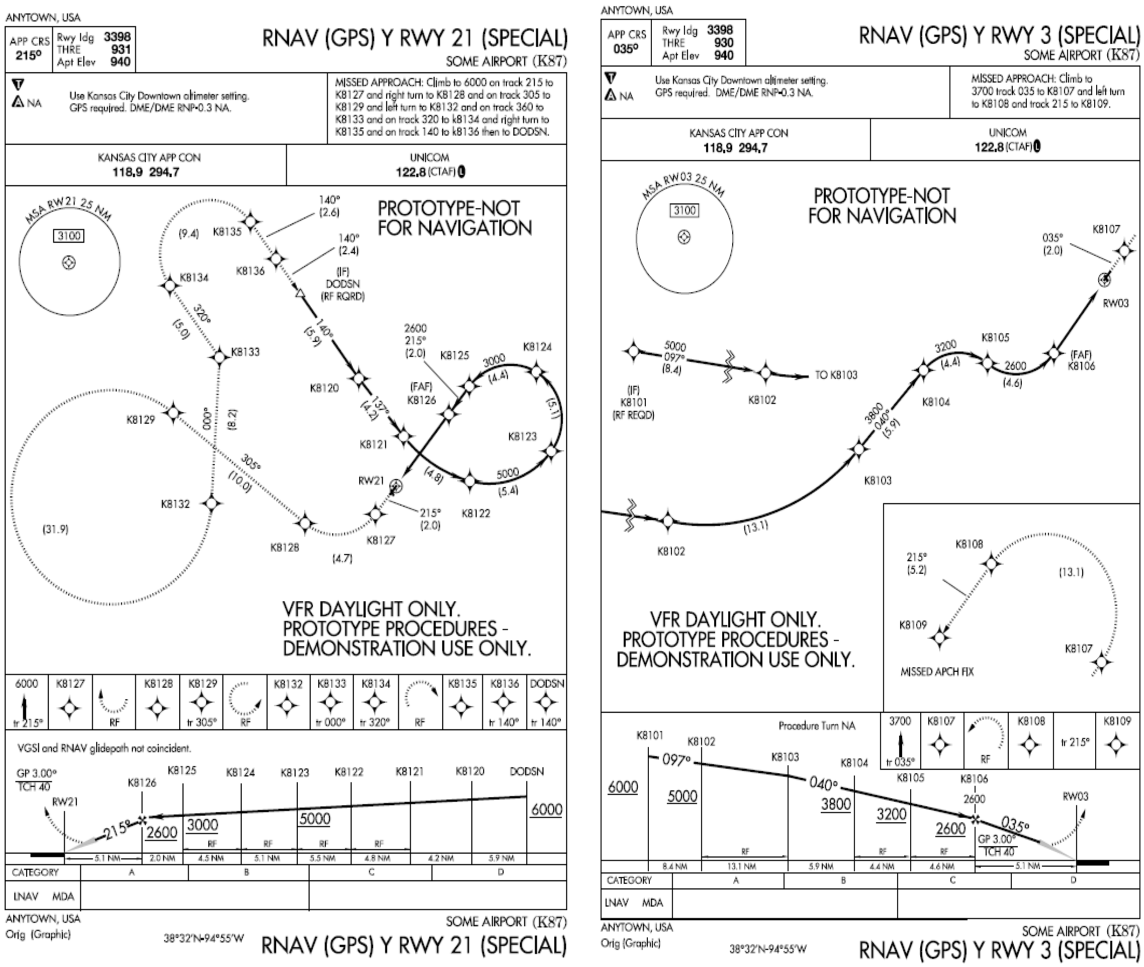

Figure L-1: Example Procedure Profiles

The procedures created from the templates will provide “stressing” situations because some license has been taken with the procedure design criteria. For example, RF legs on RNAV (GPS) approaches currently terminate at least 2 NM prior to the final approach fix, not at the final approach fix (refer to the ‘S’ turn in Figure L-1). Another example is that several RF leg radii were intentionally reduced to approach a 25 degree flight guidance system bank angle limit given the design wind criteria (reference Section L.3) and category C/D aircraft speeds.

The test procedure templates have been designed and located at an airport with an elevation of approximately 1,500 ft MSL. The turn radii have been adjusted so that the required bank angle, given the adverse wind input, would approach the bank angle limitation (25 degrees) noted in the procedure design criteria.

Waypoint information is provided for each test scenario to enable the test scenario to be incorporated into the navigation database.

L.2 Test Procedure Descriptions

L.2.1 Departures

L.2.1.1 Alpha Departure

The "Alpha Departure" shown in Figure L-2 incorporates an RF leg shortly after takeoff followed by a straight climbing segment to a series of two back-to-back RF legs with reducing radii. Waypoint information is shown in Table L-1.

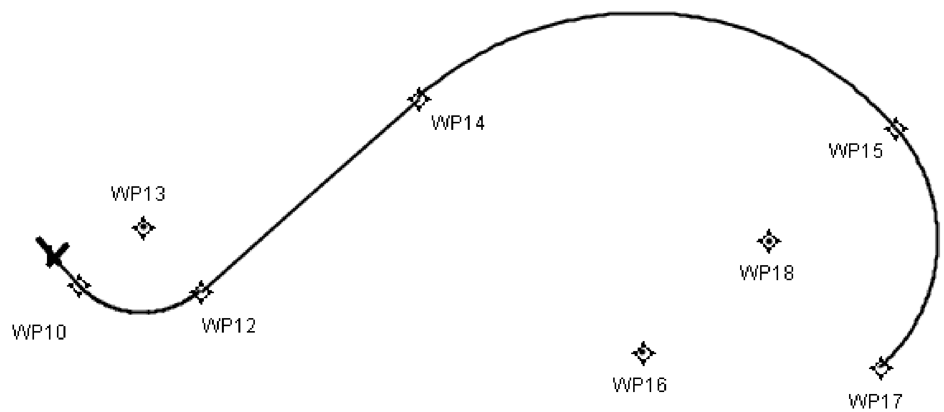

Figure L-2: Alpha Departure

Table L-1: Alpha Departure Waypoints

Runway Transition Data– Northwest1 DEP														
DB	Waypoint	Dist	Leg	FO/FB	Latitude	Longitude	TC	MC	Altitude	Speed	MEA	Arc Center Lat (D° M' S.ss")	Arc Center Lon (D° M' S.ss")	Arc Radius (NM)
NACO -FULL	DER RW13				N38 03 35.48	W097 51 17.61								
	WP10WP	1.00	CF	FB	N38 02 50.65	W097 50 27.06	138.28	132.28	+2043					
	WP12WP	4.71	RF		N38 02 36.01	W097 45 05.27						N38 04 50.54	W097 47 36.91	3.00
	WP14WP	10.03	TF	FB	N38 09 15.81	W097 35 35.10	48.37	42.37		230				
	WP15WP	18.36	RF		N38 08 14.76	W097 14 40.04						N38 00 29.33	W097 25 46.14	11.7
	WP17WP	9.23	RF		N37 59 56.88	W097 15 19.74						N38 04 21.38	W097 20 14.52	5.87

Waypoint Data

DB	Waypoint	Arc Center	Latitude Longitude	Latitude (Deg)	Longitude (Deg)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	WP10WP		380250.65N-0975027.06W	N38.0474016	W97.8408493	N38 02.844	W97 50.451	N38 02 50.65	W097 50 27.06
	WP12WP		380236.01N-0974505.27W	N38.0433368	W97.7514634	N38 02.600	W97 45.088	N38 02 36.01	W097 45 05.27
	WP13WP	Y	380450.54N-0974736.91W	N38.0807058	W97.7935850	N38 04.842	W97 47.615	N38 04 50.54	W097 47 36.91
	WP14WP		380915.81N-0973535.10W	N38.1543916	W97.5930830	N38 09.263	W97 35.585	N38 09 15.81	W097 35 35.10
	WP15WP		380814.76N-0971440.04W	N38.1374327	W97.2444558	N38 08.246	W97 14.667	N38 08 14.76	W097 14 40.04
	WP16WP	Y	380029.33N-0972546.14W	N38.0081485	W97.4294845	N38 00.489	W97 25.769	N38 00 29.33	W097 25 46.14
	WP17WP		375956.88N-0971519.74W	N37.9991334	W97.2554842	N37 59.948	W97 15.329	N37 59 56.88	W097 15 19.74
	WP18WP	Y	380421.38N-0972014.52W	N38.0726064	W97.3373679	N38 04.356	W97 20.242	N38 04 21.38	W097 20 14.52

No FAA checks included.

Database Effective Dates

Database	Date
NFDC	10/20/2011
Jeppesen	N/A
IFP Offline	N/A
AVNIS	12/15/2011
Benefits	N/A
NACO	N/A

L.2.1.2 Bravo Departure

The "Bravo Departure" shown in Figure L-3, consists of an RF leg shortly after takeoff followed by a brief straight segment, then two back-to-back RF legs with a turn direction reversal. The turn radii also vary as the aircraft climbs and increases performance. Waypoint information is shown in Table L-2.

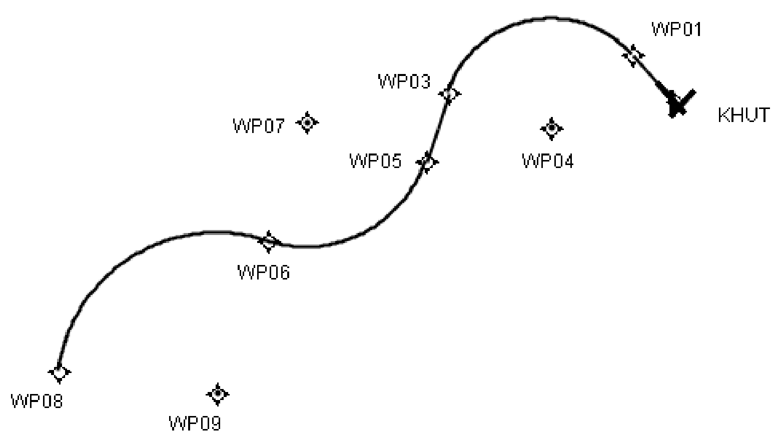

Figure L-3: Bravo Departure

Table L-2: Bravo Departure Waypoints

Runway Transition Data– Southwest1 DEP														
DB	Waypoint	Dist	Leg	FO/FB	Latitude	Longitude	TC	MC	Altitude	Speed	MEA	Arc Center Lat (D° M' S.ss")	Arc Center Lon (D° M' S.ss")	Arc Radius (NM)
NACO -FULL	DER RW13				N38 04 27.15	W097 52 15.90								
	WP01WP	1.00	CF	FB	N38 05 11.97	W097 53 06.49	318.27	312.27	+2043					
	WP03WP	6.40	RF		N38 04 07.23	W097 59 40.21						N38 03 09.74	W097 55 59.72	3.05
	WP05WP	2.00	TF	FB	N38 02 13.13	W097 00 27.73	198.23	192.23						
	WP06WP	5.53	RF		N37 59 58.37	W097 06 05.17				230		N38 03 19.16	W097 04 41.65	3.52
	WP08WP	7.86	RF		N37 59 19.81	W097 13 30.08				250		N37 55 41.30	W097 07 51.90	4.50

Waypoint Data										
DB	Waypoint	Arc Center	Latitude Longitude	Latitude (Deg)	Longitude (Deg)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	WP10WP		380511.97N-0975306.49W	N38.0866586	W97.8851359	N38 05.200	W97 53.108	N38 05 11.97	W097 53 06.49
	WP12WP		380407.23N-0975940.21W	N38.0686757	W97.9945032	N38 04.121	W97 59.670	N38 04 07.23	W097 59 40.21
	WP13WP	Y	380309.74N-0975559.72W	N38.0527067	W97.9332567	N38 03.162	W97 55.995	N38 04 50.54	W097 55 59.72
	WP14WP		380213.13N-0980027.73W	N38.0369801	W98.0077039	N38 02.219	W98 00.462	N38 02 13.13	W098 00 27.73
	WP15WP		375958.37N-0980605.17W	N37.9995476	W98.1014351	N37 59.973	W98 06.086	N37 59 58.37	W098 06 05.17
	WP16WP	Y	380319.16N-0980441.65W	N38.0553211	W98.0782353	N38 03.319	W98 04.694	N38 03 19.16	W098 04 41.65
	WP17WP		375619.81N-0981330.08W	N37.9388359	W98.2250232	N37 56.330	W98 13.501	N37 59 19.81	W098 13 30.08
	WP18WP	Y	375541.30N-0980751.90W	N37.9281393	W98.1310840	N37 55.688	W98 07.865	N37 55 41.30	W098 07 51.90

No FAA checks included.

Database Effective Dates

Database	Date
NFDC	10/20/2011
Jeppesen	N/A
IFP Offline	N/A
AVNIS	12/15/2011
Benefits	N/A
NACO	N/A

L.2.2 Arrivals

As the simulated aircraft descends and decelerates, it follows a path consisting of a series of RF legs with a turn direction reversal after the first. The second directional turn consists of two back-to-back RF legs with decreasing radii. The arrival is shown in Figure L-4 and waypoint information is shown in Table L-3.

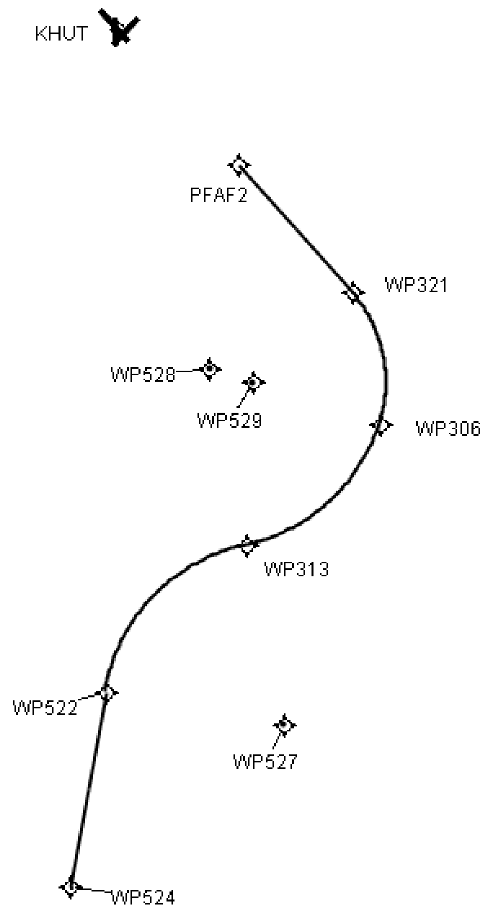

Figure L-4: Arrival

Table L-3: Arrival Waypoints

Runway Transition Data– South RNAV STAR														
DB	Waypoint	Dist	Leg	FO/FB	Latitude	Longitude	TC	MC	Altitude	Speed	MEA	Arc Center Lat (D° M' S.ss")	Arc Center Lon (D° M' S.ss")	Arc Radius (NM)
	WP524WP		IF		N37 40 27.46	W097 53 15.62								
	WP522WP	5.40	TF	FB	N37 45 46.51	W097 52 03.10	10.23	4.23						
	WP313WP	5.91	RF		N37 49 46.57	W097 47 09.39						N37 44 52.99	W097 45 51.24	5.00
	WP306WP	5.19	RF		N37 53 05.51	W097 42 30.19						N37 54 37.47	W097 48 27.02	4.95
	PFAF2WP	3.86	RF		N37 56 42.35	W097 43 28.16						N37 54 14.09	W097 46 56.16	3.69
	WP321WP	4.73	TF	FB	N38 00 12.21	W097 47 26.74	318.04 `	312.04						

Waypoint Data									
DB	Waypoint	Arc Center	Latitude Longitude	Latitude (Deg)	Longitude (Deg)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	PFAF2WP		375642.35N-0974328.16W	N37 9450982	W97.7244900	N37 56.706	W97 43.469	N37 56 42.35	W097 43 28.16
	WP306WP		375305.51N-0974230.19W	N37.8848637	W97.7083862	N37 53.092	W97 42.503	N37 53 05.51	W097 42 30.19
	WP313WP		374946.57N-0974709.39W	N37.8296033	W97.7859430	N37 49.776	W97 47.157	N37 49 46.57	W097 47 09.39
	WP321WP		380012.21N-0974726.74W	N38.0033911	W97.7907609	N30 00.203	W97 47.446	N38 00 12.21	W097 47 26.74
	WP522WP		374546.51N-0975203.10W	N37.7629185	W97.8675290	N37 45.775	W97 52.052	N37 45 46.51	W097 52 03.10
	WP524WP		374027.46N-0975315.62W	N37.6742955	W97.8876734	N37 40.458	W97 53.260	N37 40 27.46	W097 53 15.62
	WP527WP	Y	3744452.99N-0974551.24W	N37.7480540	W97.7642320	N37 44.883	W97 45.854	N37 44 52.99	W097 45 51.24
	WP528WP	Y	375437.47N-0974827.02W	N37.9104090	W97.8075046	N37 54.625	W97 48.450	N37 54 37.47	W097 48 27.02
	WP529WP	Y	375414.09N-0974656.16W	N37.9039145	W97.7822680	N37 54.235	W97 46.936	N37 54 14.09	W097 46 56.16

No FAA checks included.

No TERPS Surfaces included.

Database Effective Dates

Database	Date
NFDC	10/20/2011
Jeppesen	N/A
IFP Offline	N/A
AVNIS	12/15/2011
Benefits	N/A
NACO	N/A

L.2.3 Approaches

L.2.3.1 Approach 1

Three approaches are provided to assess RNP equipment guidance capability through a series of RF leg approach designs. As shown in Figure L-5, Approach 1 is a teardrop procedure that incorporates a descending RF right turn to final, rolling out at the final approach fix. Note that there is no straight segment 2 NM prior to the final approach fix which will be stressing for RNAV (GPS) final approach guidance due to the reduced scaling transition from terminal mode to approach mode. This path requires the simulated aircraft to descend, decelerate, and then configure for landing all during the RF leg. The missed approach also contains an RF leg en route to the missed approach hold. Waypoint information is shown in Table L-4 and vertical error budget information is shown in Table L-5.

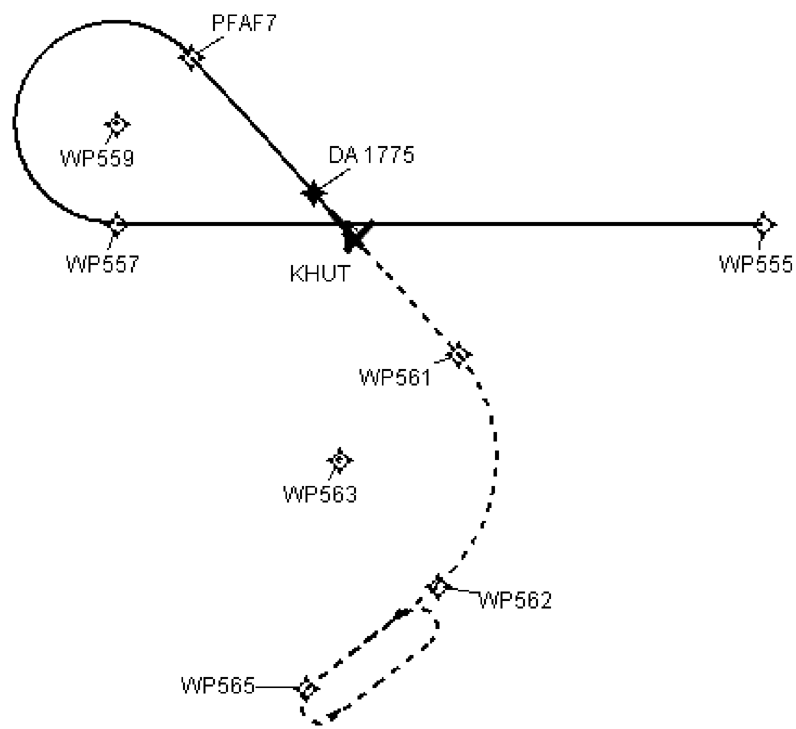

Figure L-5: Approach 1

Table L-4: Approach 1 Waypoints

Leg Table 1

Segment	Leg Type	Start	End	Turn Type	Glide Path End AR	Min Obs./ ATC End AR	Max End AR	Turn Radius Comp Alt	Descent Grad	Climb Grad	End Spd	Turn Radius Comp Spd	RNP	Turn Dir
Intermediate	IF	WP555	WP555	FB	10129			10129.22	0.0			300.0	1.0	
Intermediate	TF	WP555	WP557	FB	6235			6235.10				165.0	1.0	LEFT
Final	RF	WP557	PFAF7	FB	3172			6235.10				165.0	0.3	RIGHT
Final	TF	PFAF7	KHUT;RW13;AER	FB	1580			1580.00				165.0	0.3	
Missed	TF	DA1775	WP561	FB				4337.40				265.0	1.0	
Missed	RF	WP561	WP562	FB				4873.04				265.0	1.0	
Missed	TF	WP562	WP565	FB				6881.69				265.0	1.0	
Missed	HM	WP565	WP565	FB				8890.33				265.0	1.0	

Leg Table 2

Segment	Leg Type	Start	End	Turn Type	Leg Length (NM)	Leg Length (FT)	Start Course Magnetic	End Course Magnetic	Course Change	RF/ Flyby Leg Radius	RF/ Flyby Turn Bank Angle	Tailwind	RF Leg Arc Center
Intermediate	IF	WP555	WP555	FB	0.00	0.0000							
Intermediate	TF	WP555	WP557	FB	15.58	94644.27202	264.04	263.84					
Final	RF	WP557	PFAF7	FB	9,62	58427.49136	263.86	131.96	228.10	2.4156	19.95	59.35	WP559
Final	TF	PFAF7	KHUT:RW13:AER	FB	5.00	30380.57743	131.96	132.00	0.00		N/A	30.00	
Missed	TF	DA1775	WP561	FB	5.22	31746.48819	131.96	132.00					
Missed	RF	WP561	WP562	FB	6.30	38255.73029	132.00	226.20	94.20	3.8294	24.89	56.65	WP563
Missed	TF	WP562	WP565	FB	4.02	24409.52927	226.16	226.12					
Missed	HM	WP565	WP565	FB	4.02	24409.52927	226.16						

Waypoint Data

DB	Waypoint	Latitude (Deg)	Longitude (Deg)	Latitude (Deg, Decimal Min)	Longitude (Deg, Decimal Min)	Latitude (Dº M' S.ss")	Longitude (Dº M' S.ss")
	PFAF7WP	N38.1361836	W97.9417693	N38 8.171	W97 56.606	N38 08 10.26	W097 56 30.33
	WP555WP	N38.0691650	W97.6507673	N38 4.150	W97 39.046	N38 04 08.99	W097 39 02.76
	WP557WP	N38.0688801	W97.9796143	N38 4.133	W97 58.771	N38 04 07.97	W097 58 46.25
	WP559WP	N38.1091856	W97.9796419	N38 6.551	W97 58.779	N38 06 33.07	W097 58 46.71
	WP561WP	N38.0170377	W97.8059367	N38 1.022	W97 48.356	N38 01 01.34	W097 48 21.37
	WP562WP	N37.9237951	W97.8164481	N37 55.428	W97 48.987	N37 66 25.66	W097 48 59.21
	WP563WP	N37.9742701	W97.8659231	N37 58.456	W97 51.966	N37 68 27.37	W097 51 57.32
	WP565WP	N37.8826581	W97.8832395	N37 52.959	W97 52.994	N37 62 67.57	W097 52 59.66

PFAF

	LAT	LON
LTP/FTP	N38 04 27.15	W097 52 15.90
Runway True Bearing	138.00	
FAF Altitude	6235.10	
LTP/FTP Elevation	1525.00	
TCH	55.00	
Glidepath Angle	3.00	
GPI	1049.46	
FAF Distance From LTP/FTP	88808.07 Feet	
	14.62 NM	
PFAF	LAT	LON
	N38 04 07.97	W097 58 46.25

Table L-5: Approach 1 Vertical Error Budget

RNP Value	0.30
LTP MSL Elevation	1525.00
Distance (ft) LTP to PFAF	88808.07
MSL PFAF Altitude	6235.10
Glidepath Angle	3.00
TCH	55.00
Delta ISA (dISA)	0.00
Semiuspan	131.00

Max Glidepath Angle	3.50
PFAF Elevation	6235.10
LTP Elevation	1525.0
ACT	0.00

Min Glidepath Angle	3.10	
NA Below	11.95(C)	53.51 (F)
NA Above	46.85 (C)	116.32 (F)

Dist (ft) LTP to OCS ORIGIN	3324.78
OCS Slope (run:rise)	19.15:1
VEB ROC @ PFAF	72.14

Error Components	(Enter Bank Angle, WPR, FTE, and ATIS values beloew)		@250 ft	@ PFAF
ISAD	(dh x dISA)/288+dISA-0.5 x .00198 x [dh + h])		0.00	0.00
BG	40.48	semispan x sin (Bank Angle)	40.48	40.48
ANPE	1.225 x RNP x tan(a)		117.03	117.03
VAE	D x (tan (a) – tan(a - .01)) D=250/tan(a)		0.83	15.73
WPR	60.00	WPR x tan(a)	3.14	3.14
FTE	75.00		75.00	75.00
ASE	-8.8 x 10^-8 x (h + D x tan(a))^2 + 6.5 x 10^-3 x (h + D x tan(a)) + 50		61.26	87.11
ATIS	20.00		20.00	20.00

L.2.3.2 Approach 2

Approach 2, as shown in Figure L-6, is also a descending right turn to final but has a series of four RF legs with differing radii. Similar to Approach 1 in Figure L-5, this path will require the simulated aircraft to descend and decelerate during the RF leg. Waypoint information is shown in Table L-6 and vertical error budget information is included in Table L-7.

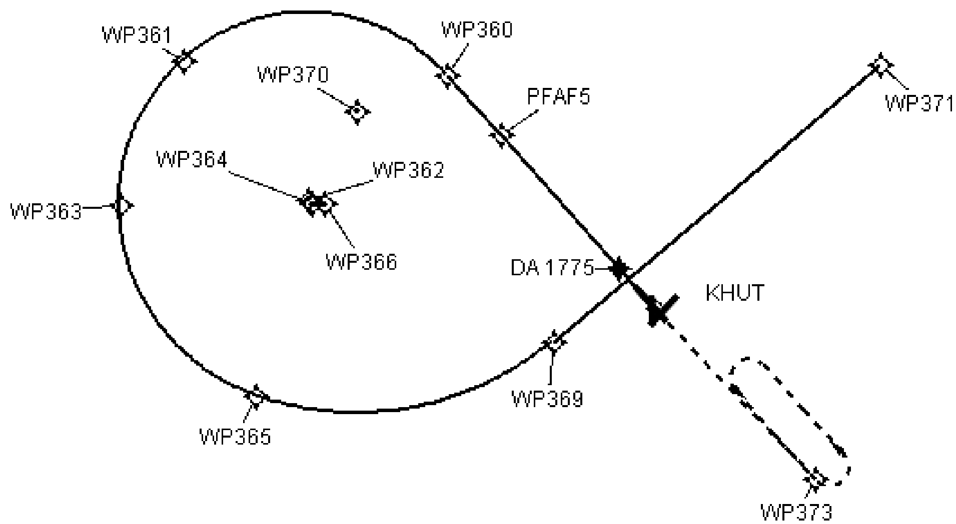

Figure L-6: Approach 2

Table L-6: Approach 2 Waypoints

Leg Table 1

Segment	Leg Type	Start	End	Turn Type	Glide Path End Alt	Min Obs./ ATC End Alt	Max End Alt	Turn Radius Comp Alt	Descent Grad	Climb Grad	End Spd	Turn Radius Comp Spd	RNP	Turn Dir
Intermediate	IF	WP371	WP371	FB	12677			12676.98				300.0	1.0	
Intermediate	TF	WP371	WP369	FB	10009			10009.28				300.0	1.0	RIGHT
Intermediate	RF	WP369	WP365	FB	8044			10009.28				300.0	1.0	RIGHT
Intermediate	RF	WP365	WP363	FB	6499			8043.55				250.0	1.0	RIGHT
Intermediate	RF	WP363	WP361	FB	5486			6499.25				250.0	1.0	RIGHT
Intermediate	RF	WP361	WP360	FB	3672			5486.00				250.0	1.0	RIGHT
Intermediate	TF	WP360	PFAF5	FB	3172			3172.36				165.0	1.0	RIGHT
Final	TF	PFAF5	KHUT:RW13:AER	FB	1580			1580.00				165.0	0.3	
Missed	TF	DA1776	WP373	FB				5312.04				265.0	1.0	
Missed	HM	WP373	WP373	FB				3725.00				265.0	1.0	RIGHT

Leg Table 2

Segment	Leg Type	Start	End	Turn Type	Leg Length (NM)	Leg Length (FT)	Start Course Magnetic	End Course Magnetic	Course Change	RF/ Flyby Leg Radius	RF/ Flyby Turn Bank Angle	Tailwind	RF Leg Arc Center
Intermediate	IF	WP371	WP371	FB	0.00	0.00000							
Intermediate	TF	WP371	WP369	FB	10.67	64836.91202	223.80	223.70					
Intermediate	RF	WP369	WP365	FB	7.86	47776.01926	223.70	283.69	59.89	7.6100	19.36	66.82	WP370
Intermediate	RF	WP365	WP363	FB	6.18	37533.46966	283.59	353.36	69.76	6.0700	19.68	62.93	WP366
Intermediate	RF	WP363	WP361	FB	4.05	24626.69378	353.36	42.16	48.81	4.7600	19.79	69.87	WP364
Intermediate	RF	WP361	WP360	FB	7.25	44079.46700	42.16	132.22	90.05	4.6200	19.65	67.86	WP362
Intermediate	TF	WP360	PFAF5	FB	2.00	12152.23097	132.22	132.23	0.02		N/A	30.00	
Final	TF	PFAF5	KHUT:RW13:AER	FB	5.00	30380.67743	132.23	132.28	1.16		N/A	30.00	
Missed	TF	DA1775	WP373	FB	7.17	43590.62964	131.07	131.14					
Missed	HM	WP373	WP373	FB	4.00	24304.46194	131.07						

Waypoint Data

DB	Waypoint	Latitude (Deg)	Longitude (Deg)	Latitude (Deg, Decimal Min)	Longitude (Deg, Decimal Min)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	PFAF5	N38.1364523	W97.9413803	N38 8.187	W97 56.483	N38 08 11.23	W97 56 28.97
	WP360WP	N38.1613379	W97.9696326	N38 9.680	W97 58.172	N38 09 40.82	W97 58 10.32
	WP361WP	N38.1673998	W98.1073660	N38 10.044	W98 6.441	N38 10 02.64	W98 06 26.48
	WP362WP	N38.1099519	W98.0422797	N38 6.597	W98 2.637	N38 06 36.83	W98 02 32.21
	WP363WP	N38.1073598	W98.1408183	N38 6.442	W98 8.449	N38 06 26.50	W98 08 26.95
	WP364WP	N38.1082105	W98.0403093	N38 6.493	W98 2.419	N38 06 29.56	W98 02 25.11
	WP365WP	N38.0285723	W98.0696613	N38 1.714	W98 4.180	N38 01 42.86	W98 04 10.78
	WP366WP	N38.1082629	W98.0337636	N38 6.496	W98 2.026	N38 06 29.75	W98 02 01.55
	WP369WP	N38.0510922	W97.9138308	N38 3.066	W97 54.830	N38 03 03.93	W97 54 49.79
	WP370WP	N38.1466107	W98.0164594	N38 8.797	W98 0.988	N38 08 47.80	W98 00 59.25
	WP371WP	N38.1661249	W97.7418464	N38 9.967	W97 44.611	N38 09 58.05	W97 44 30.64
	WP373WP	N37.9941400	W97.7766721	N37 59.648	W97 46.600	N37 59 38.90	W97 46 36.02

PFAF

	LAT	LON
LTP/FTP	N38 04 27.15	W097 52 15.90
Runway True Bearing	138.00	
FAF Altitude	3172.36	
LTP/FTP Elevation	1525.00	
TCH	55.00	
Glidepath Angle	3.00	
GPI	1049.46	
FAF Distance From LTP/FTP	30380.58 Feet	
	5.00 NM	
PFAF	LAT	LON
	N38 08 11.23	W097 56 28.97

Table L-7: Approach 2 Vertical Error Budget

RNP Value	0.30
LTP MSL Elevation	1525.0
Distance (ft) LTP to PFAF	30380.58
MSL PFAF Altitude	3172.36
Glidepath Angle	3.00
TCH	55.00
Delta ISA (dISA)	0.00
Semiuspan	131.00

Max Glidepath Angle	3.50
PFAF Elevation	3172.36
LTP Elevation	1525.0
ACT	0.00

Min Glidepath Angle	3.10	
NA Below	11.95 (C)	53.51 (F)
NA Above	45.68 (C)	114.23 (F)

Dist (ft) LTP to OCS ORIGIN	3324.90
OCS Slope (run:rise)	19.15:1
VEB ROC @ PFAF	216.86

Error Components	(Enter Bank Angle, WPR, FTE, and ATIS values beloew)		@250 ft	@ PFAF
ISAD	(dh x dISA)/288+dISA-0.5 x .00198 x [dh + h])		0.00	0.00
BG	25.00	semispan x sin (Bank Angle)	25.00	25.00
ANPE	1.225 x RNP x tan(a)		117.03	117.03
VAE	D x (tan (a) – tan(a - .01)) D=250/tan(a)		0.83	5.50
WPR	60.00	WPR x tan(a)	3.14	3.14
FTE	75.00		75.00	75.00
ASE	-8.8 x 10^-8 x (h + D x tan(a))^2 + 6.5 x 10^-3 x (h + D x tan(a)) + 50		61.26	69.73
ATIS	20.00		20.00	20.00

L.2.3.3 Approach 3

Approach 3 is shown in Figure L-7. This procedure uses an RF leg early in the procedure followed by a brief straight segment, then two back-to-back RF legs with a turn direction reversal. The second RF leg terminates at the final approach fix. As on the other approaches, the simulated aircraft will be required to descend, decelerate and configure for landing during the series of RF legs. The missed approach also includes an RF leg to the missed approach hold. Waypoint information is shown in Table L-8 and vertical error budget information is included in Table L-9.

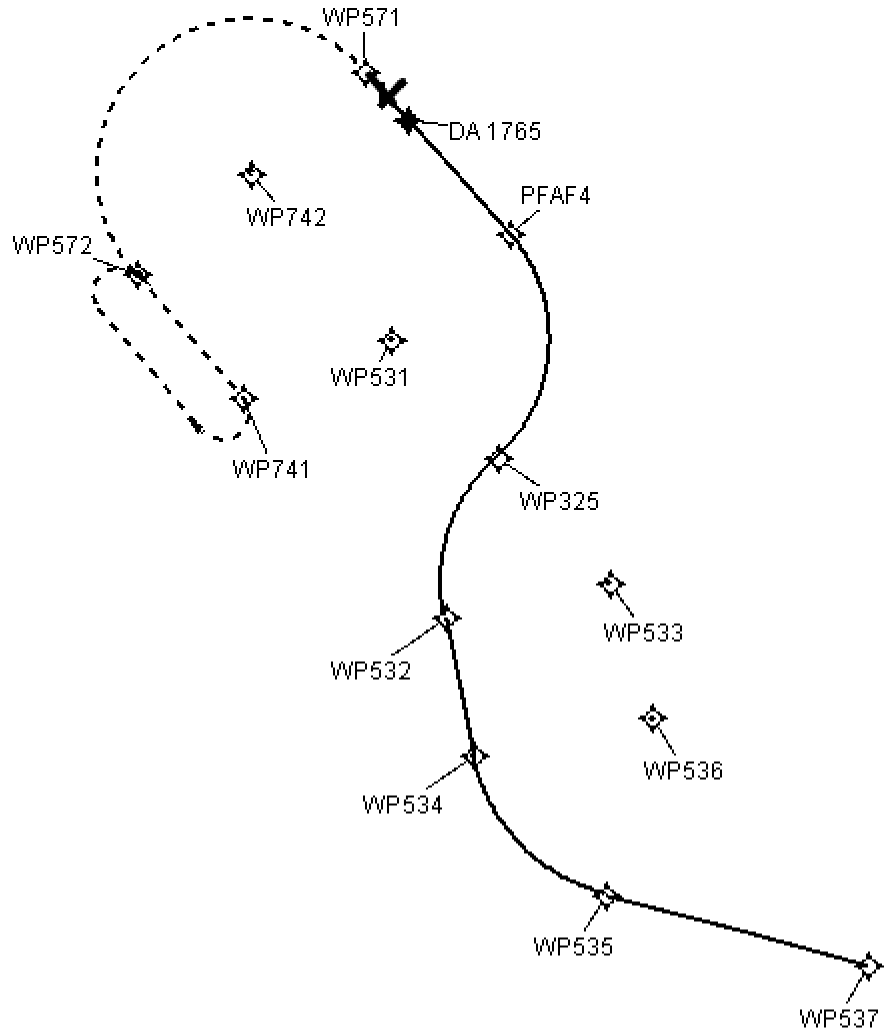

Figure L-7: Approach 3

Table L-8: Approach 3 Waypoints

Leg Table 1

Segment	Leg Type	Start	End	Turn Type	Glide Path End Alt	Min Obs./ ATC End Alt	Max End Alt	Turn Radius Comp Alt	Descent Grad	Climb Grad	End Spd	Turn Radius Comp Spd	RNP	Turn Dir
Intermediate	IF	WP537	WP537	FB	10584			10583.57	0.0			300.0	1.0	
Intermediate	TF	WP537	WP535	FB	8641			8641.47				250.0	1.0	RIGHT
Intermediate	RF	WP535	WP534	FB	7193			8641.47				250.0	1.0	RIGHT
Intermediate	TF	WP534	WP532	FB	6193			6192.56.				250.0	1.0	RIGHT
Intermediate	RF	WP532	WP325	FB	4937			6192.56				250.0	1.0	RIGHT
Intermediate	RF	WP325	PFF4	FB	3162			4936.79				250.0	1.0	LEFT
Final	TF	PFAF4	KHUT:RW31:AER	FB	1570			1570.00				165.0	0.3	
Missed	TF	DA1766	WP571	FB				2615.00				265.0	0.5	LEFT
Missed	RF	WP571	WP572	FB				8536.36				265.0	1.0	LEFT
Missed	TF	WP572	WP741	FB				10854.65				265.0	1.0	LEFT
Missed	HM	WP741	WP741	FB				13172.95				265.0	1.0	RIGHT

Leg Table 2

Segment	Leg Type	Start	End	Turn Type	Leg Length (NM)	Leg Length (FT)	Start Course Magnetic	End Course Magnetic	Course Change	RF/ Flyby Leg Radius	RF/ Flyby Turn Bank Angle	Tailwind	RF Leg Arc Center
Intermediate	IF	WP537	WP537	FB	0.00	0.00000							
Intermediate	TF	WP537	WP535	FB	7.77	47201.70006	278.82	278.72					
Intermediate	RF	WP535	WP534	FB	5.80	35214.94480	278.72	342.26	63.54	6.2220	19.5	64.11	WP536
Intermediate	TF	WP534	WP532	FB	4.00	24304.46194	342.26	342.25					
Intermediate	RF	WP532	WP325	FB	5.02	50520.94148	342.25	42.26	60.00	4.7980	19.44	69.26	WP533
Intermediate	RF	WP325	PFF4	FB	7.10	43126.62487	42.26	312.31	89.95	4.6209	19.67	66.77	WP531
Final	TF	PFAF4	KHUT:RW31:AER	FB	5.00	30380.67743	312.31	312.27	0.00		N/A	30.00	
Missed	TF	DA1765	WP571	FB	1.80	10937.00787	312.31	312.29					
Missed	RF	WP571	WP572	FB	13.64	82894.71614	312.29	133.02	179.27	4.3623	24.99	63.90	WP742
Missed	TF	WP572	WP741	FB	4.64	28172.46233	133.02	133.02					
Missed	HM	WP741	WP741	FB	4.64	28172.46233	133.02						

Table L-9: Approach 3 Vertical Error Budget

RNP Value	0.30
LTP MSL Elevation	1525.0
Distance (ft) LTP to PFAF	30380.58
MSL PFAF Altitude	3162.36
Glidepath Angle	3.00
TCH	55.00
Delta ISA (dISA)	0.00
Semiuspan	131.00

Max Glidepath Angle	3.50
PFAF Elevation	3162.36
LTP Elevation	1525.0
ACT	0.00

Min Glidepath Angle	3.10	
NA Below	11.97 (C)	53.55 (F)
NA Above	45.70 (C)	114.27 (F)

Dist (ft) LTP to OCS ORIGIN	3324.90
OCS Slope (run:rise)	19.15:1
VEB ROC @ PFAF	216.83

Error Components	(Enter Bank Angle, WPR, FTE, and ATIS values beloew)		@250 ft	@ PFAF
ISAD	(dh x dISA)/288+dISA-0.5 x .00198 x [dh + h])		0.00	0.00
BG	25.00	semispan x sin (Bank Angle)	25.00	25.00
ANPE	1.225 x RNP x tan(a)		117.03	117.03
VAE	D x (tan (a) – tan(a - .01)) D=250/tan(a)		0.83	5.50
WPR	60.00	WPR x tan(a)	3.14	3.14
FTE	75.00		75.00	75.00
ASE	-8.8 x 10^-8 x (h + D x tan(a))^2 + 6.5 x 10^-3 x (h + D x tan(a)) + 50		61.20	69.68
ATIS	20.00		20.00	20.00

L.2.3.4 Approach 4

Approach 4 is shown in Figure L-8. The key feature of this procedure is that the first leg of the missed approach is an RF leg. The initial RF leg is followed by two consecutive RF legs in the same direction of increasing radius. The third RF leg on the missed approach is followed by a TF leg that terminates at WP770. In this missed approach, the simulated aircraft will be required to capture and track the first RF leg immediately after sequencing the missed approach waypoint, while climbing and accelerating during the series of RF legs. Waypoint information is shown in Table L-10 and vertical error budget information is included in Table L-11.

Note: Where crew action is required to sequence the missed approach waypoint, equipment designers should consider the potential impact of any significant delay in this action

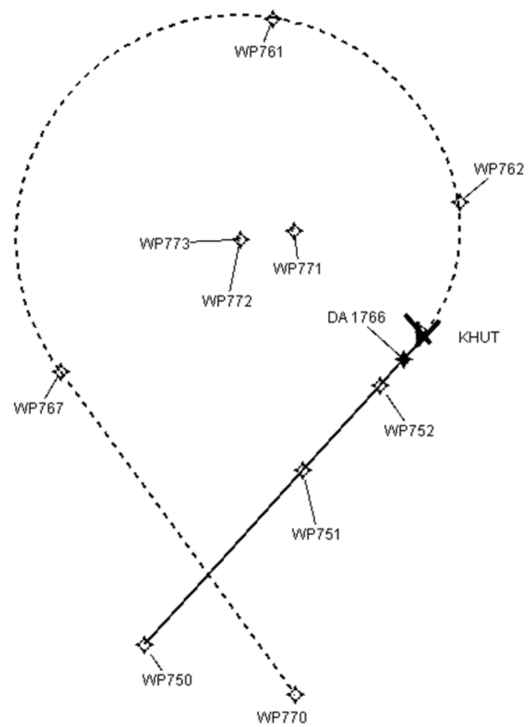

Figure L-8: Approach 4

Table L-10: Approach 4 Waypoints

Leg Table 1

Segment	Leg Type	Start	End	Turn Type	Glide Path End Alt	Min Obs./ ATC End Alt	Max End Alt	Turn Radius Comp Alt	Descent Grad	Climb Grad	End Spd	Turn Radius Comp Spd	RNP	Turn Dir
Intermediate	IF	WP750	WP750	FB	4971		3400	3400.00	0.0			250	1.0	
Intermediate	TF	WP750	WP751	FB	3200			3199.68	250			165.0	1.0	
Final	TF	WP751	WP752	FB	2112			2112.38	318.5			165.0	0.3	
Final	TF	WP752	KHUT:RW04:AER	FB	1571			1571.0	318.5			165.9	0.3	
Missed	RF	KHUT:RW04: AER	WP762	FB				1566.0				265.0	1.0	Left
Missed	RF	WP762	WP761	FB								265.0	1.0	Left
Missed	RF	WP761	WP767	FB								265.0	1.0	Left
Missed	TF	WP767	WP770	FB								265.0	1.0	

Leg Table 2

Segment	Leg Type	Start	End	Turn Type	Leg Length (NM)	Leg Length (FT)	Start Course Magnetic	End Course Magnetic	Course Change	RF/ Flyby Leg Radius	RF/ Flyby Turn Bank Angle	Tailwind	RF Leg Arc Center
Intermediate	IF	WP750	WP750	FB	0.0	0.0							
Intermediate	TF	WP750	WP751	FB	7.09	43054.7	36.31	36.37	0.06			30	
Final	TF	WP751	WP752	FB	3.41	20744.4	36.38	36.41	0.03			30	
Final	TF	WP752	KHUT:RW04: AER	FB	1.70	10329.2	36.40	36.42					
Missed	RF	KHUT:RW04 :AER	WP762	FB	4.58	27830.9	36.42	344.36	52.05	5.0400	15.36	30	WP771
Missed	RF	WP762	WP761	FB	8.38	50902.8	344.36	272.44	71.03	6.6800	11.71	30	WP772
Missed	RF	WP761	WP767	FB	15.69	95309.0	272.44	137.81	134.62	6.6800	11.71	30	WP773
Missed	TF	WP767	WP770	FB	12.00	72913.4	137.81	137.90				30	

Waypoint Data

DB	Waypoint	Latitude (Deg)	Longitude (Deg)	Latitude (Deg, Decimal Min)	Longitude (Deg, Decimal Min)	Latitude (D° M' S.ss")	Longitude (D° M' S.ss")
	WP750	N37.90891	W98.03603	N37 54.53467	W98 2.16167	N37 54 32.08000	W098 02 9.70000
	WP751	N37.99630	W97.93545	N37 59.77783	W97 56.12717	N37 59 46.67000	W097 56 7.63000
	WP752	N38.03837	W97.88691	N38 2.30217	W97 53.21450	N38 02 18.13000	W097 53 12.87000
	WP761	N38.22164	W97.95474	N38 13 29863	W97 57.28419	N38 13 17.91791	W097 57 17.05128
	WP762	N38.13013	W97.83636	N38 7.80785	W97 50.18133	N38 07 48.47124	W097 50 10.87986
	WP767	N38.04564	W98.08928	N38 2.73849	W98 5.35700	N38 02 44.30923	W098 05 21.41989
	WP770	N37.88395	W97.94012	N37 53.03696	W97 56.40730	N37 53 2.21756	W097 56 24.43804
	WP771	N38.11601	W97.94129	N38 6.96055	W97 56.47760	N38 06 57.63311	W097 56 28.65604
	WP772	N38.11139	W97.97543	N38 6.68363	W97 58.52586	N38 06 41.01778	W097 58.31.55178
	WP773	N38.11139	W97.97543	N38 6.68362	W97 58.52587	N38 06 41.01708	W097 58 31.55191

PFAF

	LAT	LON
LTP/FTP	N38 03 33.52	W097 51 45.78
Runway True Bearing	42.00	
FAF Altitude	3199.68	
LTP/FTP Elevation	1516.00	
TCH	55.00	
Glidepath Angle	3.00	
GPI	1049.46	
FAF Distance From LTP/FTP	31073.60 Feet	
	5.11 NM	
PFAF	LAT	LON
	N37 59 46.67	W097 56 07.63

Table L-11: Approach 4 Vertical Error Budget

RNP Value	0.30
LTP MSL Elevation	1525.0
Distance (ft) LTP to PFAF	31073.60
MSL PFAF Altitude	3199.68
Glidepath Angle	3.00
TCH	55.00
Delta ISA (dISA)	0.00
Semiuspan	131.00

Max Glidepath Angle	3.50
PFAF Elevation	3199.68
LTP Elevation	1516.0
ACT	0.00

Min Glidepath Angle	3.10	
NA Below	11.97 (C)	53.54 (F)
NA Above	45.74 (C)	114.33 (F)

Dist (ft) LTP to OCS ORIGIN	3347.00
OCS Slope (run:rise)	18.05:1
VEB ROC @ PFAF	129.46

Error Components	(Enter Bank Angle, WPR, FTE, and ATIS values beloew)		@250 ft	@ PFAF
ISAD	(dh x dISA)/288+dISA-0.5 x .00198 x [dh + h])		00.00	00.00
BG	25.00	semispan x sin (Bank Angle)	25.00	25.00
ANPE	1.225 x RNP x tan(a)		117.03	117.03
VAE	D x (tan (a) – tan(a - .01)) D=250/tan(a)		0.83	5.62
WPR	00.00		00.00	00.00
FTE	00.00		00.00	00.00
ASE	-8.8 x 10^-8 x (h + D x tan(a))^2 + 6.5 x 10^-3 x (h + D x tan(a)) + 50		61.20	69.90
ATIS	00.00		00.00	00.00

L.3 Simulated Wind Environment

If practical, the simulated wind direction should be set to a tailwind for each turn entry. The wind velocity for the respective altitude should approximate the values shown below.

Use linear interpolation to obtain wind values for altitudes AGL that fall between the table values. For altitudes greater than 15,000 ft, this formula should be used:

V_{KTW} = 0.00198 x (altitude) + 47.

Note: If the simulator cannot model variable winds and various levels, select the wind direction and velocity that will most effectively simulate the worst case tailwind for the procedure.

<= 2000 ft = 30 kts
3000 ft = 53 kts
4000 ft = 55 kts
5000 ft = 57 kts
6000 ft = 59 kts
7000 ft = 61 kts
8000 ft = 63 kts
9000 ft = 65 kts
10,000 ft = 67 Kts
11,000 ft = 69 kts
12,000 ft = 71 kts
13,000 ft = 73 kts
14,000 ft = 75 kts
15,000 ft = 77 kts

APPENDIX M FLIGHT TECHNICAL ERROR DATA COLLECTION AND ANALYSIS

M.1 Introduction

The flight technical error (FTE) of an RNP system is a measure of the system's ability to follow the lateral and vertical desired trajectory that the RNP equipment has computed. Industry-accepted FTE values can be found in Table 2-7 of this standard; however, these values are extremely conservative and many equipment designers find it advantageous to compute their own FTE values. The purpose of this appendix is to provide guidelines for the collection and analysis of FTE data.

M.2 Data Collection

M.2.1 Pilot Selection

Data should be collected by multiple pilots whose combined experience approximates the proficiency of an "average" pilot.

Note 1: The definition of an "average" pilot should depend upon the type of aircraft the RNP equipment is to be used on.

Note 2: See AC 120-29A section 5.19.2.1 for additional recommendations.

M.2.2 Aircraft Selection

When the RNP equipment can be installed on multiple aircraft types, the data collection should be performed using multiple aircraft that bound the expected performance range.

When multiple aircraft are used, each aircraft should fly the complete set of procedures that apply to that aircraft type.

M.2.2.1 Flight Simulators

Data collected using a high-fidelity flight simulator may be used for analysis as long as it is validated by flight test data.

Note 1: A hypothesis test is an acceptable means to use the flight test data to validate the flight simulator data by showing statistical equivalence.

Note 2: It is recommended that representative wind conditions are added to the simulation when collecting simulated flight data.

M.2.3 Flight Procedure Selection

The flight procedures flown should provide stressing lateral and/or vertical profiles containing multiple course changes appropriate for the phase of flight.

Note 1: An example of stressing lateral geometry for the en route/cruise phase is a course change between 45 and 90 degrees.

Note 2: An example of stressing lateral geometry for the terminal and approach phases is a fly-by waypoint with a course change between 90 and 135 degrees.

Terminal and approach procedures should include multiple RF legs with stressing geometry.

Note 3: Appendix L of this standard contains guidelines and example procedures for testing RF legs with stressing geometry.

Approach phase procedures should include the missed approach segment.

If vertical FTE data is being collected, the terminal and approach procedures should include a flight path angle. If the RNP equipment does not support flight path angles in terminal procedures, it is sufficient to generate a suitable flight path angle by a GPP path between two consecutive AT altitude constraints.

Note 4: There is no requirement to collect vertical FTE data during a vertical fly-by maneuver (at a change in FPA) due to the allowance allowed for height loss.

M.2.3.1 Position Sensors

A separate data collection and analysis for the different types of position sensors available to the RNP equipment position estimation function is not necessary unless the path steering function uses different algorithms to determine the path deviation and steering commands based upon the position sensor(s) in use.

Note: Path steering error (PSE) attributable to a position sensor change should be classified as position estimation error (PEE) not FTE.

M.2.3.2 Aircraft Control Modes

A separate data collection and analysis should be conducted for each applicable control mode (e.g. autopilot coupled, flight director, or manual CDI/map-only).

M.3 Data Analysis

M.3.1 Statistical Assumptions

As noted in Section 2.2.5.1 of this MOPS, the FTE data may be assumed to have a Normal (Gaussian) distribution.

Other statistical methods may be used provided they are shown to be at least as conservative as the assumed Normal (Gaussian) distribution.

M.3.2 Sample Independence

Depending on the sampling rate used, consecutive FTE data samples may be highly correlated and thus, not independent. For example, an aircraft cannot instantaneously change to any value of a FTE data sample set [D_L D_R] where D_L is the maximum FTE distance to the left of a defined path and D_R is the maximum FTE distance to the right of a defined path. Instead, the aircraft must move through consecutive FTE data samples that correspond to its response to path steering commands provided either manually or via an autopilot.

The time between independent FTE samples may change based on aircraft, phase of flight, control mode, etc. Additionally, the time between independent lateral FTE samples may be different than the time between independent vertical FTE samples. Consequently, a time-correlation analysis should be performed on the FTE data sample set to ensure independence between the FTE data samples used in the statistical data analysis.

In lieu of performing a time-correlation analysis, independent FTE samples can be assumed to occur at a minimum of 70 seconds apart.

M.3.3 FTE Computation

When using a Normal (Gaussian) distribution, the 95% bound on the FTE should be computed using the mean and standard deviation of the data for each phase of flight/control mode combination.

If a non-Gaussian assumption was used, the 95% bound on the FTE data should be computed using an appropriate method that is at least as conservative as a Normal (Gaussian) distribution.

M.3.4 Confidence Analysis

In order to ensure that a sufficient number of independent data points have been used, a 99% confidence factor should be applied to the 95% FTE bound.

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APPENDIX N - TIME OF ARRIVAL CONTROL (TOAC)

N.1 Introduction and Scope

Note: For additional information on estimated time of arrival and time of arrival control functions, associated installation and operational issues, and other considerations, see RTCA/DO-236C Change 1.

N.1.1 TOAC Assumptions

N.1.1.1 Desired Path – Time of Arrival Control Effects

This appendix assumes that altitude constraints and speed restrictions will be published that allow for aircraft paths as described in Section 2.2.2.2 of this MOPS. The procedure designs are expected to establish speed and altitude constraints in a way that supports the use of TOAC by not overly constraining the system defined path. In particular, a speed constrained descent and a time constrained descent may not be compatible except under specific conditions, e.g., it is not expected that AT or AT OR ABOVE speed restrictions will precede a time constraint in descent. This must be taken into account in operations and procedure design. The time of arrival control performance requirements defined in the MASPS can only be expected to be met by the RNP equipment when essential information such as current and accurate wind forecasts, temperatures, etc. are provided to and used by the system.

N.1.1.2 Flight Plan Updates

It is expected that flight crews will periodically update the entered forecast winds and temperature, and update any flight plan changes as soon as possible.

N.1.2 Verification Procedures

The Time of Arrival Control verification procedures specified in this document are intended to augment existing navigation system verification procedures. These procedures provide an acceptable means of showing compliance with the requirements in this appendix. Existing testing and verification requirements for navigation equipment as specified under current FARs, CSs, ACs, AMCs, etc. all need to be satisfied; the additional tasks of showing compliance to the new requirements are stated in Section 4.0 of this document.

N.1.3 Time of Arrival Control Definitions

The definitions of several key terms used throughout this document follow. A complete glossary can be found in Appendix A.

The following definitions apply for the time errors associated with TOAC (illustrated in **Figure N-1**).

Note 1: In all time definitions, the crossing of a fix refers to the estimated aircraft position.

RANGE OF ACHIEVABLE ETAs: The full range of times that the system predicts it could cross a specified constraint fix.

ACTUAL TIME OF ARRIVAL (ATA): The time at which the system estimated position crosses a fix.

Note 2: Time of arrival error due to the crossing time of the "actual" aircraft is handled through the navigation accuracy requirement.

Note 3: A fix crossing occurs when either crossing the fix, or angle bisector of the turn passing the fix.

REQUIRED TIME OF ARRIVAL (RTA): The time at which the system is required to cross a fix, also described as a time constraint.

TIME CONTROL ERROR (TCE): The difference between required time of arrival at a fix (RTA) and estimated time of arrival (ETA at that fix), e.g., TCE = RTA – ETA.

TIME ESTIMATION ERROR (TEE): The difference between estimated time of arrival at a flight path location (ETA) and the actual time of arrival (ATA) at that location, e.g., TEE = ETA – ATA.

Note 4: TEE is unknown at all times and locations along the path except when the fix is crossed. It is not a part of the aircraft control; it is part of the performance for ETAs. Assessment of TEE is part of showing compliance with the performance requirements as described in Section N.5.1 and is illustrated in Figure N-1.

Note 5: The term "flight path location" is used here relative to ETA computation rather than the term "fix" to allow for the fact that ETA can be to any location (e.g., top of climb, top of descent, etc.) not just to fixes in the flight plan.

Note 6: Time of arrival error due to the crossing time of the "actual" aircraft is handled through the navigation accuracy requirement, and thus TEE does not take the navigation position error into account.

TIME DEFINITION ERROR (TDE): The difference between RTA represented in the system and the time of arrival that was requested by ATC.

Note 7: As in the case of lateral paths where PDE = 0 for WGS-84 compliant systems, TDE is likely zero when both requested time of arrival and the RTA are represented in seconds unless an error occurs in transmission to the aircraft. This error is presumed to be zero.

TOTAL TIME ERROR (TTE): The sum of the time control, time estimation and time definition errors, e.g., TTE = TCE + TEE + TDE.

Note 8: As noted above, TDE is likely zero, which leaves TTE = RTA – ATA when the fix is crossed.

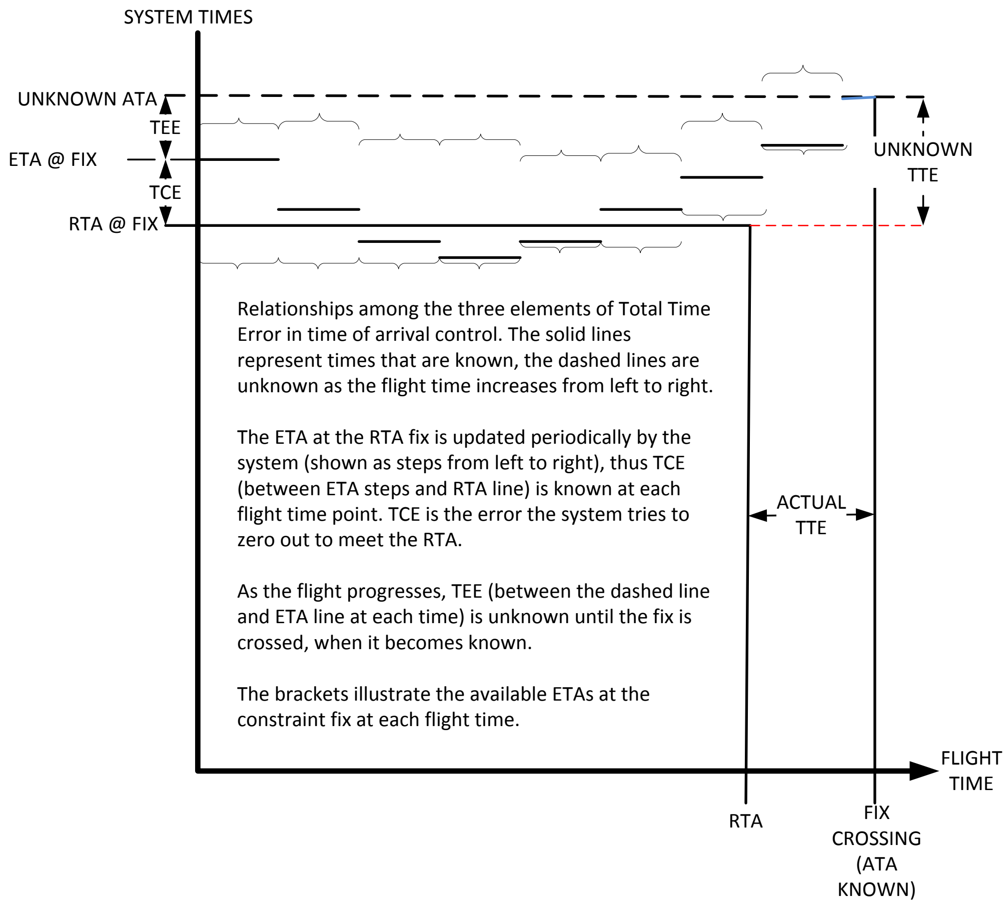

Figure N-3: TOAC Definitions

N.2 Requirements

This section describes the minimum functional and performance operating standards for the time of arrival control functions of RNP equipment.

N.2.1 Functional Requirements

N.2.1.1 Time Constraints

The RNP equipment shall provide for the entry of a time constraint (Required Time of Arrival) for at least a single flight plan fix. The equipment shall provide the means to display the time constraint. The time constrained fix shall be selectable either on the ground or after flight begins. The equipment shall provide the means for the display of an ETA or the TCE at the time constraint fix.

Note: Time constraints may also be received in an ATC datalink message and should be processed consistent with datalink message preview and acceptance by the flight crew.

N.2.1.1.1 Time Constraint Types

The RNP equipment shall support time constraints of type “AT”, “AT or AFTER”, and “AT or BEFORE”. For an “AT OR BEFORE” time constraint, the aircraft may arrive at any time before the constraint time but shall meet the required accuracy AFTER the constraint time. For an “AT OR AFTER” time constraint, the aircraft may arrive at any time after the constraint time but shall meet the required accuracy BEFORE the constraint time (see Figure N-2 for illustration of how the accuracy requirement applies in these cases).

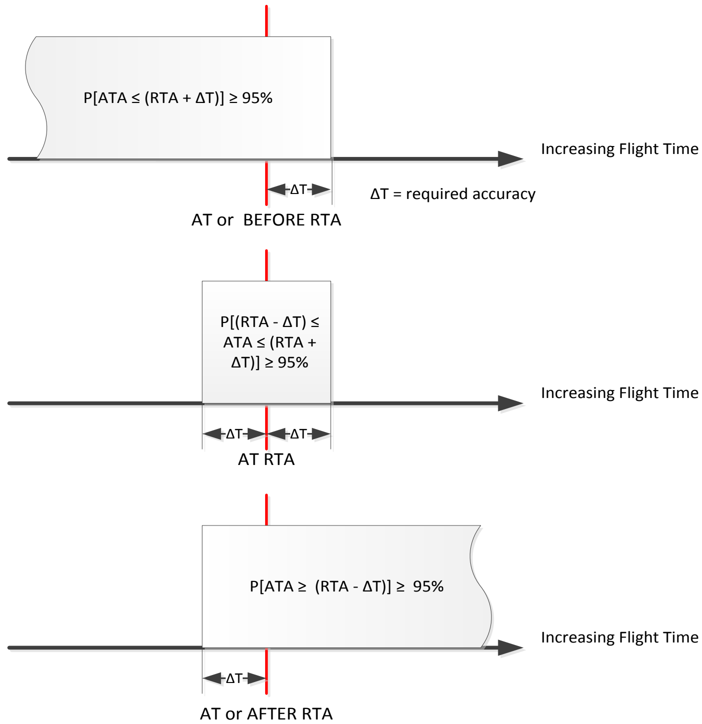

Figure N-4: Application of TOAC Accuracy to Time Constraint Types

N.2.1.2 Time of Arrival Control Function

When the RNP equipment is able to provide a TOAC function, it shall be available in cruise and descent flight phases as long as sufficient time remains before reaching the time constraint fix to provide for control.

Note 1: Crossing time - when a waypoint crossing occurs at a course change with a fly-by transition, the ETA and time constraint are associated with the lateral bisector of the turn.

Note 2: The higher priority of altitude constraints or speed restrictions compared to time constraints results in a reduction of speed control range available to meet the time constraint. This may jeopardize the ability of the system to meet the time constraint. This does not mean that the time constraint can be ignored when such constraints exist in the flight plan; the function should continue to minimize the total time error.

Note 3: The equipment designer should take into account the flight deck and operational effects of over-active throttle control by the TOAC control function.

Once the TOAC function is engaged, the RNP equipment shall provide a means for speed tracking consistent with the accuracy required in meeting the RTA.

The RNP equipment shall respect all speed restrictions, aircraft performance limits and restrictions in the flight plan including those at the time constraint point.

Note 4: The integration of the TOAC speed tracking function with external aircraft systems will be heavily dependent on the system architecture of the *intended aircraft installation. This integration is left to the equipment designer. It may take a variety of forms, including but not limited to:*

- *Display of the target speed or speed error, in numeric and/or non-numeric formats, on an integral display or output to an external display,*
- *Output of speed/thrust targets or pitch/thrust commands to external flight guidance and thrust management systems.*

When a specific TOAC accuracy is entered into the RNP equipment (e.g. as a result of an ATC request to the flight crew or via ATC datalink), and the equipment is unable to use an accuracy value equal to or lower than the requested accuracy, the equipment shall provide an indication to the flight crew.

Upon sequencing of the time constraint fix, if the fix lies in cruise, the RNP equipment shall revert to the normal speed profile. If the fix lies in descent, the equipment shall maintain the current aircraft speed subject to other downpath elements of the descent profile. If the fix lies in the vicinity of top of descent, the equipment may apply either above behavior.

Note 5: The rationale for the requirement in the vicinity of top of descent is due to possible movement of the descent path upon insertion of the time constraint causing the placement of the time constraint fix as being in cruise or descent to be indeterminate. As far as the definition of the term "vicinity", it is suggested that this determination be chosen to contain the possible movement of the top of descent between minimum and maximum descent speed.

Note 6: This requirement does not preclude pilot action to select a manual speed target as desired after sequencing the time constraint fix.

When the TOAC function is engaged and the aircraft is detected to have departed the defined lateral path, the RNP equipment shall retain the active time constraint and shall maintain the current aircraft speed subject to other down path elements of the profile. The TOAC function may continue to update its speed as long as the speed is not used for control.

Note 7: The tracking of TOAC speed may resume when the aircraft has returned to a defined lateral path, if appropriate and feasible, as determined by pilot / controller procedures.

Note 8: ATC expectation is that when vectored off path, aircraft will maintain their speed, thus this requirement is meant to fulfill that expectation by maintaining the current TOAC target speed when departing the lateral path even though the target may continue to be updated for later use.

The time constraint is one of the flight plan constraints even if it cannot be met. The RNP equipment shall not delete a time constraint without specific action by or notification to the flight crew.

Note 9: As an example, a time constraint could be deleted automatically during an engine out event and accompanied by a notification to the flight crew of the removal of the time constraint.

When the time constraint is predicted to be missed, the RNP equipment shall provide appropriate speed commands in order to minimize the total time error.

N.2.1.3 Achievable Times of Arrival

When there is no time constraint in the flight plan, the equipment shall be able to compute and display the range of achievable ETAs associated with any single flight plan fix up to and including the destination runway.

The equipment may provide a method for the pilot to enter a maximum and/or minimum speed for use by the TOAC function. For example, this function could allow the crew to limit the TOAC function maximum speed to turbulence penetration speed when needed.

The requirement to display the range of achievable ETAs at a flight plan fix does not apply when the TOAC function is active, since the achievable range is intended to allow selection of a time constraint within the capability of the RNP equipment system.

Note: The above applies to both the display of the range of achievable ETAs to the flight crew, as well as datalink requests for the range.

If the equipment supports an ATC request for the range of achievable ETAs at another fix while TOAC is active, the equipment shall compute the range as follows: if the request is for the current time constraint fix or prior, the equipment calculations shall ignore the current time constraint; if the request is for a fix after the current time constraint fix, the equipment shall use the ETA at the constraint fix when predicting the range for the requested fix.

N.2.1.4 Time Initialization

The RNP equipment shall have the means to be synchronized to a time source.

Note: The time source is expected to be within one second of UTC in order to meet the TOAC performance requirements.

N.2.1.5 User Interface Requirements

N.2.1.5.1 Displays and Controls

Table N-1 shows the required minimum display/entry resolution for the RNP equipment with TOAC capabilities (e.g., the control display unit or integral display capability).

Note 1: Where the RNP equipment does not include a control and display function intended for flight crew use, the requirements of Table N-1 apply to the resolution supported by the data input and output interfaces.

Table N-1: Display/Entry Resolutions

Parameter	Resolution	
	Display	Entry
ETA	1 min	Not Applicable
Achievable ETA range	1 second	Not Applicable
Time constraint	1 second	1 second
ETA at time constrained fix or time control error	1 second	Not Applicable
TOAC Accuracy	1 second	1 second

Note 2: With all displayed information, it is desired to display computed values rounded rather than truncated.

N.2.1.5.2 Alerting

When the TOAC function is engaged, the RNP equipment shall have the means to provide an alert when the time constraint is not achievable.

Note 1: The time constraint is a contract with ATC, and the crew is the primary means for informing ATC of an inability to comply with the time constraint.

Note 2: The equipment designer should give due consideration to the avoidance of transient conditions/states that may result in nuisance alerts.

N.2.2 TOAC Performance Requirements

This section contains RNP equipment performance requirements for time of arrival control.

Note: It is expected that once aircraft reconfiguration begins, aircraft speeds will be set to perform the landing and the TOAC function will no longer be controlling to the time and the time of arrival performance requirement may not apply.

N.2.2.1 Time of Arrival Control

N.2.2.1.1 Accuracy

When the RNP equipment provides a time of arrival control capability, and the RTA is selected from within the range of achievable ETAs computed by the system, the TTE, in the presence of the meteorological uncertainty model described in N.2.2.4, shall be less than or equal to the required accuracy in 95% of the attempts.

The RNP equipment shall be capable of supporting an aircraft level accuracy requirement of 10 seconds for descent fixes and 30 seconds for cruise fixes.

Note 1: TOAC accuracies of 10 and 30 seconds are expected to be the values typically used in the RNP equipment. Meeting an accuracy level also meets the performance to a larger accuracy value, but not to a smaller accuracy value.

Note 2: The performance requirements are only intended to be demonstrated in laboratory tests, because the actual flight conditions cannot be guaranteed to be representative of meteorological conditions present during TOAC operations.

Note 3: An "attempt" is a single TOAC fix crossing.

Note 4: As with position, this accuracy requirement will bound both estimation error and control error. It should result in designers developing good, adequate predictions (ETAs) and good control algorithms to achieve the effect of "steering" ETA to meet the RTA, but still allow trade-offs between the two.

Note 5: One difference between the position case and the time case is that the position accuracy applies along the path, at all times, where the time accuracy is only measured at the time the TOAC point is actually passed. While there is always a true position (at any time) there is only one true time of arrival (ATA), and that is when the point is crossed. Hence "flying *time" is replaced by "attempts", so that in 95% of the times TOAC is applied to a time within the displayed range of achievable ETAs, it will be met within tolerance.*

Note 6: When AT or AT OR ABOVE speed restrictions exist in descent and the time constraint is in descent, the range of available ETAs will be reduced or the ability to meet the time constraint will be significantly impaired depending on the relative locations of the constraints. It is expected that this will be accounted for in operations and procedure design.

N.2.2.2 Integrity

There is no integrity requirement associated with Time of Arrival Control operations.

N.2.2.3 Continuity

There is no continuity requirement associated with Time of Arrival Control operations.

When the TOAC function is available, it shall meet an annunciated loss of function requirement of 10^{-3} per flight hour.

Note 1: Only availability is applicable to TOAC operations. Availability is determined solely by the flight path, time to go to the time constraint fix and aircraft performance, which cannot be specified as a percent availability for the function.

Note 2: Annunciation of the inability to achieve the RTA is not considered loss of function.

N.2.2.4 Meteorological Uncertainty Model

For design and compliance determination, the average ground speed error due to meteorological forecast error (wind and temperature) along a flight plan follows a Gaussian statistical law with mean error = 0kts and 2σ = 10kts when all wind and temperature meteorological data for the following altitudes are used: FL050, FL100, FL140, FL180, FL240, FL300, FL340, FL390, FL450 and FL530.

Note 1: This description of error is for comparing the forecast to the actual atmosphere and does not prescribe that the full forecast must be enterable or loadable in the system. It is sufficient if a simpler system wind forecast model can meet the requirements of the TOAC / ETA system.

Note 2: The meteorological error is considered along the flight plan. It means that the 5kt of standard deviation integrates the wind direction error and is then to be considered as a head/tail wind error for performance demonstration purposes.

Note 3: This uncertainty model is intended to assure a defined level of control robustness to the system. The intent is for this model to match the error expected in a good forecast such that the TOAC accuracy performance will achieve the 10/30 seconds in actual flight operations.

N.2.3 TOAC Performance - Environmental Conditions

The requirements of Section 2.3 apply.

N.2.4 TOAC Test Requirements

N.2.4.1 General

This section describes an acceptable means of showing compliance to the RNP equipment performance requirements in Section N.2.2.

The TOAC flight should be repeated enough times, with randomized initial conditions, to show compliance with the 95% requirement using the same TOAC fix in each run.

N.2.4.2 Performance Accuracy Compliance

N.2.4.2.1 Time of Arrival Control

This section presents an acceptable means of showing compliance with the required performance of Time of Arrival Control in N.2.2.1.1 provided that the time constraint is within the range of achievable ETAs for the constraint fix when TOAC is engaged.

A combination of performance analysis, simulation or flight demonstration will be performed to substantiate compliance. The chosen method(s) will evaluate system performance considering all system elements which can contribute to it.

The following list provides some (but not all) of the items that should be considered:

- The 10 second accuracy requirement in descent applies to a flight duration to the time constraint of 40 minutes or less, provided that the time constrained fix does not appear downstream of a speed restriction by more than approximately 40 nm;
- The 10 second accuracy requirement in descent only applies to fixes that are located subsequent to completion of the transition from cruise to a stabilized descent and prior to the point where configuration for landing is necessary.
- The 30 second accuracy requirement in cruise applies to a flight duration to the time constraint of 90 minutes or less;
- System operating configurations (e.g., architecture, manual/coupled system, etc., which impact performance);
- Expected performance (which includes guidance and path definition error);
- Non-faulted performance;
- Display resolution;
- The meteorological uncertainty model described in this appendix must be included in all scenarios;
- System internal wind and temperature model error (see note);
- System performance envelope, altitude constraints and speed restrictions applicable to the flight plan.
- Relative locations of fixes that have speed and time constraints

  Note: The baseline for wind and temperature models is to model forecasts at each cruise waypoint at predicted altitude and the descent region with ten levels. If a system does not model this many points, then the induced error must be included in the performance analysis.

N.3 Example of TOAC Compliance Analysis

N.3.1 Time of Arrival Control Accuracy and Reliability Analysis

The following provides an example method of demonstrating compliance to the TOAC accuracy requirements defined in Section N.2.2.1.1. This analysis must include the meteorological uncertainty model defined in Section N.2.2.4 for every test, and is expected to only include scenarios that are well-defined and predictable in both the lateral and vertical domains (e.g., no heading legs, altitude terminations, fly-over transitions, flap extensions, etc.).

Demonstration of compliance is expected to include scenarios which contain each of the following parameters and related variations at least once, but it does not require every combination.

- RTA time: since any times within the range of achievable ETAs must meet the 95% requirement, it is sufficient to test the edge cases from the achievable range.
  - Earliest.
  - Latest.
- Initial speed profile: a time constraint may be more difficult to achieve if it causes a large change in speed when beginning to control to the time constraint.
  - High to low speed situation
  - Low to high speed situation
- Speed limits:
  - Full envelope: minimum and maximum speeds are available to TOAC system.
  - Narrow envelope: TOAC minimum and maximum speeds are restricted by speed restrictions or crew entry (if this function is available to the crew)
- Lateral route structure:
  - Relatively straight lateral route.
  - Route with at least one large fly-by transition.
- Phase of flight: the time constraint fix should be placed both in cruise and descent.
- Cruise
- Descent: RTA speed control should begin in the cruise phase.
  - Fix placed before a speed and altitude constraint.
  - Fix placed on a speed and altitude constraint.
  - Fix placed after a speed and altitude constraint provided that the time constraint is not further downstream than approximately 40 NM.
- Wind and temperature model:

  Note: A possible source of error due to widely spaced waypoints and wind entry data points is not expected to be considered as part of this analysis. However, if a system cannot accept wind entries on every waypoint or cannot accept 10 levels, then it may introduce additional error.

- The following wind and temperature model parameters assume the wind and temperature uncertainty model described in Section N.2.2.4 has been applied to every scenario in addition to the below wind model parameters and variations.
- Wind and temperature uncertainty model utilization:
  - Statistical analysis may be run using random meteorological error values and random wind bearing error consistent with the model of Section N.2.2.4.

  - To reduce the total number of test runs, the meteorological error can be set to a fixed conservative value equal to the 95% meteorological error (10kts headwind error or tailwind error) applied during the entire operation (for all cases)
- Wind speeds:
  - Low speeds: average of 30 knots.
  - High speeds: average of 100 knots.
- Wind speed variation:
  - Constant wind speeds.
  - Speeds vary by altitude and/or lateral distance.
- Wind bearing:
  - Headwind.
  - Tailwind.
  - Crosswind.
- Wind bearing variation:
  - Constant wind bearing.
  - Bearing varies by altitude and/or lateral distance.

The defined parameters are expected to be independent in their effect on TOAC therefore, approximately 25 scenarios should be sufficient.

N.3.2 TOAC Compliance

N.3.2.1 Introduction

The TOAC compliance section of DO-236C Change 1 describes how the TOAC performance must be tested in a bench environment since the atmospheric disturbances cannot be controlled in flight. The bench test requires implementation of full aircraft systems such as autopilot, autothrottle (if equipped), and sensor systems, and must show robustness to a defined meteorological uncertainty environment.

Since the purpose of this RNP equipment standard is to allow the equipment to be certified independently of the full aircraft environment, the TOAC aircraft level performance requirement demonstration cannot be accomplished to the same level of fidelity unless full details of how the system will be integrated at the aircraft level are known. This section therefore provides criteria for validation of the TOAC performance of the system at the equipment level to allow TSO certification prior to integration with an aircraft.

N.3.2.2 TOAC Bench Test Options

This section discusses three (3) options for bench demonstration of TOAC functionality primarily, with some performance evaluation (depending on the bench capability) leading to an equipment-level approval of the TOAC function:

Option 1: Demonstrate basic functional response only**:** Test only basic functional response to TOAC situations in the absence of models of the autopilot, autothrottle, sensor, etc.

Option 2: Use representative aircraft system models: Keep the bench test similar to the MASPS TOAC bench tests by requiring representative models of the full aircraft systems such as autopilot, autothrottle, sensors, etc..

Option 3: Apportion the allowed errors: Apportion the performance requirement from the MASPS to different components of the system.

For each option, the details of the equipment test procedures are left to the equipment designer.

N.3.2.2.1 Option 1: Demonstrate Basic Functional Response Only

Without knowing how the RNP equipment will be integrated with the aircraft, this option enables the equipment to be evaluated against the functional requirements of Section N.2.1 to facilitate integration of TOAC control at the aircraft level.

This bench test should create scenarios that involve combinations of different aircraft states and flight plan constraints. The RNP equipment shall accept the following inputs from external sources:

- RTA at a fix
- Min speed for aircraft configuration
- Max speed for aircraft configuration
- Planned speed profile

Using the above inputs, the RNP equipment shall calculate an adjusted speed to fly to meet the time constraint, compare that speed to the aircraft limits, and generate an alert to the flight crew if unable to comply. The RNP equipment shall output a speed to fly and optionally a decrease/increase speed cue. The sign of the speed target adjustment shall be consistent with the sign of the time error (speed up when late, slow down when early). Alerts given shall be consistent with the predicted time error and proximity to the edges of the speed envelope.

Alternatively, if the bench test setup provides interfaces with simulated but non-representative aircraft autopilot, speed control and sensor systems, the flight scenarios in Appendix O for the equipment-level ETA compliance analysis could be used. This would allow for a more dynamic functional evaluation, including activation of the TOAC control function, etc. However, a definitive assessment of the TOAC accuracy performance would not be possible.

N.3.2.2.2 Option 2: Use Representative Aircraft Systems Models

Since the MASPS TOAC performance requirement is already a bench test of an integrated aircraft, the test of the equipment-level requirements could be approached from the direction of specifying that the RNP equipment should be tested on a bench with representative autopilot/autothrottle and sensor models, thus effectively making it similar to the TOAC performance evaluation described in the MASPS.

Although this option requires detailed integration and performance information for the external equipment, it should be possible to evaluate the TOAC accuracy performance to the level of confidence equivalent to the MASPS test, thus greatly simplifying the integration of TOAC control at the aircraft level.

N.3.2.2.3 Option 3: Apportion Allowed Errors

In some prior situations of equipment level testing, the approach followed to deal with aircraft level requirements has been to subdivide the MASPS performance requirements between the RNP equipment and the aircraft systems. In this case, a portion of the time error would be allocated to the equipment.

If the RNP equipment is tested with error-free autopilot/autothrottle and sensor systems, the requirement for 10 second error 95% of the time at the aircraft level must be reduced, with the equipment meeting a smaller number of seconds of time error. However, it is not clear how this value could be derived, or what requirements should be placed on the autopilot/autothrottle and sensor systems to ensure that the aircraft system as a whole would meet the MASPS requirement when fully integrated.

A disadvantage of this option is that, if the RNP equipment is tested on a system integration test bench incorporating actual or simulated external aircraft components, it is also not clear that the equipment level analysis could in fact assume zero external system errors.

This option is viewed as the least desirable of the three options.

N.4 Installed Equipment performance

The performance of the TOAC implementation in the RNP equipment shall be validated by flight demonstration or an equivalent approved method.

N.5 Operational Characteristics

N.5.1 Time of Arrival Control

When the RNP equipment provides VNAV and time of arrival control, the fidelity of time of arrival estimates and extent of aircraft controllability will depend upon:

- accurate definition of a flyable lateral and vertical path, including information for fix altitude constraints and speed restrictions, winds, temperatures, etc.,
- specified/known aircraft performance limits

  Note: The optional datalink interface described in this MOPS is one means to facilitate supplying additional flight path and environmental information to the RNP equipment.

Over-active throttle control is not acceptable to flight crews. The TOAC function should consider flight deck and operational effects.

APPENDIX O EXAMPLE OF ETA COMPLIANCE ANALYSIS

O.1 Introduction

This appendix provides examples of acceptable methods of demonstrating compliance with the ETA accuracy requirements defined in Section 2.2.3.1.

O.2 ETA Performance Analysis

O.2.1 Example Methods

(a) Reference Trajectory Method: This method is based on comparing ETA values computed by the system for defined sets of conditions to those of reference trajectories; this avoids concerns of needing to account for simulation performance modeling errors, which is not required to demonstrate compliance. The error between each computed ETA value and that of the reference trajectory must comply with the performance requirement.

(b) Periodic ETA Sample Method: This alternative bench test method is based on gathering periodic samples of ETA data during simulated flights along a lateral and vertical flight profile for defined sets of conditions. Each individual ETA data sample must comply with the performance requirement.

O.2.2 General Analysis Requirements

The analysis need not take navigation and guidance performance errors into account, and is expected to only include scenarios that are well-defined and predictable in both the lateral and vertical domains (e.g., no heading legs, altitude terminations, fly-over transitions, flap extension, etc.).

Demonstration of compliance is expected to include scenarios which contain each of the following parameters and related variations at least once, but it does not require every combination.

- Lateral route structure:
- Relatively straight lateral route.
- Route with at least one large fly-by turn (track change greater than 90 degrees)

  Note 1: These lateral route features may be combined into a single flight scenario.

- Phase of flight: fixes should be placed across all phases of flight (climb, cruise, and descent). There should be examples of both constrained and unconstrained fixes, including both individual or combined altitude constraints and speed restrictions, and altitude-based speed restrictions.
- Wind model: the following wind model parameters assume no intentional wind forecast modeling errors are introduced.
- Wind speeds:
  - Low speeds: average of 30 knots.
  - High speeds: average of 100 knots.
- Wind speed variation:
  - Constant wind speeds.
  - Speeds vary by altitude and/or lateral distance.
- Wind bearing:
  - Headwind.
  - Tailwind.

    - Crosswind.
- Wind bearing variation:
    - Constant wind bearing.
    - Bearing varies by altitude and/or lateral distance.

Note 2: A flight scenario with a sufficiently complex lateral path may obviate the need for wind speed and bearing variations as a function of lateral distance. If a constant wind speed/bearing environment is used, the lateral path should include at least one instance of the equivalent of a 180 degree course reversal that can be typically achieved by an RF leg, or a sequence of connected legs, such as downwind, base and final segments.

Note 3: Wind speed/bearing variations as a function of altitude need be simulated only for the descent portions of the flight. For climb, it is sufficient to define the wind speed/bearing at the cruise altitude. No climb vertical wind profile is required. For the purposes of this analysis the wind speed may be assumed to decrease linearly from the cruise altitude value to zero at the surface.

Note 4: A possible source of error due to widely spaced waypoints and wind entry data points is not expected to be considered as part of this analysis.

- Temperature model:
    - Temperatures in the system and simulation are expected to match.

O.2.3 Example Flight Scenario

An example of a suitable flight scenario, comprising 26 fixes, is described below.

- Route from KSLC to KDEN with a SID, an enroute connection, a STAR and approach: KSLC.NSIGN2.EKR.FRNCH3.KDEN using the RNAV (RNP) Z 35L approach.
- Temperature and pressure: standard

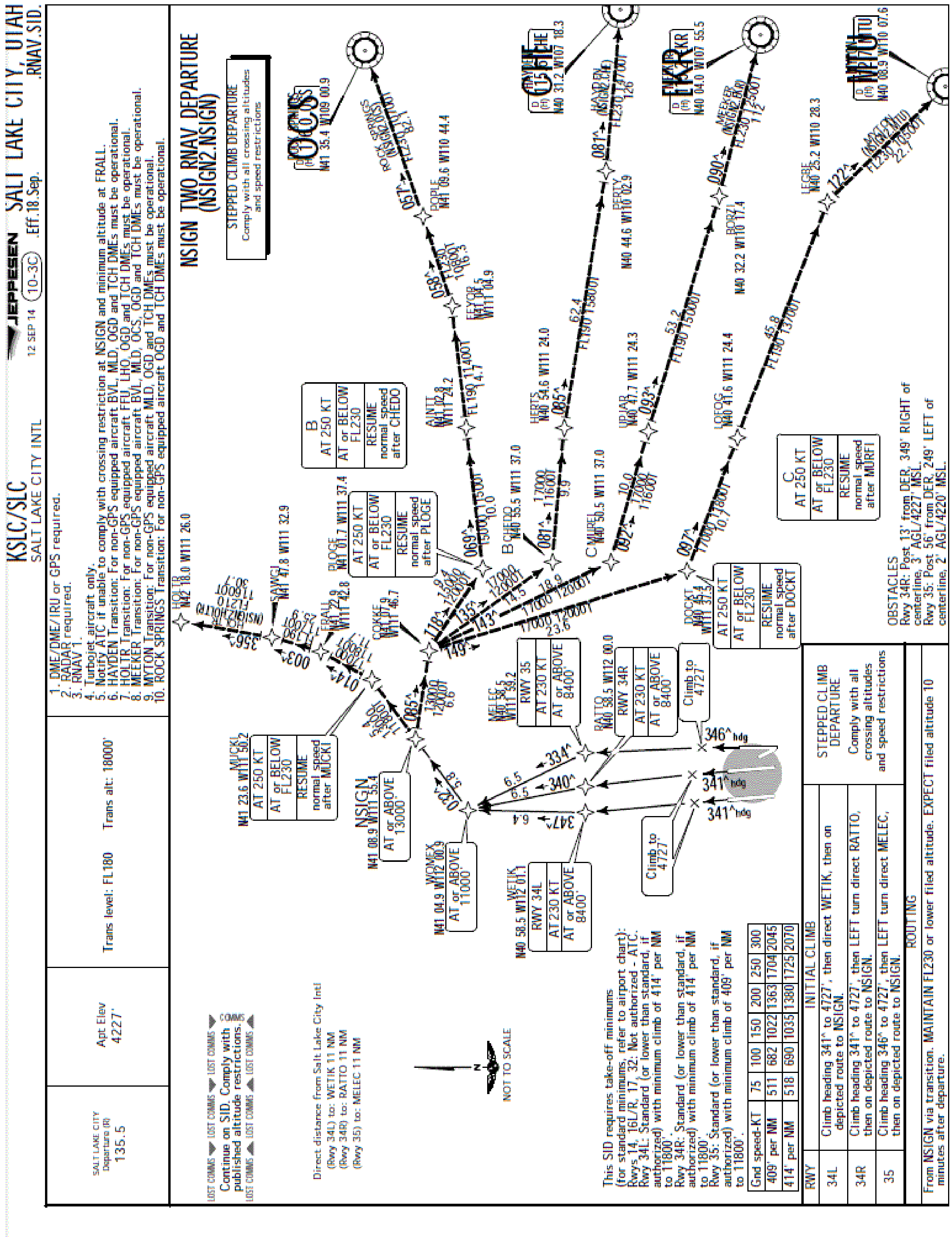

Figure O-1: ETA Performance Analysis Flight Scenario - RNAV Departure

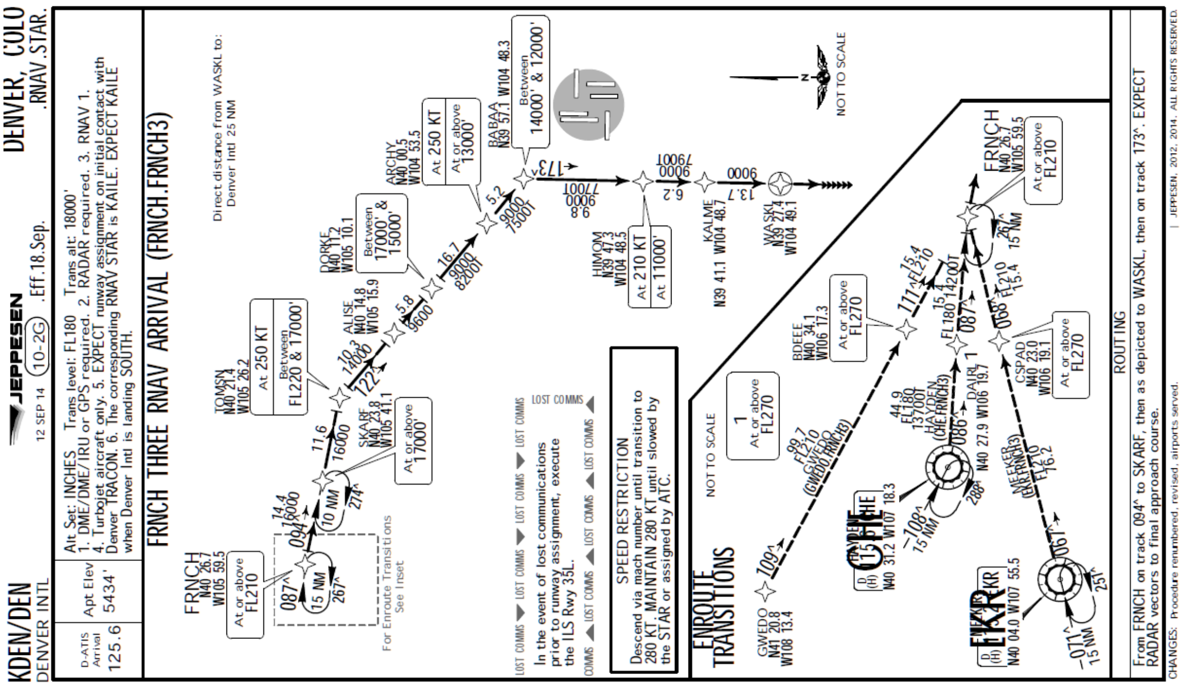

Figure O-2: ETA Performance Analysis Flight Scenario - RNAV Arrival

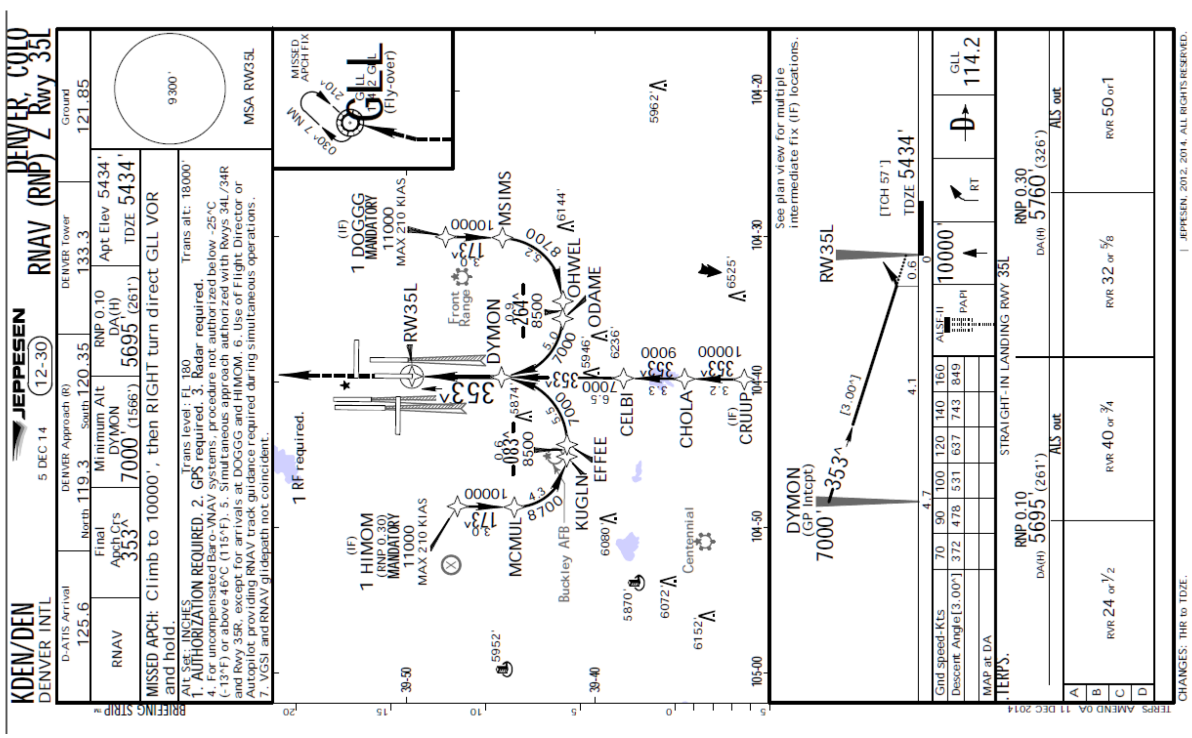

Figure O-3: ETA Performance Analysis Flight Scenario - RNAV (RNP) Approach

APPENDIX P EXAMPLE OF VNAV COMPLIANCE ANALYSIS

P.1 Introduction

This appendix provides examples of an acceptable method of demonstrating compliance with the VNAV equipment accuracy requirements defined in Section 2.2.2.6.1. The analysis is restricted to equipment-related errors only, since other VNAV error sources are outside the control of the equipment. Section P.3 provides additional information on VNAV error sources for any analysis of total vertical system error that may be performed.

While no specific tests are defined to demonstrate the accuracy of the VNAV function of the RNP equipment, the objective of the tests represented by Tables P-1 and P-2 is to demonstrate that the equipment-related accuracy requirement of Section 2.4.3.16.1 has been met for both FPA and GPP descent path constructions over a range of waypoint and altitude combinations, e.g., high, low altitude, and nominal, maximum and greater than maximum flight path angles. Alternative cases consistent with this objective will be acceptable when accompanied by rationale and supporting assessment.

The equipment required to perform the VNAV tests should be defined by the equipment manufacturer. Lateral and vertical position sensors can be simulated and can be error-free, provided the data format and resolution of the interfaces are representative. The static bench testing concepts of Sections 2.4.2.1 and 2.4.3.3 apply.

P.2 VNAV Static Accuracy Tests

The static tests are conducted by adjusting the altitude sensor simulator with specified inputs of waypoint altitude(s), station elevation (if required), and descent angle (if provided). Altimeter settings of 29.92 inches of mercury are assumed for all altitude inputs used in these tests. Entries are dictated by the problems to be solved in Tables P-1 and P-2.

The tests of Table P-1 are required for equipment that defines a vertical profile by means of a line through a single waypoint at a specified gradient angle. The tests of Table P-2 are required for equipment that defines a vertical profile by means of a line connecting two waypoints with their associated altitudes. The tests in both tables are required. The test sequence implied by the tables is not intended to be constraining, and manufacturers may perform the tests in any sequence provided all conditions are tested.

Figures P-1 and P-2 illustrate the geometries defined by Table P-1 and P-2 respectively. When completed, the following requirements will have been demonstrated.

a. Waypoint Altitude

b. Vertical Path Deviation

c. Vertical Profile

d. VNAV Equipment Accuracy Requirement

Table P-1: Single Waypoint Plus Descent Angle

Test No.	Waypoint Altitude (feet) (Note 1)	Descent Angle	Aircraft Position			Vertical Deviation Error (feet)	
			Altitude (feet)	Distance (D1) to WPT (nmi)	Reference (- = Above Path)	With Full Sensor Errors	With Error-Free Sensors
1	5,000	-9.9	9,391	4.0	-150	See Table 2-11	10
2	3,500	-6.0	5,266	3.0	+150		6
3	4,000	-3.0	4,637	2.0	0		3
4	3,000	-1.5	3,159	1.0	0		2
5	0	-1.5	3,159	1.0	(Note 3)		2
6	9,000	(Note 4)	9,450	0	-450		3
7	15,000	(Note 4)	14,650	0	+350		3
8	15,000	(Note 4)	14,750	0	+250		3
9a	15,700	(Note 4)	14,750	0	(Note 3)		2
9b	(Note 5)	(Note 4)	14,750	0	(Note 3)		

Notes:

1. Resolution of the waypoint altitude entries and vertical deviation outputs shall be 10 feet or better for Tests 1 through 5 and 100 feet or better for Tests 6 through 9.
2. A digital readout of vertical deviation would normally be positive for an aircraft altitude above the path.
3. For Test 5, set the waypoint altitude to zero. The deviation output shall indicate 150 feet or more above the path (negative, or fly-down indication).
4. No descent angle specification is required for Tests 6 through 9. A descent profile is required to ensure compliance with the waypoint/altitude constraint. Its form is left to the equipment manufacturer for specification.
5. For test 9, set the waypoint altitude to the maximum operational altitude specified for the equipment or 15,700 feet, whichever is greater. The deviation output shall indicate 500 feet or more below the path (positive). If the maximum operational altitude is below 15,700 feet, the equipment manufacturer shall specify an equivalent test.

Table P-2: Dual Waypoints with Associated Altitudes

Test No.	WPT 2 Altitude (feet) (Note 1)	WPT 1 Position (Note 2)		Aircraft Position			Vertical Deviation Error (feet)	
		Altitude (feet)	Distance from WPT 2 (nmi)	Altitude (feet)	Distance (D1) to WPT 2 (nmi)	Reference (- = Above path)	With Full Sensor Errors	With Error-Free Sensors
1	5,000	15,600	10.0	9,390	4.0	-150	See Table 2-11	10
2	3,500	9,890	10.0	5,267	3.0	+150		6
3	4,000	7,190	10.0	4,638	2.0	0		3
4	3,000	4,600	10.0	3,160	1.0	0		2
5	0	1,600	10.0	3,160	1.0	(Note 3)		2
6	9,000	12,000	10.0	9,450	0.0	+450		3
7	15,000	18,000	10.0	14,650	0.0	+350		3
8a	15,600	15,600	10.0	14,750	0.0	(Note 5)		2
8b	(Note 5)	(Note 5)	10.0	14,750	0.0	(Note 5)		

Notes:

1. Same as Notes 1 and 2 of Table P-1.
2. Waypoint 1 position is relative to Waypoint 2 (optional radial and distance). Conversion to latitude/longitude may be required on some earth-based coordinate systems.
3. For test Number 5, the deviation output shall indicate 150 feet or more above the path (negative, or fly-down indication).
4. For test Numbers 6 through 8, a straight line profile between Waypoints 1 and 2 is not required. A descent profile is required to ensure compliance with the waypoint/altitude constraint. Its form is left to the equipment manufacturer for specification.
5. For test Number 8, set Waypoint 1 and 2 altitudes to the maximum operational altitude specified for the equipment or 15,600 feet, whichever is greater. The deviation output shall indicate 500 feet or more below the path (positive). If the maximum operational altitude is below 15,600 feet, the equipment manufacturer shall specify an equivalent test.

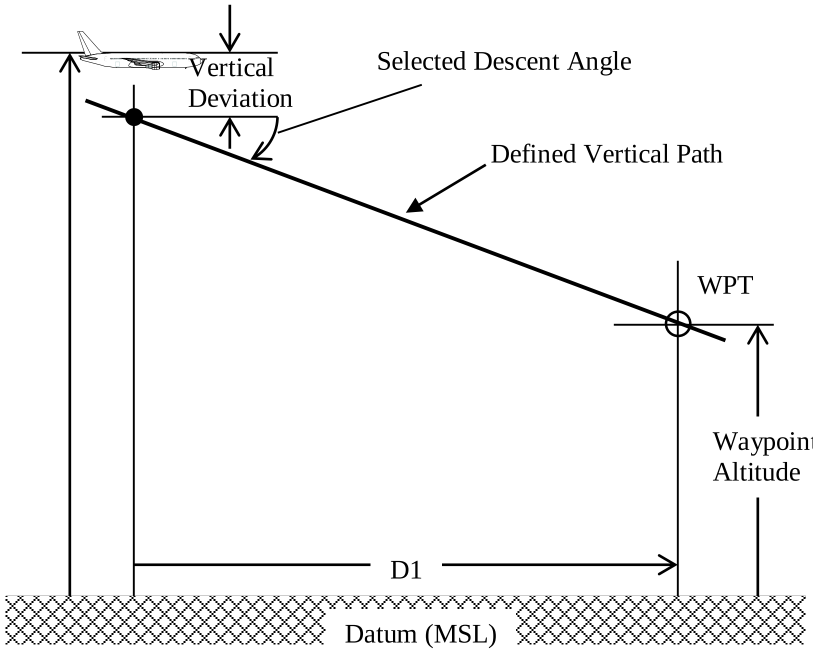

Figure P-1: Vertical Path for Single Waypoint/Descent Angle

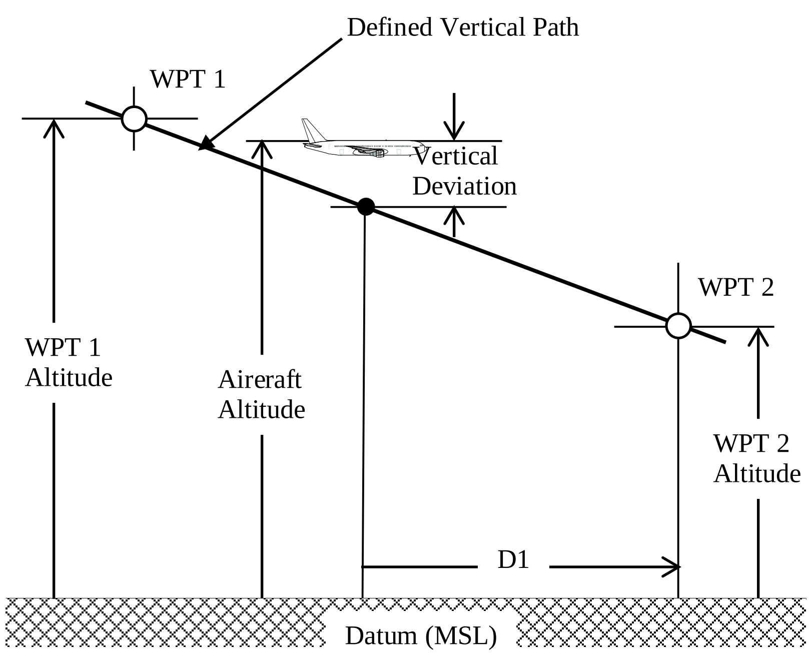

Figure P-2: Vertical Path for Dual Waypoints with Associated Altitudes

P.3 Total Vertical System Error Analysis

An analysis of total vertical system error may take the following into consideration:

a) ASE = $-8.8\text{x}10^{-8}\text{xH}^2 + 6.5\text{x}10^{-3}\text{xH} + 50$ feet, where H is the true height above mean sea level. The ASE error model generates 3-sigma values and is valid for all altitudes.

b) PSE_Z could be established by the results of constraints including manual flight with flight director or autopilot-coupled operation or on the basis of crew management of the vertical path of the aircraft. The FTE_Z allocation for manual flight operations will depend on the vertical flight phase.

On the final approach segment, FTE_Z can be assumed not to exceed 75 feet. For manual flight during other operations outside the final approach segment, FTE_Z can be assumed not to exceed 250 feet, although a lower value may be more appropriate, depending on the target VPPL and the display characteristics.

Note: For all normal operations, pilots are expected to limit the vertical deviation to +/- one half the vertical deviation full scale deflection. Brief deviations from this standard (e.g., overshoots or undershoots) during and immediately after flight path angle changes on the descent path of up to one times the vertical deviation full scale deflection are allowable.

c) HCE = Along track PEE * tan (flight path angle). In the performance analysis of the final approach segment, the Along Track PEE can be assumed to be limited to 1.225 times the RNP.

For final approach segment operations, HCE shall be accounted for during equipment performance analysis. For other phases of operations, i.e. where geometric and curvilinear vertical paths are permitted or applied, HCE is excluded from the calculation of TSE_Z. For these other operations, it is assumed that the airspace/procedure design will account for HCE.

d) Where a flight path angle defines the vertical path, PDE_Z is derived from the vertical angle error (VAE), which can be assumed to be fixed at 0.01 degree. For other operations, PDE_Z may be derived from the waypoint resolution error, which can be assumed to be fixed at 60 feet along track.

e) The only error term allocated to the RNP equipment (FTE_Z) is directly measurable. Equipment-related errors can be assumed, or can be demonstrated to be negligible. Other sources of vertical error are outside the control of the equipment.

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APPENDIX Q DESCENT PATH ILLUSTRATIONS

Q.1 Introduction and Scope

This appendix is provided to more clearly illustrate considerations and issues with the application of the MOPS vertical path construction criteria. RNP path design is expected to be a coordinated effort between those responsible for procedure design and those whose aircraft and systems are expected to fly the procedures. If the path construction criteria is applied with such coordination, where the aircraft will be in the airspace and how the aircraft will fly the procedure will be predictable and understandable. This appendix example illustrates situations where small excursions may occur outside window-based geometric path boundaries of the descent profile discussed in Section 2.2.2.2.6.1. It also illustrates the case where consecutive hard altitude constraints require a geometric vertical path between the constraints from which no such deviations are allowed.

Q.2 Descent Path Examples

Q.2.1 Window-Based Containment Boundaries

As specified in Section 2.2.2.2.6, for descents planned between any order of window and hard altitude constraints that allow maneuvering, the geometric path boundaries between the constraints are meant to limit off-path excursions, and keep the aircraft aligned with the flow of the arrival. However, small excursions are allowed and expected when deceleration is necessary but not accounted for in the path slope implied by the progression of constraints.

RNP equipment will routinely compute performance paths for minimum thrust, and short shallow segments that facilitate aircraft deceleration to meet speed restrictions. These computed segments may briefly cross a geometric boundary, but will return shortly once the excess energy has been dissipated, and will always cross on the correct side of any altitude constraints (Figure Q-1).

RNP equipment should not intentionally compute level segments followed by a descent, through a series of descent constraints just for the purpose of remaining at a higher altitude ("keep high" strategy). The RNP equipment also should not intentionally compute a steep descent and level off at the next constraint altitude ("dive and drive" strategy).

Note: Both of the above strategies may have other disadvantages. For example, the "keep high" aircraft may inadvertently cross an ATC sector boundary while in level flight, resulting in ATC workload to accommodate it. Additionally, when operating in an Interval Management environment, either strategy in descent may cause loss of longitudinal separation with a preceding or following aircraft due to the difference in groundspeed caused by the altitude difference while both aircraft maintain the same airspeed in descent.

Arrival and approach procedures that are designed to take into account aircraft performance and deceleration needs will allow RNP equipment to compute optimized performance and deceleration segments that remain within the geometric boundaries defined by the altitude constraints.

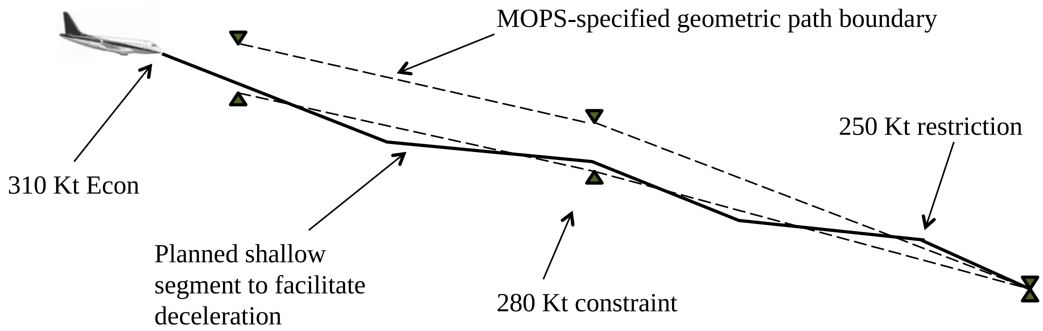

Figure Q-1: Geometric Path Boundaries Between Constraints

Q.2.2 Geometric Point-to-Point Paths

For additional clarification of intent; it is a further requirement of Section 2.2.2.2.6 that, in the case of a computed path between two AT altitude constraints, without any intermediate altitude constraints, the RNP equipment will compute a simple straight line between the AT constraints (i.e. a geometric point-to-point path). No optimized paths, shallow segments, or deceleration slopes will be computed (Figure Q-2).

Note: *Equipment designers should take into consideration that the descent gradient of the resulting GPP path may have been intentionally designed to be 1.5 degree or less, and this gradient should be respected by the RNP equipment.*

If this defined path intercepts an altitude-based speed restriction, or the lower waypoint also has a speed restriction, this path construction can only be achieved when the procedure design ensures that the slope of the geometric path takes into account the deceleration requirement.

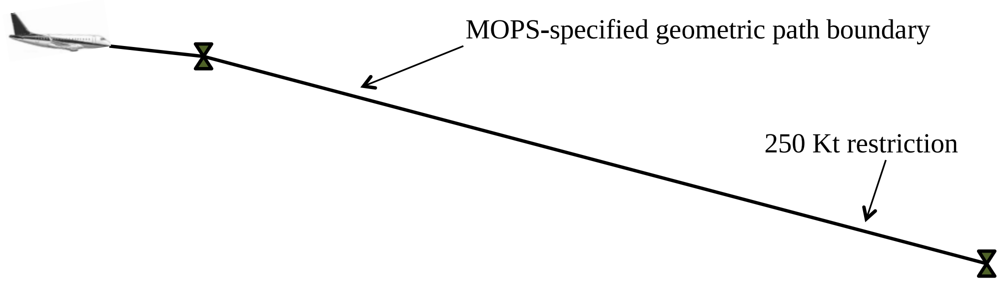

Figure Q-2: Point-to-Point Altitude Constraints