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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

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- 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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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-236(), and ED-75(). These standards specify system characteristics that should be useful to designers, manufacturers, installers and users of the equipment.

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Equipment conforming to the requirements of this document is herein referred to as "RNP" equipment. The requirements of the MOPS are intended to be consistent with the definition of RNP developed by the International Civil Aviation Organization (ICAO) Performance Based Navigation (PBN) study group and enable PBN-based operational applications. 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 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.

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.

Time of Arrival Control (TOAC) requirements are defined for RNP equipment that provide the optional TOAC capability. TOAC requirements and guidance were derived from material provided by EUROCAE WG-85 and are based upon projects in the European SESAR program.

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 aviation authorities.

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

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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 describes membership list.

Appendix A contains glossary, acronyms, and abbreviations.

Appendix B is removed.

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

Appendix K is intentionally left blank.

Appendix L contains an example application of 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

Appendix R contains application of statistical hypothesis testing to fault detection in ground-based navaids

Appendix S contains details about flight planning with terminal route transitions

Appendix T contains guidance on the use of position estimation error requirements

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.

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 be 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 requirements defined in DO-236() and ED-75().

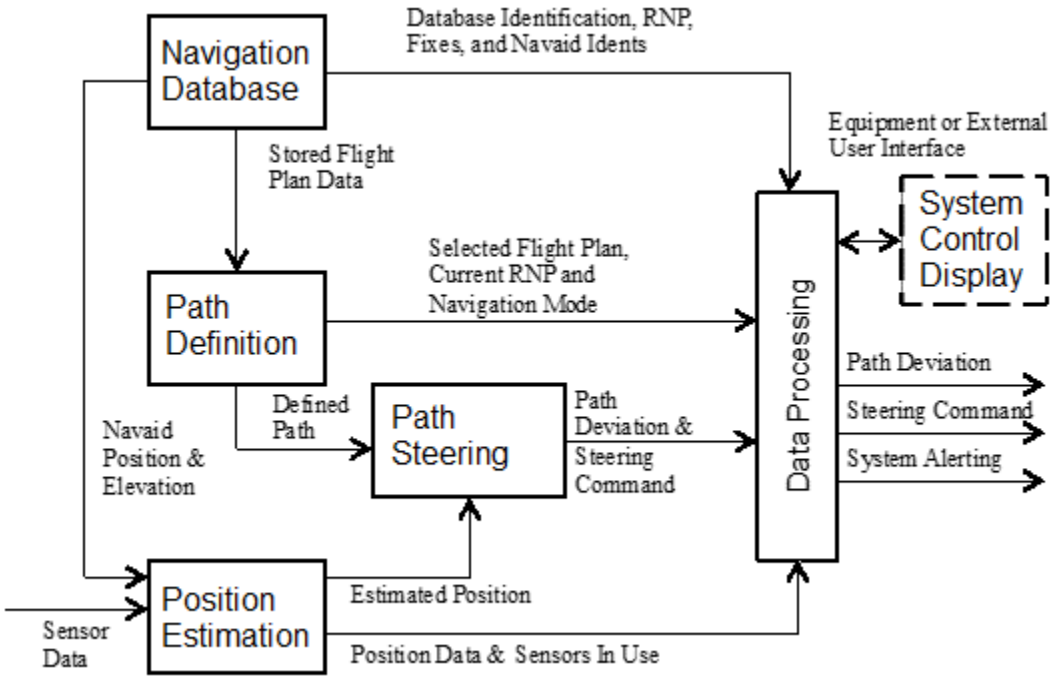


Figure 1-1: Navigation Equipment Block Diagram

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

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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.

Note 1: The MOPS uses the term constraints where specific factors (altitude, speed and location) affect the definition and specification of a path. In the case of speed, it is also specified by the term "restriction" where it is applied to ensure the safe and appropriate aircraft performance and behavior in a flight operation.

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 2: 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.

The digital air/ground datalink interface has 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.

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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

RNP operations, especially at lower RNPs, are characterized by reliable, predictable and repeatable ground path. This is achieved by aircraft equipment and operating environments that utilize the same airspace and path definitions. Additionally, the aircraft equipment and

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operating environment 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 limits defined by the RNP operations 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 (see Figure 1-4). 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 airspace with RNP routes 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.

1.4 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-236()/ED-7(), integrate the concepts of Required Navigation Performance with that of Area Navigation to provide this level of confidence.