

The ICASC Technical Working Group view on R-NAV DME/DME Flight Inspection

Mike Spanner

Technical Director
Cobham Flight Inspection
Darlington, Durham, United Kingdom
Fax: +44 1325 333 591
E-mail: mike.spanner@cobham.com



HERVE RENOUF

Deputy Manager of DSNA/DTI flight inspection unit
DSNA/DTI
Toulouse, France
Fax: +33 562145327
E-mail: herve.renouf@aviation-civile.gouv.fr



ABSTRACT

Flight Inspection of P-RNAV procedures using ground facilities such as DME/DME infrastructure has become an issue of concern in the last few years for Air Navigation Service Providers. The documentation available, both recommendation and requirement based, that covers this subject is one hand diverse, and on the other, not detailed enough to determine the responsibility of the Flight Inspection organisation.

In order to suggest guidance to ANSP's which intend to implement such procedures and for Flight Inspection organisation who may be asked to check them, Mr Joe Doubleday, Chairman of ICASC¹, decided to entrust the ICASC Technical Working Group ITWG experts with the task of harmonizing practises on this topic.

This paper covers a review of documents that are published and readily available within the international environment. The relevance and connection between the documents are highlighted and recommendations made to guide ANSP's and Flight Inspection organisations towards a common approach to the subject.

¹ International Committee for Airspace Standards and Calibration

Introduced within the IFIS presentation accompanying this paper are some practical experiences of carrying out Procedure Inspections by some Flight Inspection Organisations and how the complete process of Procedure Validation was performed.

INTRODUCTION

DOCUMENT REVIEW

Published Documents

The ITWG identified a list of documents that were currently published on the subject of RNAV and specifically P-RNAV DME/DME. These documents² were:

- Performance Based Navigation Manual Volume I&II- working draft 5.1 final (March 07) issued by ICAO, drafted by RNPSORSG (RNP Special

² The documents were identified as available, but not all specifically reviewed.

Operational Requirements Study Group) (was called **DOC 9613- The RNP Manual**)

- Volume I Concept and Implementation Guidance
- Volume II Implementing RNAV and RNP
- Guidance Material for the Flight Inspection of RNAV Procedures- Version March 2005 issued by Eurocontrol, drafted by Eurocontrol working group and agreed by the Airspace and navigation Team (ANT).
- United States Flight Inspection Manual 8200.1- latest version FAA website
- ICAO SARPS- Annex 10 Volume 1 Radio Navigation Aids
- ICAO DOC 8071 Chapter 3, para 4 and Chapter 8, para 8.3.15 to 8.3.18
- ED75A Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation
- Evaluation of DME coverage- draft produced by NSP, Navigation Systems Panel
- JAA TGL 10, FAA AC90-100
- Technical Memorandum OU/AEC 06-24TM15689/003-3: Review of Flight Inspection Requirements, concepts, and implementation for Distance Measuring Equipment (DME) Facilities in the National Airspace System (NAS)
- Eurocontrol “Guidance Material for P-RNAV Infrastructure Assessment” V 1.0 08/10/07. This document was agreed by Eurocontrol Airspace and Navigation Team.

The last Eurocontrol document, derived from ICAO material, was found by the group to be a good reference source of information and in many places covered the material originally identified as important by the ITWG. Thus it was decided to concentrate work on this Eurocontrol document. A brief summary of this document is presented later in this paper.

Document Relationship

The number of documents that are available make it complex to determine the authority and relevance of each material. In order to structure the ITWG thoughts, the following hierarchy of documents was found to be useful:

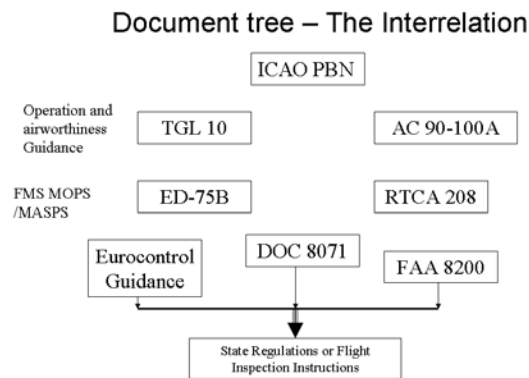


Figure 1. Published Documents.

Each country is likely to develop their own Flight Inspection procedures and policies with reference to the available documents. In a later section, some general guidance is suggested for organisations that do not have any background or experience in this domain, from which they might develop their own working policies.

SUMMARY OF EUROCONTROL GUIDANCE MATERIAL FOR P-RNAV INFRASTRUCTURE ASSESSMENT DOCUMENT

Purpose and Scope (§1.2³)

The guidance material is intended to provide the necessary guidance for ANSP to conduct infrastructure assessments in order to satisfy the requirements of P-RNAV (§4 c) of JAA TGL-10).

It can be used both to determine compliance with P-RNAV, as well as to consider what infrastructure changes could be undertaken in order to achieve it.

The document discusses both GNSS and especially DME based RNAV. The focus on DME is due to fact that accuracy error budgets become relevant in qualifying DME infrastructure for RNAV-1.

This guidance is consistent with the corresponding parts in ICAO Documents 8168 (PANS-OPS) and 8071 (Manual on Testing of Radio Navigation Aids).

RNAV infrastructure requirements (§2)

Conventional infrastructure (2.1.3)

³ Paragraph numbers refer to Eurocontrol Document “Guidance Material for P-RNAV Infrastructure Assessment V1.0 8th October 2007.

Given the standardization challenges of VOR for TMA RNAV applications, states are encouraged not to rely on VOR. Consequently, the only role given to VOR is as a means of crosschecking (for example, to detect map-shifts) and to ensure that FMS's do not encounter inaccurate guidance if reverting through a DME/DME coverage gap.

RNAV Procedure Service Volume (2.2.1)

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.

Designated Operational Coverage (DOC) (2.2.2)

DOC is the term used to declare the coverage boundary of a navaid. The ANSP is responsible to ensure that the navaid meets Annex 10 requirements within DOC, including minimum field strength.

...for a DME to be used in the infrastructure assessment process, DOC needs to include the associated RNAV service volume. This may require an extension of DOC, either omni-directionally or on a sector basis, and could include specific altitude constraints.

ILS coupled DME facilities (2.2.5)

Some RNAV systems do not use ILS coupled DME facilities. This is partly because some of these facilities have intentional offsets. Consequently, ILS associated DME facilities are not suitable to support RNAV and should be excluded from the assessment.

Use of software tool versus Flight Inspection (2.2.6)

The initial infrastructure assessment should be conducted by using a software tool to identify DME facilities that meet the requirements and constraints identified above...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. Some or all of the flight inspection may be omitted if sufficient experience/evidence exists with the adequate performance of a specific DME or set of DME's in a particular airspace.

DME/DME infrastructure assessment process (§3)

Process overview :

- Step 1: Collect Necessary Data
- Step 2: Identify Individual Qualifying DME Facilities (with software tools)
- Step 3: Establish Supporting DME Pairs (with software tools)
- Step 4: Identify Specific Issues (with software tools)
- Step 5: Prepare and Conduct Flight Inspection
- Step 6: Finalize Assessment and Implementation Measures (with software tools)

Step 1

The engineering authority should receive all the necessary information from the procedure design... 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.

Step 2

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 (3NM<range<160NM, angle<40°).

Eliminate all facilities that are ILS coupled or have a co-channel station within line of sight. Note that the closer co-channel DME may need specific coordination of maintenance actions to avoid incorrect usage of the further away DME.

Step 3

Define all 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 $\pm 0.866\text{NM}$ (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... This may also require coordination with neighbouring states.

Step 4

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... The infrastructure assessment needs to identify the number of critical DME

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 do not meet Annex 10 requirements. These are DME facilities whose signals are receivable at far distances at low elevation angles.

Military facilities (TACAN), old and out of State installations may also deserve specific considerations with respect to deleterious effects.

Step 5 Prepare and Conduct Flight Inspection

- 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 in certain areas.

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.

- Flight inspection data: prepare the list of DME facilities to be flight inspected and communicate any findings 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).

- Flight Inspection Equipment Considerations: it is recommended to use a flight inspection system with the capability to record multiple DME signals simultaneously and accurately for efficiency reasons. 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 with more confidence that Annex 10 requirements are met along the procedure path.

... Furthermore, it is not possible to get an accurate field strength measurement by automatic gain control (AGC)

voltage calibration. Hence, AGC lock status and system reply efficiency can also be used as indicators of potential problem areas.

Because the accuracy error budget cannot be met after the DME interrogator goes into memory mode, such occurrences constitute a gap in coverage.

Current flight inspection systems are generally not suited to determine exact limits of coverage. This is due to the AGC limitations mentioned above, as well as because angles of incidence from different DME ground transponders vary greatly. Consequently, simple calibrations of the horizontal antenna gain pattern cannot be more accurate than approximately 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 P-RNAV flight inspections. Which ever system is used, the measurement uncertainty requirements should be assessed and an assurance gained that they are met accordingly.

Step 6 Finalize Assessment and Implementation Measures

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 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

Technical topics (§4)

Negative Elevation angles (§4.1): 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

Critical DME facilities (§4.3): 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...The existence of a critical DME needs to be declared on the procedure chart.

Gaps in DME/DME RNAV Service (§4.4): 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 30 seconds worth of positioning delay (the DME's must be available for 30 seconds prior to being used by the R-NAV solution). There are various mitigations available for consideration.

4.4.1 Dead reckoning (§4.4.1): if the gap is during a straight path segment, the aircraft can continue on course based on dead reckoning... procedure design tolerances need to be applied

INS or IRU (§4.4.2): initial position error is either the last DME/DME achieved accuracy or 0.17NM (95%, NSE) for a runway update. The inertial drift rate is 8NM/hour (95%)

The gap that can be covered by inertial coasting is dependent on meeting the same 0.866NM (95%) NSE requirement as for DME/DME. (cf. 2.3.4 du doc P-RNAV infrastructure assessment)

For SID's, note that 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.

IMPLEMENTATION FOR A FLIGHT INSPECTION ORGANISATION

Role and responsibilities

The chain of events leading to the publication of a new or revised procedure (both conventional or RNAV) follows a process that is depicted in Figure 2.

Each step may be undertaken by one organization, or a mixture of several organizations. This will depend on the country and state regulations (or processes) in use.

It is important for an individual organization to know what its responsibilities might be and the expectations of the other organizations with which they interface with.

In the area of RNAV inspections (DME/DME), additional pre flight inspection evaluations are normally carried out leading to the need to define a set of expected data that the Flight Inspection organization might need in order to conduct an effective evaluation of the proposed procedure and navigational infrastructure.

A boundary layer exists that makes it impossible to define the exact requirements for an individual organization, as this will depend on the capability of that organization. The essential and desirable elements for DME/DME based procedures are brought out in the following paragraphs, along with some general principles that should be taken into account when evaluating these tasks.

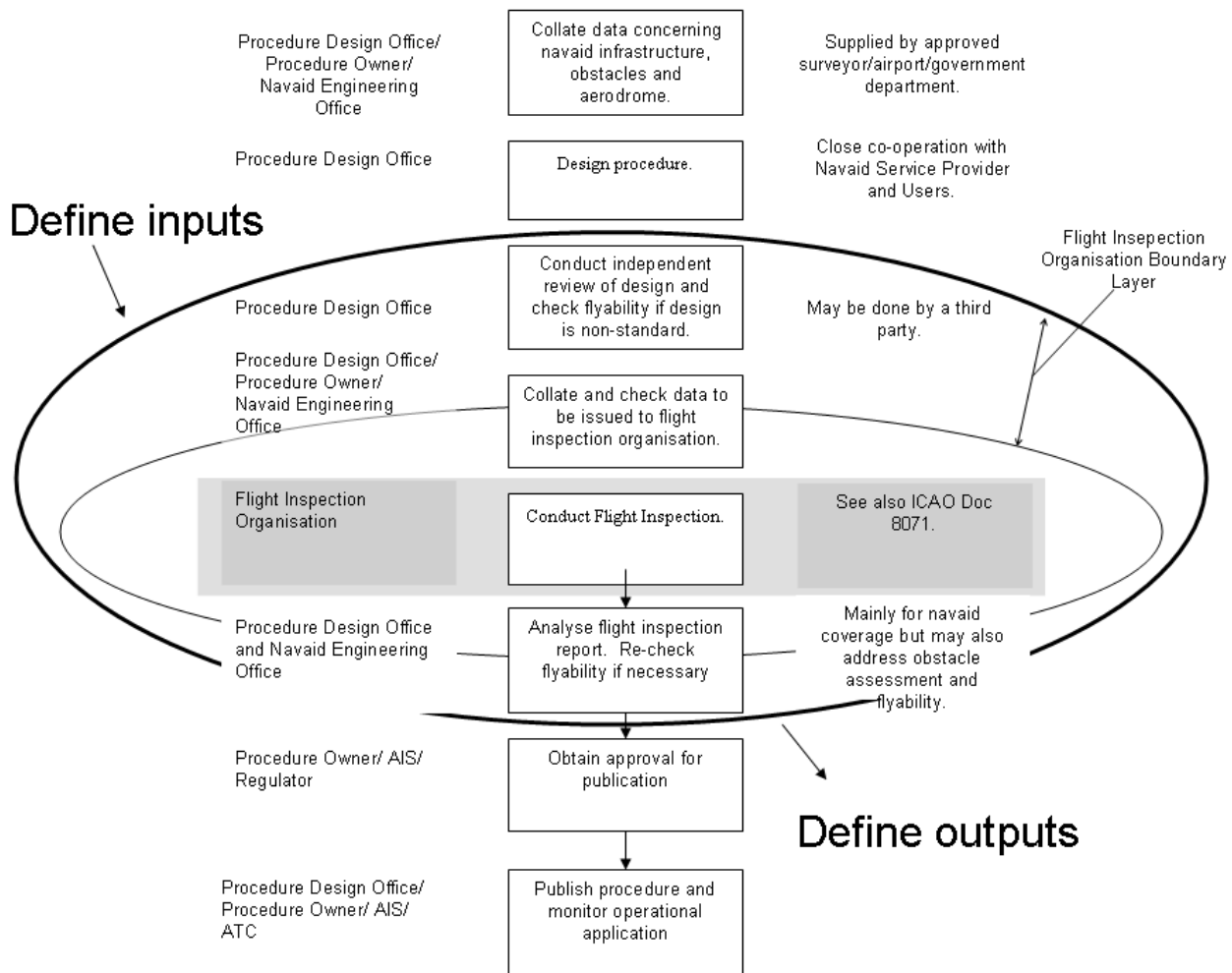


Figure 2. Procedure Design Process.

The role of Flight Inspection:

There are 2 basic elements of the DME/DME assessment:

- 1) Confirming signal in space compliance with ICAO Annex 10, accuracy and field strength of individual DME facilities supporting R-NAV.
- 2) Providing evidence to determine if the initial assessment made by the software tool has been confirmed or if any unforeseen effects have been discovered.

- define all possible combinations of pairs at each point usable by FMS ($3\text{NM} \leq \text{range} \leq 160\text{NM}$, elevation angle $\leq 40^\circ$):
- evaluate the subtended angle ($30^\circ \leq \alpha \leq 150^\circ$)
- calculate the PEE (must be ≤ 0.866 to ensure that the 1 NM TSE containment can be assured).
- identify critical DME's

Principles for Initial Assessment and Flight Inspection of DME/DME Infrastructure:

It is highly recommended for efficiency and cost saving reasons to use a software tool (terrain modelling model) in order to:

- identify individual qualifying DME facilities
- determine which DME are within line of sight

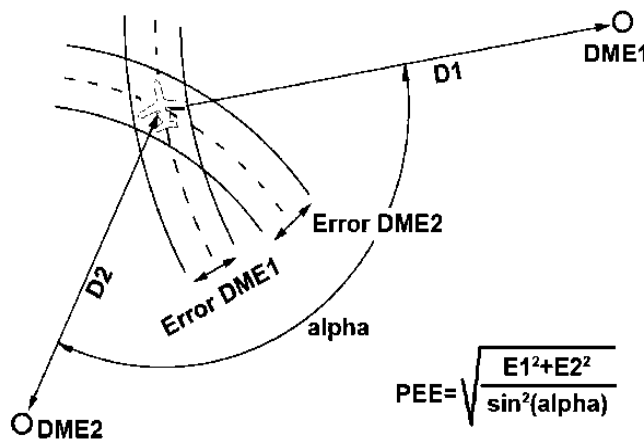
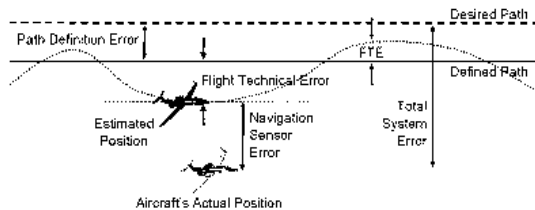


Figure 3. PEE Calculation

The TSE requirement can be met if each DME used according to the FMS selection model has less than 0.2 NM error (1σ).

Required Navigation Precision ≤ 1 Nm 95% (TSE)



TSE = Total System Error < 1 Nm (ICAO PBN Manual)

FTE = Flight Technical Error $< 0.5^4$

NSE or PEE = Navigation System Error < 0.866

With modern Flight Inspection systems, it is possible to compare the Modelled PEE prior to flight with that obtained with actual DME error results during the inspection.

It is generally sufficient to flight inspect the procedure on the centreline at the lowest published altitude⁵, however

⁴ The source of this figure is not known at the time of writing. Perhaps someone could advise the authors of this information.

⁵ When a procedure is based on Flight Levels, one should consider flying at the height resulting from the lowest potential pressure in the region. This could be up to 1800' lower than the equivalent 1013 Mb altitude.

topographical features should be taken into account when assessing which profiles to fly.

It is not necessary to flight inspect the totality of the procedures if the number of DME are sufficient in a particular airspace.

Based on experts experience and evidence (such as previous flight inspection data) some flight inspection may be omitted.

DME's that are associated with ILS's or have offsets that affect the DME range information compared to its location are not to be used in DME/DME R-NAV procedures.

A DME/DME pair must be valid for a 30 second period prior to it being used for Navigational Purposes.

Input/Output list for conduction a Flight Inspection Task

The ITWG identified the following information that should be provided as an output from the Flight Inspection task, as a way of determining the input requirements:

Output List- DME/DME	
• Required:	<ul style="list-style-type: none"> - Basic DME Accuracy as defined in ICAO SARPS for each DME - Signal in Space, peak power pulse density (determine coverage volume and restrictions) - Operational (Designated Operational Coverage, consideration of Extended Service Volume) - Critical DME performance - Whether in Scanning or Individual Fixed mode - Potential DME interference - Feedback to Procedure Designer - Notification of any DME that causes the PEE to exceed tolerance.
• Desirable:	<ul style="list-style-type: none"> - PEE for measured sample (e.g at frequency of data recording) - TSE for measured sample (e.g at frequency of data recording) - Location of DME 'unlocks' and periods of 'coasting' - Whether procedure is available with DME/DME or only as DME/DME/IRU - Flyability - Validation of DME/DME modelling - Comparison of FMS vs Flight Inspection System (but be aware of the FMS certification issue)

Figure 4. Flight Inspection Output

From this a series of Inputs were derived to enable the Outputs to be obtained:

Input List- DME/DME	
• Required:	<ul style="list-style-type: none"> - Identification of Critical DME's - A means by which the desired route can be flown - Intended procedure (waypoint data and positions of DME's) - List of DME's that are part of the procedure design (Including ranges and heights). Take note of DME's that might be used below their height. - Identification of facilities that are to be used outside of their currently defined operational volumes. - Knowledge of whether Flyability assessment is required.
• Desirable:	<ul style="list-style-type: none"> - Predicted coverage of DME's to be inspected - Consideration of Expanded Service Volumes - List of restrictions applicable to the DME's under inspection - Review of existing DME Flight Inspection records

Figure 5. Flight Inspection Output

Flight Inspection Equipment

It is recommended to use Flight Inspection equipment with the capability to record multiple DME simultaneously and accurately to save on repeating flight profiles. There are 3 possibilities to consider in this aspect:

1. Independent single channel transponders
2. Scanning DME transponders
3. Spectrum Analysis of the entire L Band

Whilst the independent transponder has the advantage of permanently tracking a station so that multipath unlocks and effective power density can be determined easily, one transponder per DME being inspected is required. This might not be possible on an airframe with TCAS fitted, due to the availability of non interfering antenna locations. The Scanning DME is relatively easy to implement and can simulate the tracking mode of a regular DME transponder, but has the disadvantage of not being able to determine power density. Specialist Spectrum Analysis techniques are now being employed by some organisations to measure the environment in a more comprehensive way which overcomes some of the limitations of a dedicated transponder.

ICAO Annex 10 suggests that the received Power Density shall be greater than -83 dBW/m^2 (-89 dBW/m^2 for post 1989 systems). If the flight inspection DME can be shown to only lock when a signal is above the required level, the lock/unlock status could be used as a crude indication that the Power Density is sufficient. Whilst not giving any technical analysis of power density levels, which might be useful for investigation of multipath effects, this method could be used to overcome the limitation posed by scanning DME's not providing a measurement of received signal level.

(Need to get agreement on this within ICASC group. Is a similar method that is used for SSR type work- minimum trigger levels.)

FMS or not

There are two schools of thought on the use of FMS's whilst carrying out Flight Inspection of R-NAV procedures. In theory, the assessment of the Navigation Infrastructure can take place by an aircraft with a suitably equipment DME analysis system and a way by which the aircraft can be flown around the correct airspace. This does not have to be by published procedure or preproduction database- it can be simply by flying a set of waypoints that take the aircraft over the relevant points of interest. However, if the flight includes validation of the procedure as designed for use in an FMS, this would require such a system fitted. Therefore, it is important to ensure that when carrying out an assessment that these two independent checks are correctly understood by the final customer, as each demand different system capabilities and have different sets of results.

- No FMS- use waypoints in BRNAV GPS= Infrastructure Verification only
- Use FMS- use preproduction or database NOTAM'd out of service= Infrastructure Verification and Procedure Validation

The Procedure Validation carried out is only valid for one type of FMS, with the database sourced via one supplier and one database packing company. Thus is not a full Validation of the entire Procedure Design to Publication process. It is beyond the scope of R-NAV flight inspection to evaluate the navigational outputs of the aircraft specific FMS. The internal operation of an FMS, which selects DME's according to its own criteria from its database and its outputs for aircraft guidance, is proprietary to each FMS manufacturer and should be considered a part of the avionics certification process, rather than a flight inspection activity.

CONCLUSIONS

The DME/DME RNAV environment poses several new issues to be evaluated that have not been part of conventional Flight Inspections so far. The current ICAO recommendation documents are not sufficiently detailed to enable a flight inspection operator to determine what the best approach to take is. The ITWG identified that this shortfall is covered to some degree in the guidance information provided by Eurocontrol. The information provided in this paper adds to that available internationally and provides more guidance for those organisations performing DME/DME RNAV inspections.

The ITWG members hope that the contribution made through this paper, derived from the international expertise across the flight inspection community, helps to increase understanding and standardisation in the Flight Inspection of DME/DME supported RNAV procedures.

RECOMMENDATIONS

- Although ICAO do not require flight checks for commissioning of RNAV procedures, all ITWG experts consider it is prudent to do so.
- Conduct a commissioning flight inspection mission to allow the ANSP to physically check “the real world” and detect any interferences or multipath problems.
- Clearly define the boundaries of the flight inspection to ensure that all parties know what each is expected to do.
- Use modeling techniques to reduce the flying overhead for multiple DME routes. Note: If a critical DME appears not to be transmitting verify with ATC that the facility is in service (this might be obvious, but has been seen in the past).
- Consider the content of the ICAO PBN Manual, FAA 8200, Euro Control P-RNAV and ICAO DOC 8071 documents as source material for developing own procedures.
- Consider the flight inspection report to include more than simple performance of a single DME (for example a chart with a direct comparison

between calculated and measured PEE, or verification of Power Density environment)

FUTURE WORK

The ITWG will continue to debate this issue and develop practical flight inspection guidance for the inspection of DME/DME RNAV procedures. Results of the meetings and proposed material will be published on the ICASC website:

avnwww.jccbi.gov/icasc

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