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EUROCONTROL Guidelines for RNAV 1 Infrastructure Assessment

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Abstract

This document describes the methods and processes that should be used to evaluate if a specific navigation infrastructure is suitable to support aircraft flying RNAV 1 procedures (formerly called P-RNAV in Europe). Infrastructure that is suitable to support RNAV 1 is also suitable to support RNAV 5 procedures. This guide is based on infrastructure requirements and corresponding navigation specifications as defined in the Performance Based Navigation Manual, ICAO Doc 9613.

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CONTENTS

EXECUTIVE SUMMARY

This document describes the methods and processes that should be used to evaluate if a specific navigation infrastructure is suitable to support aircraft flying RNAV 1 procedures (formerly called P-RNAV in Europe). Infrastructure that is suitable to support RNAV 1 is also suitable to support RNAV 5 procedures. This guide is based on infrastructure requirements and corresponding navigation specifications as defined in the Performance Based Navigation Manual, ICAO Doc 9613.

Section 1 gives the generic context and background information. Section 2 describes the requirements for RNAV 1 infrastructure assessment. Section 3 explains all the steps required to conduct such an assessment, while section 4 gives more detail on specific technical topics.

1. Introduction

1.1 Background and context

Air Navigation Service Providers (ANSP) [1] have a responsibility to provide infrastructure (e.g., navigation aids) that is “sufficient” to support all procedures, including RNAV. This generic provision responsibility and the demand for “sufficiency” are documented as follows:

Convention on International Civil Aviation (ICAO Doc 7300/9 [RD 1] Article 28): “Each … state undertakes … to provide … radio services … and other navigation facilities to facilitate international air navigation …”

ICAO Annex 11, Air Traffic Services [RD 2] (RNP Routes, Attachment B), “…infrastructure must be provided sufficient to support …”

In Europe, the PBN Implementing Rule (Commission Implementing Regulation (EU) 2018 / 1048) [RD 10] requires the transition to a complete PBN environment based on GNSS. Its Annex AUR.PBN.2005 (4) requires that SID and STAR routes are based on the RNAV 1 specification. However, article 6 on contingency measures requires providers of ATM/ANS to “take the necessary measures to ensure that they remain capable of providing their services through other means where, for unexpected reasons beyond their control, GNSS or other methods used for performance-based navigation are no longer available”. Such service continuity assurance of PBN “shall include, in particular, retaining a network of conventional navigation aids”. Since conventional navigation procedures are to be withdrawn (article 5), provision of DME/DME is the only non-GNSS infrastructure suitable to support aircraft using RNAV 1 procedures.

In the case of RNAV 1, the use of DME/DME is only a contingency in the sense that it is not GNSS, as recognised in the guidance material on acceptable means of compliance [RD 13] (Annex II, GM6 on article 4): “In fact, some of the navigation specifications contemplated in AUR.PBN.2005 could be entirely supported by ground-based NAVAIDs without having to resort to GNSS signals. (…) For instance, the arrival and departure procedures within a particular terminal control area (TMA) could be designed in accordance with the RNAV 1 specification, and the primary means of navigation could be predicated on the use of GNSS. However, after a GNSS outage, reversion to a secondary DME/DME infrastructure could equally ensure that RNAV 1 applications are flown **with the same performance**.”

The initial RNAV operations with 1 NM accuracy were implemented in Europe on the basis of the P-RNAV requirements defined by JAA TGL 10 [RD 19]. Currently EASA is not granting RNAV approvals based on JAA TGL10 anymore, the applicable certification specification being CS-ACNS [RD 14] which “considers GNSS equipped aircraft and focuses on compliance with RNP navigation specifications”. In accordance with this specification, any aircraft with RNP capability will also meet the requirements of the RNAV 1 specification. Moreover, for multi-sensor RNP systems, loss of RNP capability does not imply loss of RNAV capability if an inertial or DME navigation source(s) is(are) still operable. Additionally, many aircraft with an approval based on TGL10 continue to be in operation. Therefore, the infrastructure assessment assumptions both in the ICAO RNAV 1 specification and in TGL10 relating to DME/DME positioning remain valid. While this manual also (briefly) addresses GNSS and VOR, the main focus is DME/DME positioning, as implied in TGL 10:

JAA TGL 10, section 4c) “The design of a procedure and the supporting navigation infrastructure (including consideration for the need of redundant aids) have been assessed and validated to the satisfaction of the *responsible airspace authority demonstrating aircraft compatibility and adequate performance* for the entire procedure. This assessment includes flight checking where appropriate.”

[1] The European regulations use the more generic term “ATM/ANS providers”. However, the navigation service is comprised only in the scope of the Air Navigation Services.

These standards and specifications define the responsibility for the infrastructure assessment task, which becomes more complex when intended to support RNAV applications. Detailed guidance on the relationship between navigation infrastructure, navigation specifications and their application in a specific airspace are contained in ICAO Doc 9613 [RD 6], Performance Based Navigation Manual.

Individual navigation specifications invoke particular requirements on navigation infrastructure. Among the various specifications, RNAV 1 has already been implemented in many airspaces (Doc 9613, Volume II, Part B, Chapter 3). The RNAV 1 specification was a result of harmonisation between the existing regional specifications P-RNAV (based on TGL 10) in Europe and U.S.-RNAV (based on AC90-100A [RD 15]). Infrastructure that supports airspace users approved for RNAV 1 also supports RNAV 5 approved users. The same is true for RNAV 2, even if this navigation specification is generally not used in Europe and has not been addressed in the PBN Implementing Rule.

1.2 EUROCONTROL Guidelines

EUROCONTROL guidelines, as defined in EUROCONTROL Regulatory and Advisory Framework (ERAF), are advisory materials and contain:

"Any information or provisions for physical characteristic, configuration, material, performance, personnel or procedure, the use of which is recognised as contributing to the establishment and operation of safe and efficient systems and services related to ATM in the EUROCONTROL Member States."

Therefore, the application of EUROCONTROL guidelines document is not mandatory.

In addition, EUROCONTROL Regulatory and Advisory Framework specifies that:

"EUROCONTROL Guidelines may be used, inter alia, to support implementation and operation of ATM systems and services, and to:

- *complement EUROCONTROL Rules and Specifications;*
- *complement ICAO Recommended Practices and Procedures;*
- *complement EC legislation;*
- *indicate harmonisation targets for ATM Procedures;*
- *encourage the application of best practice;*
- *provide detailed procedural information."*

1.3 Purpose and scope of the document

This guidance material is intended to provide the necessary guidance for ANSP to conduct infrastructure assessments in order to satisfy the requirements of RNAV 1, in particular assumption c) in section 4 of JAA TGL 10 (and subsequent corresponding certification documentation, e.g. CS-ACNS). The document is consistent with the Performance Based Navigation Manual by providing additional detail guidance. It can be used both to determine compliance with RNAV 1, as well as to consider what infrastructure changes could be undertaken in order to achieve it.

Performance Based Navigation provides procedures that can be flown with a variety of navigation aids and airborne sensors. However, each combination of navigation aid and sensor still needs to be assessed to see if the requirements to support a specific procedure are met. Consequently, an ANSP can declare which navigation infrastructures are available to support RNAV 1 in a given airspace (a method of publication is under preparation in PANS-AIM [RD 9]). The role of VOR is discussed in section 2.1.3.

Closely related to RNAV infrastructure assessment is RNAV instrument flight procedure validation, which looks at flyability and other operational aspects. It differs from RNAV flight inspection, which focuses on signal in space compliance with ICAO Annex 10 [RD 1] only. Guidance on instrument flight procedure validation is contained in ICAO DOC 9906 [RD 8] (Quality Manual, esp. Vol 5). Guidance on ground analysis and flight testing for PBN is discussed in chapter 8 of ICAO DOC 8071 [RD 4] (Manual on Testing of Radio Navigation Aids), Volume 1 (2018 edition). Further context on the evolution of conventional navigation aids as a complementary infrastructure to GNSS in support of PBN can be found in ICAO Annex 10, Attachment H.

Note that the term “procedure” has been used consistently throughout the document to indicate both specific procedures (as published on a procedure chart) as well as RNAV routes.

1.4 Relationship with other EUROCONTROL PBN publications

This document is one of a series of inter-related PBN publications, each of which can be used independently. Handbooks 1 & 3 are mainly aimed at ATM/operational audiences, whilst the EUROCONTROL Guidelines for RNAV 1 Infrastructure Assessment (EUROCONTROL - GUID – 114) and Handbook No 4 primarily target Infrastructure Managers. Handbooks 5 & 6, provide the link between the two audiences on subjects of shared importance.

For more information, please see the PBN Portal at:

https://pbnportal.eu/epbn/home/home.html or

Contact the NAV User Support Cell at:

nav.user.support@eurocontrol.int

EUROCONTROL NMD Training Zone:

https://trainingzone.eurocontrol.int/clix/index.jsp?dmy=1626697959459 – in particular Training Catalogue '+ Navigation'

1.5 Use of the document

This document is intended to be read and used by all civil and military ATS Providers in the EUROCONTROL Member States (41) and Comprehensive Agreement States (2).

EUROCONTROL makes no warranty for the information contained in this document, nor does it assume any liability for its completeness or usefulness. Any decision taken on the basis of the information is at the sole responsibility of the user.

1.5.1 Description of actors

Airspace Planning: Usually part of the operational division of an ANSP, airspace planners define the operational requirements for new or existing procedures. They are responsible for assessing the impact of procedures on ATC operations, including the provision of safe separation.

Procedure Design: Based on the coordination with airspace planners, the procedure design office is responsible for defining a new procedure in accordance with ICAO PANS-OPS, which takes into account the infrastructure supporting a given procedure. This includes the creation of procedure charts and all associated data, which is needed for publication in the AIP and transmission to the airborne navigation data providers. They are typically also responsible for RNAV procedure validation, and may coordinate flight validation tasks with the flight inspection organisation, if applicable.

Designated Engineering Authority: The designated engineering authority is responsible to assess that the navigation signals in space of both ground and space based navigation equipment meet the appropriate requirements to support a specific procedure. The engineering authority is typically part of the technical division of an ANSP and usually carries out its task under a regulatory charter. The engineering authority carries out the infrastructure assessment in response to the needs of the procedure design office, assists in defining flight inspection tasks and completes the evaluation of the flight inspection report. They will coordinate relevant actions with maintenance personnel. The engineering authority will also consider service volume modifications in cooperation with frequency planners.

Flight Inspection Organisation: This organisation conducts the flight inspection of RNAV procedures and supporting facilities, if required. For the purposes of the infrastructure assessment, this only includes confirming signal in space assumptions. However, in the frame of RNAV procedure commissioning, some or all of the associated RNAV procedure flight validation may be conducted at the same time.

1.5.2 Interactions during the assessment process

The need for a new or modified RNAV procedure can be due to various reasons, such as requests by airports, airspace users, regulatory requirements or airspace redesign and optimisation. Airspace planners and procedure designers will work together to precisely define the operational requirements and develop a proposed procedure that meets those requirements. The proposed procedure design, as well as any specific operational requirements (such as in section 4.5, RNAV offset's and direct-to's), are then communicated to the engineering authority.

The engineering authority then reviews the procedure and conducts the infrastructure assessment. If necessary, the engineering authority will review assumptions about the procedure or possibilities for optimisation with the procedure designer and the airspace planner. Finally, if necessary, the engineering authority will prepare the flight inspection together with the procedure designer and the flight inspector, and the flight inspection organisation will conduct the flight inspection.

Depending on the findings of the procedure design, the engineering authority analysis and/or the flight inspection results, infrastructure or even operational requirements may have to be modified. This may involve changes to the procedure itself or to specific aspects of the ground infrastructure. Such changes should be discussed by all actors to ensure that the impact of those changes is clearly understood.

ANSP's should make sure that all staff involved in PBN implementation, infrastructure assessment and evolution are appropriately trained.

1.5.3 Responsibility for Area Navigation infrastructure assessment

Nominally, the responsibility for assessing the suitability of navigation signals lies with the engineering authority. While the procedure designer may be able to undertake some of this task with the support of appropriate software tools to model signal in space coverage, these cannot replace in their entirety the need to consult with the engineering authority. This is because the engineering authority has the most up to date knowledge of signal in space performance of a particular navigation aid, both historical and actual. Therefore, close cooperation between the procedure design office and navaid engineering staff is required. Note that one of the goals of the infrastructure assessment is to provide evidence to the corresponding safety assessment that the navigation service supporting a certain procedure complies with the safety requirements.

1.6 Use of software tools

Appropriate tools should be used to assess RNAV infrastructure. While the assessment could be conducted using manual analysis and flight inspection, the use of a software tool is recommended in order to make the assessment more efficient. The software tool should be tailored to allow evaluating the infrastructure to meet the requirements imposed by the RNAV 1 navigation specification, as described in this document. In particular, the calculations should be in accordance with the accuracy error budget described herein. Such a tool could, but does not have to be integrated with, procedure design tools.

In general, RNAV infrastructure assessment tools should include a 3D terrain model with sufficient resolution and accuracy to allow predicting the line of sight visibility of navaids along a procedure service volume, including an analysis of their respective subtended angles and a variety of other geometric constraints. Note that the accuracy of the terrain model in the near field of the DME antenna can have a significant impact on the accuracy of the line of sight prediction.

It is not required to include any electromagnetic propagation modelling, since producing a realistic environment model would require significant effort and sophistication, while the need to conduct some flight inspection would not be eliminated. Nonetheless, a generic method such as 4/3 earth radius should be used.

The simulation tools may include specialised functionalities that require specific knowledge for data input, simulation execution and results interpretation. Therefore, for a correct and efficient use, it is highly recommended that the personnel that operates the application follows training courses organised by the tool developer/supplier.

The use of software tools does not exclude the need for flight inspection (additional information available in section 2.2.6). Moreover, the software simulation tools which are classified as non-safety-critical ATM applications, should not be used as the sole means for any safety critical decisions. The responsibility to make decisions or take actions that might impact safety needs to reside in further agents (human or system) that shall, among others, analyse the input provided by the application considered. Software tools classified as non-safety-critical ATM applications are in general not developed to comply to a minimum Software Assurance Level (SWAL).

Note: The EUROCONTROL software tool DEMETER and its associated training course supports the assessments described in this document. More information is available on https://www.eurocontrol.int/online-tool/distance-measuring-equipment-tracer and https://trainingzone.eurocontrol.int.

1.7 Flight Management System functionalities and track deviations

This guidance material reflects the constraints and capabilities of RNAV positioning due to FMS logic. Consequently, the infrastructure assessment as outlined here can be completed without any specific additional knowledge of FMS technology. Note that the FMS criteria for DME/DME RNAV considered are those specified by the PBN manual for RNAV 1 and RNAV 2 and associated aircraft airworthiness approval criteria specified in FAA AC 20-138 [RD 16]. These limitations are based on a minimum baseline established following a best effort in consulting with aircraft and avionics manufacturers. Note that it is still possible that some specific aircraft and avionics configurations produce unacceptable track deviations. While this is the responsibility of the specific operator, the PBN manual also recommends that RNAV track keeping accuracy be analysed (Vol. II, Part B, Chapter 3.2.8). This permits to identify such operators and to recommend appropriate regulatory action, if necessary. The track monitoring activity is not intended to impose an undue burden on service providers but should be included in the scope of Step 17 (Post implementation review) of the process defined in Vol I Part B of the PBN manual and Activity 17 of the methodology described in the European Airspace Concept Handbook for PBN Implementation (PBN Handbook No 1 [RD 11]).

1.8 Maintenance of the Guidelines

This EUROCONTROL Guidelines document has been developed under the EUROCONTROL Regulatory and Advisory Framework (ERAF) and is maintained by EUROCONTROL in accordance with this framework and in line with the EUROCONTROL Standards Development Procedures. The procedures are described in detail in Annex A.

1.9 Abbreviations and acronyms

Abbreviation	Term
3D	Three - Dimensional
ABAS	Aircraft Based Augmentation System
AGC	Automatic Gain Control
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Service
AMC	Acceptable Means of Compliance (EASA)
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
ANT	Airspace and Navigation Team

Abbreviation	Term
ATC	Air Traffic Control
ATM	Air Traffic Management
CR	Change Request
CS-ACNS	Certification Specification Airborne Communications, Navigation and Surveillance (EASA)
dB	Decibel
DEMETER	Distance Measuring Equipment Tracer
DME	Distance Measuring Equipment
Doc	Document
DOC	Designated Operational Coverage
EASA	European Union Aviation Safety Agency
ERAF	EUROCONTROL Regulatory and Advisory Framework
FAA	Federal Aviation Administration (U.S.A.)
FAS	Future Airspace Strategy
FMS	Flight Management System
FOM	Figure Of Merit
FTE	Flight Technical Error
GNSS	Global Navigation Satellite System
ICAO	International Civil Aviation Organization
IDENT	Identification (of a Navigation Aid)
ILS	Instrument Landing System
INS	Inertial Navigation System
IRS	Inertial Reference System
IRU	Inertial Reference Unit
JAA	Joint Aviation Authorities (Europe)
MSA	Minimum Safe Altitude
MTBF	Mean Time Between Failures

Abbreviation	Term
MTBO	Mean Time Between Outages
NAVAID	Navigation Aid
NMD	Network Management Directorate
NOTAM	Notice to Airmen
NM	Nautical Mile
NSE	Navigation System Error
PANS-AIM	Procedures for Air Navigation Services – Aeronautical Information Management
PANS-OPS	Procedures for Air Navigation Services - Operations
PBN	Performance Based Navigation
PEE	Position Estimation Error
P-RNAV	Precision RNAV
RAIM	Receiver Autonomous Integrity Monitoring
RNAV	Area Navigation
RNP	Required Navigation Performance
RSS	Root Sum Square
SID	Standard Instrument Departure
SLA	Service Level Agreement
STAR	Standard Instrument Arrival
SWAL	Software Assurance Level
TACAN	Tactical Air Navigation (“Military DME” with additional bearing signals)
TGL	Temporary Guidance Leaflet (JAA)
TMA	Terminal Control Area
TOGA	Take-Off Go-Around (engine power setting and other functions)
TSE	Total System Error
TSO	Technical Standard Order (FAA)
VHF	Very High Frequency

Abbreviation	Term
VOR	Very High Frequency Omni-directional Range

1.10 References

ICAO

[RD 1] Doc 7300/9, Convention on International Civil Aviation, 9th Edition, 2006

[RD 2] Annex 11, Air Traffic Services, 15th Edition, July 2018

[RD 3] Annex 10, Aeronautical Telecommunications, Volume I, Radio Navigation Aids, 7th Edition, July 2018

[RD 4] Doc 8071, Manual on Testing of Radio Navigation Aids, Volume I, Testing of Ground-based Radio Navigation Systems, 5th Edition, 2018.

[RD 5] Doc 8168, Aircraft Operations, Volume II, Construction of Visual and Instrument Flight Procedures, 6th Edition, 2014.

[RD 6] Doc 9613, Performance Based Navigation Manual, 4th Edition, 2013 (update in progress).

[RD 7] Doc 9849, Global Navigation Satellite System Manual, 3rd Edition, 2017.

[RD 8] Doc 9906, Quality Assurance Manual for Flight Procedure Design, Volume 5, Validation of Instrument Flight Procedures, First Edition, 2012

[RD 9] Doc 10066, Aeronautical Information Management, 1st Edition, 2018

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[RD 10] NAV.ET1.ST16.3000-TYP-01-02, Protocol for an Agreement for the Shared Use of Radio Navigation Aids for Area Navigation, Edition 0.2, 10 June 1997

[RD 11] European Airspace Concept Handbook for PBN Implementation - PBN Handbook No 1, Edition No 4, 21 April 2021

EU / EASA

[RD 12] Commission Implementing Regulation (EU) 2018/1048 of 18 July 2018 laying down airspace usage requirements and operating procedures concerning performance-based navigation (the PBN IR):

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R1048

[RD 13] Acceptable Means of Compliance and Guidance Material to Commission Regulation (EU) No 1332/2011 and Commission Implementing Regulation (EU) 2018/1048 on common airspace usage requirements and operating procedures ‘AMC& GM to AUR’, Annexes I and II to ED Decision 2018/013/R, Issue 2, 21 November 2018

https://www.easa.europa.eu/document-library/acceptable-means-of-compliance-and-guidance-materials/amc-gm-aur-issue-2

[RD 14] CS-ACNS: Certification Specification and Acceptable Means of Compliance for Airborne Communications, Navigation and Surveillance, Annex I to ED Decision 2013/031/R

FAA

[RD 15] AC 90-100A - U.S Terminal and En Route Area Navigation (RNAV) Operations with Change 2, March 01 2007

[RD 16] AC 20-138D - Airworthiness Approval of Positioning and Navigation Systems (Including Change 2), March 28 2014

[RD 17] TSO-C66c, Distance Measuring Equipment (DME) Operating Within The Radio Frequency Range of 960-1215 Megahertz, 18 January 1991

ARINC

[RD 18] Specification 424-22 Navigation System Database, July 23 2018

Obsolete

[RD 19] JAA Administrative and Guidance Material, Section One: General, Part 3: Temporary Guidance Leaflets (TGL):

Leaflet No. 10 Rev. 1: Airworthiness and Operational Approval for Precision RNAV Operations in designated European Airspace, OST endorsed FEB 2005

1.11 Document structure

The document is structured as follows:

- Section 1 gives the generic context and background information, describes the purpose, scope and structure of the document and lists reference documents and contains a list of abbreviations.
- Section 2 describes the requirements for RNAV 1 infrastructure assessment.
- Section 3 explains all the steps required to conduct such an assessment.
- Section 4 gives more detail on specific technical topics.
- Annex A describes the Guidelines update procedure.
- Annex B Example guidance on use of INS to support RNAV SID.

2. Area Navigation infrastructure requirements

2.1 Type of RNAV infrastructure

2.1.1 Infrastructure options

RNAV procedures should always allow the use of GNSS. However, some older RNAV avionics systems may not include GNSS. In order to provide a back up to GNSS and to accommodate DME/DME or DME/DME/Inertial - only equipped users, DME based RNAV service should also be provided where practical. This may be difficult to achieve at low altitude or in low-DME coverage environments such as islands or remote areas, if there are significant ground infrastructure siting constraints (bodies of water, mountainous terrain).

Nonetheless, since most air transport aircraft today are equipped with GNSS and DME/DME multisensor avionics, DME/DME is the preferred method to providing an alternate service to GNSS (catering to possible outages of GNSS), especially in medium to high density traffic areas. This is because it allows pilots to continue navigation based on PBN.

2.1.2 GNSS infrastructure

Because GNSS (and ABAS using RAIM in particular) is available on a worldwide basis, infrastructure assessment for GNSS differs significantly from terrestrial navigation aids. Relevant aspects such as safety assessment and GNSS performance assessment are described in the GNSS Manual, ICAO Doc 9849 (2017 edition, especially chapters 7.5 and 7.8.2) [RD 7]. In addition to considering constellation performance, the ANSP should assess that the space weather and radio frequency interference environment is satisfactory for the planned procedures, and implement vulnerability mitigation measures, if appropriate (chapter 5 and appendix F of the GNSS Manual). Further guidance on assessing and measuring GNSS interference is contained in ICAO Doc 8071, Testing of Radio Navigation Aids [RD 4].

During outages of GNSS and depending on available DME facilities, ANSPs may find it useful to consider suspending planned routine maintenance activities to ensure the availability of DME/DME as an alternate source of navigation.

Note: Updated guidance on GNSS RFI related testing is under development for Volume 2 of Doc 8071. Initial (but in some aspects outdated) guidance can be found in attachment 3 to chapter 1.

2.1.3 Conventional infrastructure and role of VOR

The main assessment task is to evaluate if the DME infrastructure adequately supports the candidate RNAV procedure. Consequently, this is the main subject of this guidance material. While VOR/DME can also provide RNAV 1 guidance, it has been found too difficult to establish harmonised criteria given fleet equipage levels and actual signal in space performance for adequately supporting the accuracies required by RNAV 1. While VOR/DME supports RNAV 5, actual usage by aircraft is limited, both in terms of useful range (some FMS only use VOR up to a range of 25 NM) and sensor priority given by the FMS. However, VOR/DME may still be a useful RNAV 5 infrastructure in cases where DME/DME coverage is difficult to achieve, such as at low altitudes or in low-DME coverage environments. Doing this would however require a consultation with airspace users to ensure that they are able to take advantage of the provided coverage. VOR/DME assessments for RNAV are simply a matter of generating cumulative coverage estimations, because geometry constrains do not have to be taken into account (such as in DME/DME). Given the standardisation challenges of VOR for TMA RNAV applications, states are encouraged not to rely on VOR but to enable conventional procedures, as a contingency measure where required (also because RNAV 5 should not be used below MSA, minimum safe altitude).

While a variety of cases may exist where VOR/DME provides a useful conventional service, such as in close proximity to airports, these are not addressed here (see ICAO Annex 10, attachment H).

Consequently, the main residual role given to VOR is as a means of crosschecking for positional awareness. Care must also be taken to ensure that FMS'es do not encounter inaccurate guidance if they revert to VOR/DME through a DME/DME coverage gap. Allowing DME/DME coverage gaps is done when using RNAV 2 and DME/DME/Inertial-equipped aircraft in a given airspace, therefore this should not really be an issue for an RNAV 1 assessment (coverage gaps should normally be filled). As the implementation of RNAV matures and the number of VOR stations is reduced, the role of VOR is expected to diminish further.

Note: With the inclusion of PBN navigation specifications in EASA CS-ACNS, TGL 10 has become obsolete. While VOR/DME is an eligible sensor to support P-RNAV in TGL 10, CS-ACNS is aligned with the ICAO PBN Manual, where VOR/DME only supports RNAV 5, but not RNAV 1. In the context of RNAV 1, VOR is only discussed as a reversionary capability in the case of loss of RNAV 1 guidance.

2.2 RNAV procedure service volume and DME coverage criteria

2.2.1 RNAV procedure service volume

The airspace or service volume required for an RNAV procedure is given by the boundaries of its procedure design surfaces (e.g., primary and secondary areas). The infrastructure assessment should consider a sufficiently large area to either side of the procedure centreline to include or bound these surfaces appropriately. In the vertical dimension, the infrastructure is assessed for the minimum altitude of the published procedure. The term service volume will be used herein for RNAV procedures, while the term coverage volume will always refer to individual DME facilities supporting an RNAV procedure.

2.2.2 Designated Operational Coverage (DOC)

Designated Operational Coverage (DOC) is the term used to declare the coverage boundary of a navaid. The DOC is used in frequency assignment planning and ensures that co-channel and adjacent channel facilities are sufficiently far away to satisfy desired-to-undesired signal ratios. This ensures that avionics using a DME inside its DOC are fully protected from interference from other DME facilities (which could introduce positioning errors if not detected by on-board reasonableness checks). The ANSP is responsible to ensure that the navaid meets ICAO Annex 10 requirements within DOC, including minimum field strength. Thus, for a DME to be used in the infrastructure assessment process, its DOC needs to include the associated RNAV service volume. The basic approach to the infrastructure assessment is for the ANSP to ensure that a minimum set of qualifying DME is available. The DME/DME RNAV procedure can only be implemented if a suitable minimum set of DME facilities within DOC range is confirmed. Attaining such a minimum set may in some cases require an extension of DOC, either omni-directionally or on a sector basis, and could include specific altitude constraints. A DOC extension will need to be coordinated with the appropriate spectrum authority. This may include an additional, concentric cylindrical DOC with a larger radius but a lower altitude compared to the existing DOC. Such a "Double-DOC" may allow exploiting more of the actual facility coverage volume without adding to frequency congestion.

In addition to identifying a minimum set of qualifying DME, ANSP are also responsible to ensure that all of the DME that are within DOC range along the procedure under evaluation provide signals in compliance with ICAO Annex 10. This is inherent in the definition of coverage: coverage is achieved if all ICAO Annex 10 requirements are met in a given airspace / service area (DOC). Conversely, an ANSP has no responsibility to verify signal quality outside of DOC, even if such signals are receivable.

However, in areas where many DME within DOC are available, the burden to check all such DME may become excessive. This can be the case at large aerodromes with high density operations. Based on available flight inspection data, evidence, experience and expert judgement by the engineering authority it is possible to reduce the amount of flight inspection. This can be further supported by a monitoring of aircraft track keeping during the initial operations phase.

2.2.3 Geometric constraints due to FMS tuning

Due to the implementation of DME selection for RNAV in FMS, DME facilities should not be relied upon if the facility is at a distance of more than 160 NM or less than 3 NM, independent of the published DOC. Furthermore, if the elevation angle from the facility to the aircraft is more than 40 degrees, it should also be excluded.

2.2.4 Figure of Merit (FOM)

Some aircraft FMS make use of the Figure of Merit (FOM) coded in the ARINC 424 database [RD 18] for selecting DME facilities. The FOM is a value that can be adjusted by database providers, and does not necessarily match the DOC. It can also be different between providers, and FMS can interpret the FOM differently. It is the responsibility of the aircraft operator to ensure that needed DME facilities are not excluded from a navigation solution due to FOM. This is why it is important to ensure that the DOC for a DME facility is published in the state AIP. Aeronautical data providers are encouraged to ensure that the FOM appropriately reflects the largest DOC range that is authorised for a particular DME facility.

Note: Information provision on navigation aids in the AIP and associated digital data sets is under development / review by ICAO (currently, most ANSP publish the DOC in the navigation facility remarks column). While the latest ARINC 424 coding standard includes a data field to define the facility service volume in accordance with the DOC, this field is not used by current FMS.

2.2.5 ILS - Associated DME facilities

Some RNAV systems do not use ILS associated DME facilities, especially if they have a range offset. Range offsets have been implemented to ensure that the DME distance to the runway reads zero at the threshold, when the transponder is installed elsewhere (for example at the mid-way point of the runway or at the ILS localizer site). Another challenge is that aircraft have no means to determine if the ILS-DME coverage is omni-directional or sectorised. Note that FMS identify ILS-associated DME through the “VHF tuning channel”, i.e., by checking if the frequency is an ILS Localizer frequency as defined in ICAO Annex 10.

Due to these challenges, the use of ILS-associated DME facilities to support RNAV is discouraged. However, if ILS-associated DME provide suitable omnidirectional coverage without a range offset, while providing coverage value from a geometry point of view, their use could be considered. This will require verifying with airspace users their DME selection logic for RNAV.

2.2.6 Use of software tools, flight inspection and flight validation

The initial infrastructure assessment should be conducted by using a software tool to identify DME facilities that meet the requirements and constraints identified above. If the software tool predicts clearly sufficient coverage consistent with the experience from conventional use and regular flight inspection, additional, RNAV-specific flight inspection is not necessary. However, if the number of available DME facilities is low with coverage near the limit, additional flight inspection is recommended. The flight inspection should ensure that stable and accurate DME signals are available with sufficient field strength on the RNAV procedure path in space and be used to refine the quality of the software-based assessment. It is generally sufficient to flight inspect the RNAV procedure centreline, except when coverage of required facilities is expected to only partially cover the RNAV service volume.

The omission of flight inspection should always be based on engineering judgement, based on expertise in radio propagation aspects and knowledge of actual facility antenna patterns, as well as experience with having flight inspected the facility for conventional use. If a facility has no associated conventional use, at least a commissioning flight inspection is recommended to confirm signal in space performance in airspaces where the facility will support RNAV operations. This should include verifying the absence of unusual multipath.

All new RNAV procedures need to undergo instrument flight procedure validation, in accordance with ICAO Doc 9906, Volume 5 [RD 8]. If the procedure validation includes a validation flight with a suitably equipped aircraft, signal in space quality of the DME's supporting the procedure should always be verified.

2.3 Accuracy

2.3.1 Introduction

In addition to ensuring the availability of sufficient DME coverage, accuracy must also be considered. In the context of this guidance material, discussion of accuracy is focussed on contributions to the signal provided by the ground-based infrastructure: the signal must meet (or exceed) the accuracy requirement at all points in the defined RNAV procedure service volume. While the accuracy requirement for individual DME signals in space to support RNAV is consistent with the existing accuracy requirements in ICAO Annex 10, it is necessary to also verify if the overall error budget for RNAV 1 (as described below) is being met under the given geometry.

2.3.2 Total System Error

Lateral Track keeping accuracy for RNAV 1 is defined as Total System Error (TSE) and is required to be equal or less than ±1 NM for 95% of the flight time. TSE is derived from the Root Sum Square (RSS) of Navigation System Error (NSE) and Flight Technical Error (FTE). NSE incorporates Position Estimation Error (PEE), Path Definition Error (PDE) and display error. For the purposes of the infrastructure assessment, PDE and display error can be assumed negligible. PEE is composed of the signal-in-space error and the airborne receiver error. This section focuses on the dominant allocations in TSE, namely NSE (PEE) and FTE.

The first level of accuracy partitioning is between the Flight Technical Error (FTE) and the Navigation System Error (NSE). For RNAV 1, a value of ±0.5 NM (95%) is used for FTE. This is consistent with ICAO Doc 8168 (PANS-OPS) [RD 5] and Doc 9613 [RD 6], which generally consider being established on a procedure when within half of full scale deflection (full scale in terminal area RNAV mode is ±1 NM). While the use of flight director or autopilot is recommended, ±0.5 NM FTE is achievable in manual flight. As FTE and NSE are treated as independent errors, this FTE allocation provides for a maximum permissible NSE of ±0.866 NM (95%) using the root sum square formula. These errors are treated as circular errors, and no further allocation into along- and cross-track components is done.

2.3.3 DME/DME accuracy formula

The NSE is partitioned into two contributions: one from the airborne equipment (interrogator) and one from the ground equipment (transponder), including signal in space propagation effects. As the minimum requirement for providing RNAV with DME ranges is to have 2 DME's available with suitable geometry and sufficient range, the following DME RNAV accuracy formula has been agreed (PBN Manual, Vol. II, Part B, Chapter 3.3.3.2.2.g):

$$2\sigma_{DME1/DME2} \leq 2\frac{\sqrt{\left(\sigma^2_{DME1,air}+\sigma^2_{DME1,SIS}\right)+\left(\sigma^2_{DME2,air}+\sigma^2_{DME2,SIS}\right)}}{\sin(\alpha)}$$

Where: σ_{SIS} = 0.05 NM (or larger value if required),

σ_{air} is MAX {(0.085 NM, (0.125% of distance)},

α = subtended angle (must be within 30° to 150°).

This formula is used to determine if a specific DME pair is able to support the intended procedure. It is assumed that DME positioning is zero-mean (equivalence of 2σ and 95% requirements), and thus the $2\sigma_{DME/DME}$ result is evaluated against the maximum NSE of 0.866 NM derived above. This maximum NSE is also used as the limit in evaluating INS coasting over coverage gaps.

2.3.4 Aircraft and Signal in Space DME accuracy allocations

The allocation for σ_{air} is based on FAA TSO C66C [RD 17] or equivalent certification standards. Note that the range dependent term starts to dominate at ranges exceeding 68 NM. Despite being many years old, this is the most modern DME interrogator certification standard. Meeting performance equivalent to TSO C66C is required by the RNAV 1 and RNAV 2 specifications in the PBN Manual. TGL 10 (and subsequent certification standards) stipulates that the typical performance of eligible aircraft satisfies the overall accuracy requirement. This implies that the responsible airspace authorities allow the infrastructure assessment to be based on the assumption that RNAV 1 approved aircraft meet the performance of TSO C66C, consistent with the PBN manual.

The Signal-in-Space allocation (0.1 NM, 95%) includes an allocation for the ground transponder (0.081 NM according to ICAO Annex 10) and the remainder for propagation effects such as multi-path.

2.3.5 Impact of accuracy requirement on DME/DME coverage

The cases where DME/DME coverage cannot be supported due to exceeding the accuracy requirement are rare. It is normally only a factor when DME pairs need to be relied on at large distances. This is also the difference between assessing DME/DME for RNAV 1 versus RNAV 5. The accuracy requirement can have an impact in RNAV 1 assessments, whereas the error budget is sufficiently generous in RNAV 5 that only geometry constraints need to be considered.

2.3.6 Relationship between accuracy and route spacing

Accuracy is specified for RNAV on a 95% probability basis. This covers normal performance of the navigation system. It does not cover rare-normal performance or performance due to system failures. It also excludes blunder errors, which by their nature can lead to significant deviations. Route spacing is directly linked to normal performance, but has to take account of the potential for system failures and provide adequate safeguards to monitor and detect large track deviations. Therefore, the route spacing will have to consider the environment in which RNAV is being implemented, including the available surveillance system performance and the contribution of any monitoring tools. These elements are outside of the scope of this document which deals only with the available navigation infrastructure as it relates to the Position Estimation Error (PEE).

2.3.7 Relationship between infrastructure assessment and procedure design

The components of the accuracy error budget used for infrastructure assessment and procedure design have been harmonised at the ICAO level. However, as their respective objectives differ, the application of those components is not identical. Procedure design ensures sufficient protection from obstacles, whereas infrastructure assessment adds an additional layer of robustness to ensure that a minimum set of actual DME facilities adequately supports the procedure, taking into account all signal in space aspects. It is possible that an RNAV procedure is feasible from an obstacle clearance point of view, but not from an infrastructure or a safety point of view.

2.4 Other requirements

2.4.1 Co-channel facilities

With proper DOC declaration (see section 2.2.2) and frequency assignment methods, avionics should not be able to lock onto co-channel DME facilities (e.g., geographically separated facilities with the same frequency and pulse spacing). However, a few isolated cases of such tracking errors have been reported, presumably due to specific atmospheric conditions. Additionally, most FMS exclude co-channel facilities if they are within line of sight. Consequently, such facilities should be excluded from the infrastructure assessment. Note that avionics may lock onto a co-channel facility if the intended, closer facility is out for maintenance. Some multi-channel DME interrogators are not able to decode the facility IDENT, precluding pilots from detecting co-channel errors (other than possibly observing map-shifts).

2.4.2 Multipath

Depending on the geometry between terrain, the DME site and the RNAV procedure, signal reflections can occur, which distort the time delay measurement. This is possible for example in hilly and mountainous areas or near lakes, and can include cases where the reflected signal is stronger than the direct signal. Such phenomena should be detected in flight inspection. If a facility is found to provide misleading signals in a relevant area (as in, stationary multipath exceeding the accuracy error budget) the procedure should not be authorised for RNAV using DME/DME only.

2.4.3 Specific considerations for SID's and STAR's

Especially in areas with significant terrain, the infrastructure assessment needs to ensure that sufficient RNAV service is provided even at the lowest altitudes used for the RNAV procedure. Consequently, the minimum vertical profile is to be evaluated, including any restrictions such as minimum crossing altitudes or minimum climb gradients. The effects of differences in barometric altitudes are assumed negligible given the achievable accuracy of signal reception modelling based on terrain data only. Basing the assessment on true altitudes (or standard pressure altitudes above the transition level) is therefore acceptable for most locations (i.e., locations with very cold climates should consider using the equivalent worst-case barometric altitudes in infrastructure assessments).

For SID's, DME ranges need to be available for a sufficient amount of time before the FMS can be expected to provide a position solution. This time is 30 seconds (PBN Manual, Vol. II, Part B, Chapter 3.3.3.2.2.b). Consequently, for a SID to be used by DME/DME only equipped aircraft, the RNAV portion of the SID can only begin at a point that is derived from the minimum altitude where sufficient DME coverage exists plus a distance along the SID taking into account an appropriate maximum speed of such aircraft. The procedure design office should coordinate maximum speed assumptions with the specific users to ensure that the assumed operating scenario is realistic.

Most aircraft with DME/DME/Inertial systems are capable of providing suitable RNAV from take-off by means of the runway threshold update (TOGA Switch). Inertial coasting on the runway update can provide sufficient accuracy for RNAV 1 for several minutes. Inertial coasting is further discussed in section 4.4.2. and Annex B.

If DME/DME only users need to be able to fly the RNAV SID, and DME/DME coverage is not available as of a suitable altitude above aerodrome elevation, then the initial part of the SID needs to be based on conventional navigation. This may have an impact on airspace capacity.

For Terminal Area SID and STAR procedures where DME coverage is a challenge, it is recommended to always conduct flight inspection in order to confirm the specific altitudes of DME reception. Note that while on STAR's DME tracking may continue below line of sight, DME acquisition on SID's generally begins right at line of sight. Hence, the flight inspection should always be conducted in the correct direction (climbing or descending along the procedure).

3. DME/DME infrastructure assessment process

3.1 Introduction

This section describes the process that should be followed in order to assess whether DME/DME RNAV infrastructure meets the requirements as specified in section 2. While this assessment is nominally geared towards existing DME/DME infrastructure, it can also be used to evaluate how infrastructure changes will optimise RNAV service. More discussion on optimisation considerations, such as the treatment of DME/DME gaps, is contained in section 4.4. Note that this assessment process proves that DME based RNAV is possible using a specific minimum set of qualifying DME facilities. This does not mean that aircraft operations on the procedure will actually use the exact same set of DME facilities.

3.2 Process Overview

Step 1: Collect Necessary Data

Step 2: Identify Individual Qualifying DME Facilities

Step 3: Establish Supporting DME Pairs

Step 4: Identify Specific Issues

Step 5: Prepare and Conduct Flight Inspection

Step 6: Finalise Assessment and Implementation Measures

Note that steps 2, 3, 4 and 6 are best conducted with the support of software tools. More information on the use of tools is contained in section 1.5. The steps in this process may need to be iterated if any limitations are identified whose mitigation has an impact on the foreseen procedure.

3.3 Input data collection

The engineering authority should receive all the necessary information from the procedure design and airspace planning office. This includes all waypoint coordinates, path terminators and any vertical profile restrictions (minimum climb gradients, minimum crossing altitudes, speed categories etc.), offset, direct-to or other operational requirements, as well as the outer boundaries of the secondary protection surfaces.

3.4 Identify individual qualifying DME facilities

Using a terrain modelling tool, determine which DME facilities are within line of sight to each point of the procedure service volume and are usable by all FMS's (range more than 3 NM & less than 160 NM, elevation angle less than 40 degrees).

From the list of DME facilities that are within line of sight, eliminate all facilities that are ILS-associated or have a co-channel station within line of sight. Note the (closer) DME with a co-channel facility for coordination of maintenance actions.

If a suitable DME facility is not under the authority of the organisation performing the assessment, identify the responsible organisation (private regional aerodrome operator, ANSP in a neighbouring state, etc.). Also note any facilities known to have been first installed prior to 1989 (refer to section 4.6 for explanations).

3.5 Establish supporting DME pairs

Define sufficient possible combinations of pairs of DMEs at each point within the procedure service volume, based on the list of suitable facilities identified in the previous step. For each possible combination of qualifying DME pairs, evaluate if the subtended angle constraints are met (within 30 to 150 degrees). For each such pair, calculate the resulting NSE budget performance and check if they meet the accuracy requirement of ±0.866 NM (95%).

If a specific DME pair is the only one available for a portion of the procedure, any DME that is new to that pair must have been visible for at least 30 seconds (given an appropriate maximum speed of user aircraft) prior to being used as a valid pair.

If any DME is required to support the procedure at a range greater than its current DOC, an extension of the DOC (either omni-directional or on a sector basis) is needed. The engineering authority should contact the state's frequency planning office in order to determine is an extension of the DOC is possible. This may also require coordination with neighbouring States.

3.6 Identify specific issues

3.6.1 Critical DME

If only one valid pair of supporting DME exists, both DME facilities are considered critical to the procedure. If a particular DME is common to the list of all supporting DME pairs, that DME is critical as well. A DME is critical when an outage will disable RNAV positioning (using DME/DME only). The infrastructure assessment needs to identify the number of critical DME facilities that support a procedure. Refer to section 4.3 for considerations related to critical DME facilities.

3.6.2 Identify DME facilities with a potential to have negative effects

In addition to the qualifying DME pairs, identify DME facilities for the flight inspection to evaluate for any deleterious effects on the navigation solution, e.g., those providing receivable signals that may not meet ICAO Annex 10 requirements. These may be DME facilities whose signals are receivable at far distances at low elevation angles (such as facilities along the previous flight path), or have significant terrain or other reflectors near the site and/or propagation path. Military facilities (TACAN), old and out of State installations may also deserve specific consideration. Because avionics are required to exclude DME facilities with negative effects from their RNAV solution, this activity is not required and is thus not intended to impose an undue flight inspection burden on the service provider. However, due to the fact that the presence of such signals could impact specific operators, a preliminary investigation prior to approving the RNAV procedure for operations may be justified.

3.7 Prepare and conduct flight inspection

3.7.1 Review existing flight inspection records

For each DME in the list of supporting pairs, review existing flight inspection records. Note any specific issues, such as AGC unlocks (unstable tracking) in certain areas, which may deserve special attention. If sufficient recent records are available which cover all or part of the candidate DME facilities in the relevant airspace, all or part of the flight inspection may be omitted.

3.7.2 Prepare flight inspection data

Prepare the list of DME facilities to be flight inspected and communicate any findings (such as incomplete coverage of entire procedure volume) to the flight inspection organisation, including any specific factors to be considered. This data needs to be made available together with the same input data that was required for the assessment performed with modelling (including the path definition, vertical profile, etc).

It is recommended that the procedure design office and the engineering authority coordinate closely with the flight inspection organisation (and ATC operational staff) in the planning and preparation of the infrastructure assessment and flight inspection to make sure that all aspects are considered as efficiently as possible. This will minimise the operational impact of the flight inspection.

The role of flight inspection is to confirm signal in space compliance with ICAO Annex 10, e.g. coverage (availability) and accuracy of individual DME facilities supporting RNAV, as discussed in section 2. No amount of modelling can accurately predict what the signal in space will look like in all cases. Especially at lower altitudes, adverse influences due to reflections and shading are possible.

3.7.3 Flight Inspection equipment considerations

It is recommended to use a flight inspection system with the capability to record multiple DME signals simultaneously and accurately in order to minimise the required number of flight inspection runs (i.e., multi-channel DME analyser). Flight inspection of DME supporting RNAV procedures is identical to flight inspection of the DME as a conventional facility, except that the RNAV inspection ensures that ICAO Annex 10 requirements are met along the procedure path (where determined by the foregoing analysis to be necessary). Such paths may be geographically separate from where DME signals have been inspected in the past. Guidance on this topic is also available in ICAO Doc 8071, Volume 1 [RD 4].

Because the accuracy error budget cannot be met after the DME interrogator goes into memory mode, such occurrences constitute a gap in coverage (except when the memory mode is triggered by the IDENT).

Current flight inspection systems are generally not well-suited to determine exact limits of coverage. This is due to AGC calibration limitations, as well as because angles of incidence from different DME ground transponders vary greatly (variation of aircraft-installed antenna gain pattern). Consequently, simple calibrations of the horizontal antenna gain pattern cannot be more accurate than 5 to 10dB. For field strength measurements accurate to 3dB, 3D installed gain pattern and antenna voltage calibration needs to be employed. Additionally, for an efficient detection capability of multipath distortions, it is recommended to observe the baseband pulse video in the time domain. Such a capability may also aid in identifying (and if possible removing) the causes of propagation distortions. These methods are primarily relevant if there are gaps in DME coverage.

The accuracy required of the flight inspection system in ICAO Doc 8071 to conduct DME flight inspections is sufficient for RNAV 1 flight inspections.

3.7.4 Periodicity of flight inspection

Periodic flight inspection is not required for RNAV procedures. This is based on the assumption that periodic inspection of individual DME facilities is conducted in line with ICAO recommendations, and that such inspections will also detect issues with associated RNAV procedures. However, if a DME facility does not support any conventional navigation applications (has only been installed to support RNAV, typically a stand-alone facility), the ANSP should define a suitable flight inspection periodicity similar to what is required for DME supporting conventional procedures. If pilot or track deviation reports are received, specific investigations using flight inspection may be necessary.

3.8 Finalise assessment and implementation measures

The engineering authority should assess the flight inspection report to see if the assumptions in the initial assessment have been confirmed, or if any unforeseen effects have been discovered and take the appropriate action for remedy.

If any DME facilities are identified as being deleterious to the navigation solution, they need to be removed from the list of supporting DMEs and corresponding pairs (if applicable). While it is possible to identify such DME facilities on a procedure chart for de-selection by the pilot during a low-workload period of flight, it is not recommended to base the procedure on DME/DME or DME/DME/Inertial in such a case. Except for signal adjustments taking place during periodic maintenance actions, no such cases have been reported so far. Thus, this should be a rare phenomenon.

All DME facilities that are found to support the procedure need to have their AIP facility entries verified to ensure that the DOC matches the required and verified range. If necessary, a DOC extension process needs to be initiated. This information can be used by aircraft database providers to ensure that valid (and needed) DME facilities are not excluded from the RNAV solution due to the

FOM being too small. Any critical DME, or any facility requiring deselection (if permitted), should be clearly designated on the procedure chart and in the AIP (see section 4.3).

Depending on the findings of the assessment, maintenance actions may be recommended, to ensure full compliance of the facility to ICAO Annex 10 requirements in its coverage volume.

If the assessment has identified required DME facilities that are not maintained by the entity responsible for the RNAV procedure, service level agreements may be necessary (see section 4.2). Additionally, DME's identified to have a co-channel facility within line of sight and taken out of service during maintenance may cause unacceptable navigation performance for some users. Consequently, the procedure should be suspended (for DME users) during maintenance of such a facility.

All findings and assumptions of the assessment should be appropriately documented and compiled in a report. The report needs to be archived in a way that it can be consulted when procedure changes are being considered.

4. Technical topics

4.1 Negative elevation angles

Especially in terrain constrained areas, there may be a desire to rely on DME facilities at negative elevation angles with respect to the procedure (for example, a STAR leading into a valley airport with a DME on a nearby mountain). While this is generally not foreseen in ICAO standards, experience so far indicates that there are no specific reasons not to allow this. Also, no FMS logic has been identified that would exclude such facilities.

However, since DME aircraft antennas are usually mounted on the bottom of the fuselage and ground transponder antennas not optimised to radiate below the horizontal plane, significant variations in received signal strength are possible along the procedure. Consequently, if a DME is to be relied upon that is above the procedure altitude, careful flight inspection is required to confirm good signal reception. It is recommended to include additional signal margin before accepting the use of such a DME and include a note in the AIP. Additionally, track keeping performance should be specifically monitored during the initial operations phase of the procedure.

4.2 DME facilities not under ANSP control and Service-Level Agreements

If a required facility is not under the control and maintenance of the ANSP that is providing for operations on the RNAV procedure, it is necessary to coordinate maintenance actions, especially if the facility is critical. If the facility is not critical, the ANSP should evaluate what redundancy remains if such a facility goes out of service. This may also depend on the equipage level of the procedure users (e.g., how many aircraft on the procedure are equipped with DME/DME RNAV only) and the operational environment.

In this situation the ANSPs should consider signing a service level agreement (SLA). The need and the required level of formality for such agreements has to be decided by the regulatory authorities of the State or States involved, in accordance with the provisions of the applicable European Regulations for the provision and certification of Air Navigation Services.

4.3 Critical DME facilities

It is the responsibility of the appropriate authority in view of traffic density, environment and equipage mix to determine the acceptability of critical DME facilities.

If critical DME facilities are identified according to the process in section 3.6.1, the impact of a critical DME outage needs to be assessed in coordination with operational experts. It is advisable to conduct scheduled maintenance on such a facility only when it is not in operational use. If a critical DME facility is identified and accepted, it is recommended to review maintenance records and practices to ensure that the MTBO of the facility is maximised to the greatest extent practicable.

Because an outage of a critical DME causes a non-availability of guidance for RNAV users exclusively equipped with DME/DME, it is not advisable to deny the procedure to better-equipped users (e.g., those with DME/DME/Inertial or GNSS – which will be most users). Consequently, the existence of a critical DME needs to be declared on the procedure chart, such that DME/DME users can plan for and/or execute a diversion. ANSP's will need to ensure that AIS and ATC staff understand the connotations and possible impacts of a critical DME outage. It may also be advisable to inform local operators known to use DME/DME-only RNAV equipment.

If an authority decides that critical DME facilities are not acceptable, alternatives are to either base the procedure on GNSS only or to require inertial capability in addition to DME. The acceptance of such measures will depend mostly on the anticipated user fleet equipage levels.

Note: the above is written in the context of significant operational use of the DME/DME infrastructure.

In airspace where most users are equipped with GNSS, and the DME/DME infrastructure is provided to help ensure continued operations when GNSS is not available, the considerations above apply primarily during situations of GNSS outage.

4.4 Gaps in DME/DME RNAV service and VOR/DME reversion

If there is an insufficient number of qualifying DME pairs to support the procedure (either zero or one to two if critical DME are to be avoided), then there is a gap in DME/DME RNAV coverage. This can be at any point along the procedure, including SID procedures following a take-off, e.g., prior to attaining a sufficient altitude to enter DME coverage.

Note that since some FMS systems revert to VOR/DME navigation upon loss of DME/DME, the available VOR/DME accuracy should also be assessed (by flight inspection) to ensure that the VOR does not introduce excessive position errors (e.g., errors greater than the assumed inertial or dead reckoning drift rate as detailed further below).

The infrastructure assessment process should identify the boundaries of such gaps as exactly as possible. This is done by taking into account the (flight inspected) boundaries of DME coverage and the 30-second positioning delay. There are various mitigations available for consideration. The choice of one or more depends on the operational environment. One mitigation of DME gaps is to declare DME based RNAV as unsuitable and require GNSS for the procedure. Such a decision will need to be coordinated with airspace users. The following alternative measures can be taken to mitigate such gaps:

4.4.1 Dead reckoning

If the gap is during a straight path segment, the aircraft can continue on course based on dead reckoning. However, the corresponding procedure design tolerances need to be applied. Route spacing will most likely need to be increased. This requires an appropriate iteration with the procedure design specialist and the airspace planning office.

4.4.2 Inertial Navigation Systems (INS or IRU)

If an ANSP chooses to require DME/DME/Inertial systems, it will make the procedure unavailable to users equipped with DME/DME only systems. It requires assessing the coasting performance of the inertial system given the navigation accuracy achieved prior to entering the gap, and the expected speed of the aircraft. The following set of criteria can be used for an assessment of inertial drift performance:

Initial position error is either the last DME/DME achieved accuracy or 0.17 NM (95%, NSE) for a runway update. The inertial drift rate is 2 NM/hour (95%)[2]. The speed to be assumed should generally correspond to the slowest expected user. This can be derived from PANS-OPS speed categories.

The gap that can be covered by inertial coasting is dependent on meeting the same 0.866 NM (95%) NSE requirement as for DME/DME.

For SID’s, not all DME/DME/Inertial equipped aircraft are capable of performing a runway update (e.g., TOGA switch). If this is required, it needs to be appropriately communicated to airspace users.

Further detail on the use of inertial to support SID is given in Annex B.

4.4.3 Resiting existing or installing new DME facilities

Using the geometry criteria outlined in section 2, the ideal location of one or more additional DME facilities can be determined. The desired locations then need to be matched up with realistic sites. Ideally, this will be in locations where the ANSP already operates other infrastructure. Especially stand-alone DME facilities can be installed near other CNS infrastructure (e.g., generally a lot easier

[2] EASA CS-ACNS — BOOK 2 — Subpart C – Navigation (NAV) APPENDIX B — INS/IRU STANDARD PERFORMANCE AND FUNCTIONALITY

than with VOR/DME)

4.5 RNAV offsets and Direct-To's

Air Traffic Controllers frequently employ offsets to RNAV routes or procedures. These offsets can be quite large. Also, some waypoints of a route of procedure may be omitted by issuing a direct-to shortcut. Nominally, the assessment process described herein is not able to cater to such practices, e.g., the controller will remain responsible to maintain separation, terrain clearance and monitor route conformance. However, if airspace planners are able to specify a maximum offset or direct-to requirement, the engineering authority could potentially support this with an appropriate area based infrastructure assessment, following the same principles described in this document. As an alternative to offsets, if operational requirements permit, it is advisable to design and publish a new RNAV procedure or route parallel to the existing route.

4.6 DME transponders first installed prior to 1989

DME ground facilities installed prior to 1 January, 1989 are not required to meet all current ICAO Annex 10 requirements. It is expected that by now, such transponders are no longer in operation. However, in the rare cases that they are and will be considered in the provision of DME/DME based RNAV, the compliance of such equipment to current ICAO Annex 10 requirements must be verified, in particular with respect to the timing reference. If the transponder is using the second pulse as a timing reference, special caution is needed both in the assessment of multipath and in the application of the accuracy error budget. The key concern with second pulse timing is that a delayed first pulse could distort the second pulse timing reference significantly. Consequently, the environment of the transponder needs to be analysed to see if there are any potential reflectors (large building fronts or roofs, mountains or lakes) that could cause reflections into the procedure path with delays that correspond to the spacing of the DME pulse pairs. Such areas deserve specific attention during the flight inspection. A second issue is that the interrogator pulse spacing becomes relevant if the transponder uses second pulse timing, because practically all current interrogators use the first pulse as a reference. Consequently, the pulse spacing tolerance needs to be taken into account in the accuracy error budget. This can be done by adding the term into the Signal-in-Space allocation:

$$\sigma_{SIS} = \sqrt{\sigma^2_{Transponder} + \sigma^2_{PulseSpacingTolerance} + \sigma^2_{Propagation}}$$

Where: $\sigma_{PulseSpacingTolerance}$ = 0.02 NM

Remaining terms see sections 2.3.3. and 2.3.4

Depending on the multipath environment, this may lead to values of σ_{SIS} larger than 0.05 NM.

ANNEX A - Guidelines update procedures

It is necessary to periodically check EUROCONTROL Guidelines for consistency with referenced material. The Guidelines are also expected to evolve following real project and field experience, as well as advances in technology.

The main objectives of a regular review are:

a) to improve the quality of the requirements (e.g. clarity, testability, etc.);
b) to verify that the level of detail published is adequate;
c) to ensure that design-oriented requirements, imposing unnecessary constraints to technical solutions, have been avoided;
d) to ensure that advances in technology are properly reflected;
e) to make all stakeholders, including industry, aware of the latest developments.

The update process for this EUROCONTROL Guidelines may be summarised as follows:

Stakeholders may provide change proposals either through existing working arrangements (e.g., established working groups) or by sending a formal Change Request (CR) to the generic email address: standardisation@eurocontrol.int

The CR needs to provide following minimum elements:

• Originator information (name, Organisation, contact details)
• Guidelines title, number and edition date
• Page, chapter, section (subsection) where the issue appears
• Description of the issue and reason for change
• Specific change proposal text (incl. potential alternatives, if any).

Main steps towards a revised version:

• Agency (Standardisation unit) will assess each CR in coordination with content owners, classify the urgency and establish the CR impact category (major, minor or editorial).
• Agency will then prepare resolution proposal(s) and, if needed, discuss those with the originator and/or relevant working arrangements. Note: CR will be grouped into "change packages" to consider reasonable update cycles.
• Agreed changes will be integrated into a revised version "Proposed Issue" including a summarised list of changes.
• Consultation will be performed in accordance with the CR impact category identified:
  o Major changes need consultation at working layers (e.g., working group or Team)
  o Editorial changes may be implemented directly at any stage though grouped with change packages.

Note: Identified errors which may cause potential problems when implementing, may be corrected directly via separate "Corrigendum".

The Agency will apply this process in an objective and impartial way and will consult stakeholders as needed and in line with the formal Standards Development Process.

ANNEX B - Example guidance on use of INS to support RNAV SID

This guidance is provided as an example basis for using INS Runway Updating to support RNAV-1 Standard Instrument Departures. This text has not been published or endorsed by the UK CAA.

DME Assessment Criteria in Support of the Implementation of RNAV 1 Standard Instrument Departures (SIDs) at UK Airports

1.0 Purpose

The purpose of this Policy Statement is to detail the DME assessment criteria, including low level DME/DME coverage, in the support of RNAV 1 departures implemented at UK airports. The policy also details the rationale for determining the acceptable boundary of low level DME/DME coverage taking due account of the aircraft's Inertial capability.

2.0 Introduction

The navigation infrastructure required to support aircraft positioning on RNAV 1 Standard Instrument Departures (SIDs) is either GNSS or DME/DME. Whilst GNSS provides positioning from the runway, the CAA does not advocate sole reliance on the system. Not all aircraft are equipped with GNSS and the signal-in-space is vulnerable to both intentional and unintentional interference, including environmental effects such as those due to space weather. Therefore the safety case prepared by the ANSP is required to address the loss of GNSS through either back-up means of aircraft positioning e.g., DME/DME and/or procedures e.g., tactical vectoring using surveillance means.

DME low level coverage within a TMA environment is particularly challenging, particularly for the initial climb and first turn within a SID where line of sight propagation and the DME 30-150 degree included angle geometry requirements make it very difficult to provide a robust DME/DME positioning service at low levels. Even in the DME rich and benign terrain of the London TMA, redundant coverage deteriorates rapidly below approximately 2000'.

Within the Manchester and Scottish TMAs where the DME environment is 'thin' and there are significant terrain intrusions restricting the line of sight to the DME transponders, DME/DME RNAV coverage is poor and in some areas there is no position fixing capability due to poor geometry, or cover is only available in excess of 3000'.

At the majority of airports, the lowest levels of the SID DME/DME coverage will not be available and the only navigation positioning on the SID will be derived from GNSS as the cost of providing DME coverage will be high in relation to the small benefit.

Aircraft fleet survey data collected by IATA, EUROCONTROL and the CAA which was used to inform the development of the Future Airspace Strategy (FAS) indicated that the majority of aircraft meet their RNAV 1 capability through the use of GPS with approximately 2% being reliant on DME/DME for their RNAV 1 position fixing capability. Of these aircraft, the vast majority will be equipped with an Inertial Navigation or Inertial Reference System (INS or IRS). The Inertial Reference System provides an autonomous means of aircraft positioning which over a short period is adequate for the purposes of maintaining accuracy for RNAV 1 i.e., +/- 1 NM accuracy for 95% of the flight time. The IRS also provides an acceptable means of compliance for short term radio outages along a route where coverage may become restricted.

3.0 DME Coverage

The target level of DME/DME coverage redundancy selected to support RNAV 1 operations within a volume of airspace or airport operation will necessarily be dependent on the intended ATC operation. From an airport's perspective, the ATC operation will have defined locations for tracks over the ground, a defined frequency of usage for those tracks, and an estimated equipage levels for aircraft due to make use of those tracks in terms of RNAV 1 compliance. All of these elements will have an impact on the desired level of DME/DME coverage redundancy.

From a ground navigation infrastructure provider viewpoint, it is desirable to provide a network which is robust to single failures of DME ground equipment and adequately supports current ATC operations, as well as any potential future developments as much as practicable. The cost of adding or re-locating DME ground equipment is significant and the target will be to avoid this as much as possible, so deploying a robust network will be a key consideration.

It may be assessed as reasonable to target a practicable level of redundancy whereby levels of 'limited redundancy' are minimised. Areas of 'limited redundancy' are those where a 'critical' DME is present, common to all candidate DME pairs from which a valid position may be derived. In this scenario the infrastructure provider avoids effort in providing coverage for small volumes of airspace which may require an excessive level of DME equipment to achieve, and the ATC operator has a solid level of performance upon which base its airspace design. When very low failure rates attributable to currently deployed DME ground equipment, and credit for alternative means of navigation such as GNSS, and inertial navigation systems carried by the majority of aircraft within a controlled airspace volume are considered, this underpins the feasibility of this approach. The alternative means of navigation will provide support for small areas lacking in coverage at certain points.

4.0 Boundary of Low Level DME Coverage

The Navigation System Error requirement to support an RNAV 1 operation (1 NM Total System Error - TSE) is taken as 0.866 NM, assuming a 0.5 NM Flight Technical Error (FTE). This is taken from The EUROCONTROL Guidelines for RNAV 1 Infrastructure Assessment EUROCONTROL GUID-114 Edition V2.0 [Reference 1]

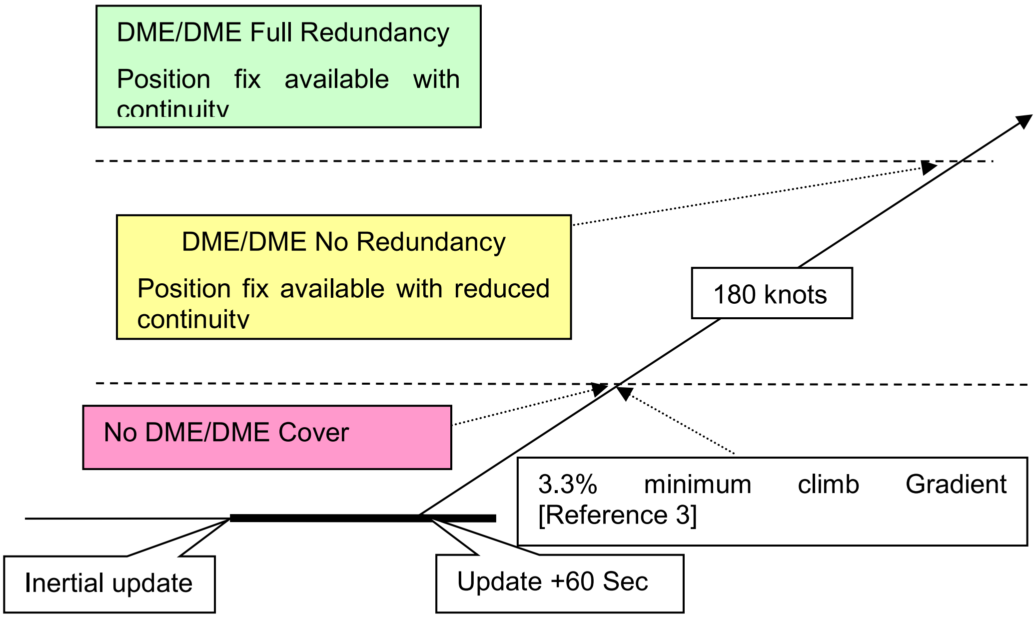
The drift performance of the IRS is assumed to be not greater than 8 Nautical Miles per Hour [Reference 2][3]

This suggests that the IRS can maintain the Navigation System Error below 0.866 NM for a maximum period of 6.5 minutes from the time that the inertial update was performed.

The figure below shows that as the aircraft climbs, it will initially have no DME/DME position and will be reliant on the aircraft inertial guidance, at some level dependent on the terrain and DME environment the aircraft will receive a DME derived position from a single DME pair. At some later height the aircraft will receive additional DME pairs and have a redundant DME capability which is tolerant to DME failure.

It is important that the transition between IRS and DME updates do not result in discontinuities in position thereby creating significant map shifts.

[3] The performance currently specified by EASA CS-ACNS is 2 NM/hour (95%) – see 4.4.2 and note 2



In determining the maximum time from Inertial Update to DME/DME fixes being available, it is assumed that:

- Aircraft becomes airborne 60 seconds after automatic runway update;
- Aircraft velocity is 180 knots with a minimum climb gradient of 3.3% leading to a rate of climb of 600 feet per minute (10 feet per second).

To maintain the required Navigation System Error (NSE) that accumulates through inertial drift, a DME position is required no later than 5.5 minutes after the aircraft is airborne[4].

Allowing 30 seconds for the aircraft to receive DME range signals and the FMS to compute a radio position update, the time interval is reduced to 5 minutes.

If a worst case calibration error of 100m (0.054 NM) is considered i.e., error relative to either the threshold or displaced threshold used for the automatic runway updating, an additional reduction of 24.3 sec should be applied.

This suggests that an aircraft inertial capability is capable of maintaining RNAV 1 performance providing that DME Coverage is available above 3,300 feet relative to the height of the runway[5].

- 30 sec rule: subtract 300 ft, coverage available approx. 3000 feet above airfield elevation
- 100m error: subtract additional 243 ft, coverage available above approx. 2,760 feet above airfield elevation

4.1 DME Redundancy

Although the ideal situation would be for the DME positioning to be supported with full redundancy (e.g., tolerant to any single DME transponder failure) at a height of 3,300 feet, this is unlikely to be achieved in areas of difficult terrain or low transponder density.

4.2 Availability

Drawing a parallel to a conventional SID that is defined by a VOR radial and a DME range, the availability of both the VOR and the DME is required to navigate along the SID in a conventional

[4] Considering the drift rate performance of 2 NM/h the maximum inertial coasting time increases to 25 minutes.

[5] Based on a maximum inertial coasting time of 25 minutes, the minimum DME coverage height becomes 15,000 feet assuming that the same climb gradient is maintained.

manner. The failure of either the VOR or the DME will result in the unavailability of the conventional SID.

The availability of an RNAV 1 SID supported by a single DME/DME pair is therefore no lower than the availability of a conventional SID defined by a VOR and DME.

4.3 Continuity

As the aircraft climbs into the coverage of additional DMEs and has a fully redundant DME positioning capability, there is a substantial reduction in the positioning continuity risk. Assuming a DME MTBF of 10,000 Hours, the loss of positioning would be:

- Single DME Pair $2 * 10^{-4}$ /Hr
- Two independent Pairs 10^{-8}/Hr

It should be noted that the aircraft exposure rate to the lower continuity risk is limited as it is expected that the aircraft continues to climb into redundant DME Coverage. In practical terms, the continuity risk equates to a potential loss of DME positioning in the single pair area once every 5000 hours, the probability of the DME failure whilst an aircraft is undertaking the SID is extremely low. The impact of the loss would also be mitigated by the on board inertial capability that had been updated by the DME before failure.

The acceptability of the height that redundant DME coverage becomes available is therefore a business continuity issue as failure of a specific DME may prevent the use of the SID for aircraft without GNSS which should be assessed by the airport operator or ANSP for acceptability.

4.4 Summary

From the above worst case assumptions, the minimum DME coverage should be for a single DME pair with acceptable geometry to be available at not greater than 2,760 feet above the airfield elevation.

5.0 RNAV 1 SID Charting

From the DME coverage assessment conducted during the design and development of an RNAV 1 departure procedure, any limitations identified by the ANSP should be published on the appropriate chart. Sample chart wording might include:

ADDITIONAL RNAV DATA

1. DME/DME only procedure: no critical navaids.

2. RNAV1 SIDs are available only for approved aircraft that are either GNSS equipped or that have DME/DME and INS/IRU with automatic runway updating capability.

Extract from London Gatwick RNAV 1 SID chart [Reference 4].

6.0 References

[Reference 1] Guidelines for RNAV 1 Infrastructure Assessment, EUROCONTROL GUID-114 Edition V2.0 (this document)

[Reference 2] INS certified under United States 14 CFR, Part 121, Appendix G

[Reference 3] ICAO Doc 8168 (PANS-OPS) Volume II Construction of Visual and Instrument Flight Procedures

[Reference 4] UK AIP AD 2-EGKK-6-11, London Gatwick RWY 26L BOGNA 1X HARDY 1X RNAV 1 (DME/DME or GNSS) Standard Instrument Departure (SID) Chart

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