Qualifying DME for RNAV Use

Gerhard E. Berz
Senior Navigation Expert
EUROCONTROL
B-1130 Brussels, Belgium
Fax: +32 2 729 9003
E-mail: gerhard.berz@eurocontrol.int

Dr. Jochen Bredemeyer
Head of Research
FCS Flight Calibration Services GmbH
D-38108 Braunschweig, Germany
Fax: +49 531 23777-99
E-mail: brd@flightcalibration.de

ABSTRACT

In the context of the introduction of P-RNAV procedures in Europe, EUROCONTROL developed Guidance Material on Infrastructure Assessment. The main focus of the document is DME. The purpose of the paper is to give a brief overview of the requirements and processes described in this document and to expand on measurement issues, in particular on the use of special multi-channel DME receivers that are designed to increase flight inspection efficiency.

The latter will include data from an actual flight campaign that measured the difference in multipath environment between a ground transponder operating in first pulse and second pulse timing reference mode. The measurements were conducted with a transponder capable of switching the pulse timing reference. The analysis focus is on the qualification of the multipath environment using the baseband pulse video, and the resulting consequences on the ability of a particular DME to support RNAV procedures.

INTRODUCTION

Due to the existing base of equipped users, Distance Measuring Equipment (DME) has been identified in Europe as the sensor of choice to support Area Navigation (RNAV) in addition to or in support of GNSS (Global Navigation Satellite System). In order to meet the requirements associated with the implementation of Precision RNAV (P-RNAV [1], or RNAV-1 according to the ICAO Performance Based Navigation Manual [2]), a detailed assessment of the DME infrastructure supporting a proposed procedure is necessary. Consequently, EUROCONTROL developed, in coordination with the ICAO Navigation Systems Panel (NSP), Guidance Material for P-RNAV Infrastructure Assessment [3]. While this document has been approved to support EUROCONTROL stakeholders, it contains no Europe-specific topics[1], such that its contents can be globally applicable. In addition to giving an overview of the document, various issues relating to flight inspection that have resulted from the supporting work over the last couple of years are presented.

GUIDANCE MATERIAL OVERVIEW

One key message of the guidance material is not of a technical nature. The use of RNAV, where the interface between navigation aid service provision and aircraft avionics is less clear cut than with individual navigation aids, requires a new level of cooperation among the

[1] While the document caters to P-RNAV requiring operator approval to JAA TGL-10, none of the European specificities of TGL-10 or other P-RNAV approval documents apply to infrastructure assessment.

various actors that has typically not existed previously. While the exact organizational arrangements may differ widely between various states, those actors include airspace planning, procedure design, the designated engineering authority and the flight inspection organization. In order to ensure a well coordinated introduction of a new P-RNAV procedure, it is necessary that these parties communicate openly to ensure that the promulgated procedure will provide a satisfactory service to all potential users. This communication becomes essential especially if DME coverage is marginal, and trade-offs between operational requirements, technical feasibility and associated cost need to be found.

Once airspace planning proposes an RNAV procedure that has been found feasible from a procedure design point of view, the engineering staff of the appropriate Air Navigation Service Provider (ANSP) will conduct a detail assessment. The most efficient method to accomplish this task is through the use of a validated software tool capable of line-of-sight predictions based on a suitable terrain model. The software tool should respect all the constraints of RNAV avionic systems, which have been summarized in the guidance material based on detailed reviews with manufacturers.

It is important to see flight inspection as an essential part of the assessment that is carried out by the engineering authority. The software tool, if sufficiently calibrated by comparison to existing flight inspection data, can in some cases completely replace the need for flight inspection. This however, still assumes that regular flight inspection of individual DME transponders is being done, and requires a good knowledge of the existing signal-in-space environment. On the other hand, flight inspection is essential to provide firm data in areas where DME coverage is marginal. In this case, the role of the pre-flight inspection assessment is to identify which facilities need to be specifically inspected in which areas. The post-flight inspection report then serves to provide definitive answers on the precise limits of RNAV service. In this way, software tools, navaid engineering staff and flight inspectors work together in an integrated process to meet operational requirements.

The guidance material describes what has been outlined above in three main chapters: one about P-RNAV requirements, another describing in detail the interactions of the assessment process and one about specific technical topics. The following chapters will summarize and expand on some areas particularly relevant to flight inspection.

Infrastructure Requirements

It is recognized in the guidance material that the ideal RNAV sensor is GNSS. Only minor activities are necessary to qualify GNSS for support of RNAV in an individual state. More information on this subject can be found in the ICAO GNSS Manual [4]. However, in order to provide redundancy and enable non-GNSS equipped users to fly RNAV procedures, it is desirable to qualify DME for RNAV use wherever possible. As DME's have traditionally been deployed as a supplement to VOR, this new and VOR-independent role of DME deserves specific care. It is expected that DME infrastructure will be optimized for RNAV support in the coming years, such that standalone DME will become more common.

The basic premise of the assessment it twofold: first, it is to prove that the procedure can indeed be flown using DME facilities that meet Annex 10 requirements within their coverage. Second, it is to identify any effects that could potentially degrade the RNAV solution. For the former, NSP agreed that supporting DME need to be available within "Designated Operational Coverage" or DOC. Despite the DOC concept not being strongly anchored in Annex 10, it is commonly understood in the service provider industry and its implications are described in the guidance material. While DOC represents the limit of responsibility for the ANSP, it is also clearly recognized that aircraft can use DME even far outside of their DOC. While DME signals are principally designed in a way that if they are receivable, they provide good signals, it is the responsibility of the avionics to detect any problems with signal quality through reasonableness checking. While industry has developed a non-harmonized Figure Of Merit (FOM) to assist Flight Management System (FMS) auto-selection and auto-tuning algorithms to accomplish this task, flight inspectors can also appreciate that this does not always function perfectly. Key suspects are DME that have likely been used for good geometry as part of an initial descent, but subsequently low-horizon propagation degrades them as the aircraft enters a terminal airspace while the FMS runs out of better options to switch to.

The guidance material also explains the accuracy error budget. Despite being many years old, it has been recognized that Technical Standard Order TSO-C66C [5] is the best available avionics standard. Because of this, the error budget has been harmonized in the relevant ICAO panels and documents to be consistent with this TSO. On the ground side, the DME is expected to provide a signal-in-space accuracy or 0.1NM (95%) or less. This has been clarified to include both transponder errors and propagation effects, and is the value that flight inspection needs to confirm in addition to minimum field strength. In general, flight inspection for RNAV is most needed for Standard Instrument Departures (SID) and Standard Instrument Arrivals (STAR). An important challenge is to

be able to determine the precise start of coverage on climb on an SID as well as gaps in coverage – this can make the difference between procedures being available to DME/DME only users or requiring DME/DME/Inertial sensors.

Finally, another subject of relevance to flight inspection are co-channel facilities. Degraded RNAV system performance has been observed when the desired DME facility was turned off for maintenance, but a co-channel facility was receivable. While the desired signal would normally clearly dominate in the receiver, this scenario may pass avionics checking. If the assessment process determines that co-channel DME's could be received, a verification by flight inspection is useful. If the co-channel facility is received, then the various ANSP should coordinate maintenance actions. In general, more careful coordination of DME maintenance than needed currently may become necessary, in particular for critical DME. Critical DME are facilities that disable RNAV positioning should they fail.

Technical Topics

As explained above, a role additional to confirming nominal performance is the identification of anomalies. While it is considered sufficient to flight inspect the procedure centerline only, additional inspections may be warranted in areas where the pre-inspection analysis predicted coverage issues, out to the boundaries of the procedure design surfaces. For this purpose, capabilities to visualize the time-domain pulse-pair shapes can be useful. In addition to typically available parameters such as AGC level and reply efficiency, this provides a clear picture of present multipath distortions. Standard geometric criteria then allow identifying the potential location of any problematic reflector. It should be noted that the ground plane in the near-field of the DME transponder antenna can have significant effects that are difficult to impossible to predict with terrain modeling.

In particular in mountainous areas, DME coverage may be limited. As part of the work of NSP, some testing has been done on using DME at negative elevation angles, e.g., when descending into an airport located in a valley while using a DME that is located on top of a mountain [6], [7]. In those campaigns, no specific error effects such as through fuselage skin propagation have been identified. Thus, such DME could be usable provided this has been confirmed. Flight inspection organizations are invited to provide further data to Eurocontrol on this subject if available.

MULTI-CHANNEL DME ASSESSMENT

Standard DME interrogators used in current flight inspection systems can provide much useful data, including, most of all, an observation of the likely effects of signal anomalies when subject to receiver filtering and processing. Other useful parameters are the reply efficiency and the Automatic Gain Control (AGC) lock status. While AGC can provide a rough indication of field strength, its limitations have been explained in [8] and [9]. However, it is desirable to further develop flight inspection capabilities to enable both better efficiency of the flight inspection itself as well as provide better analysis capabilities. In particular in high-density Terminal Control Areas (TMA), it may be challenging to impossible to accommodate multiple runs of a flight inspection aircraft while only one or two DME are inspected during a single run. Moreover, standard scanning or multi-channel DME are even less suitable to provide reliable field strength measurements than regular single channel avionics. Consequently, a multi-channel capable DME receiver has been developed (referred to as SISMOS/DME, or Signal-In-Space Monitoring System). By avoiding the use of a typical receiver AGC, reliable field strength measurements of the DME pulse peak are possible. As discussed in [9], the accuracy of such measurements can be increased even further by use of 3D antenna gain calibration. This is particularly useful when flight-inspecting precise limits of coverage gaps. Unfortunately, as such a receiver only receives pulses (e.g., does not interrogate), the round trip propagation error cannot be determined. However, the shape of the visualized pulse distortions permits an analytical assessment of compliance to accuracy requirements.

Description of Dedicated Measurement Equipment

In contrast to a regular airborne DME, SISMOS is not designed to determine a Time Of Arrival (TOA) to derive the slant range between aircraft and beacon. Its intended purpose is to evaluate multipath propagation effects on various conditions which can be performed simply by reception of the signal without interrogation facility. The signal's baseband video contains the DME pulse shapes which reflect the prevailing multipath conditions. After detecting a coherent pulse pair according to the channel's specific DME mode (X or Y), their pulse videos are recorded directly on a hard disk during measurement campaigns.

SISMOS/DME has only one but well designed physical Radio Frequency (RF) channel and achieves pseudo-multichannel capability by quickly hopping from one to another DME frequency. The receiver concept is based on a logarithmic amplification covering the entire level dynamic range from –100dBm to –30dBm analogous to [9] without the use of an AGC. It dwells on a single

channel for either a specific period of time or until a specified number of DME pulse pairs has been detected. Therefore, the number of covered channels is not limited by hardware. Instead, it is given by the physical trade-off between needing to spend sufficient time in one channel slot to get an accurate picture of the pulse video, and on the other hand, the need to return to that slot quickly enough to appropriately sample the multipath environment. Both parameters can be specified by the user. In order to ensure sufficient multipath sampling, it has been decided to use a channel sampling rate on the order of 1 Hz, while recording 100 milliseconds of pulse pairs per one-slot sample. In this manner, 6 different DME facilities can be evaluated in parallel. While this number could be increased further easily, it is expected that this would meet the needs even of most DME-rich environments.

Multi-Channel Flight Test Results

During a ferry flight from Denmark to Germany the equipment was tested receiving six DMEs / TACANs in parallel over a period of half an hour. In figure 1 the level distribution over 10s is shown. Each individual scatter of points represents the RF level samples obtained during one 100ms slot. Those that have a clear vertical distribution are TACAN (TACtical Air Navigation), while those that resemble more closely to a cloud of points are DME. After six scatter points, the sequence repeats, which can be readily observed from the consistency of the individual DME or TACAN measurements between sample points. Thus, one pass consists of six time slots, each dedicated to a single beacon in which the vertical distribution of a level line depicts the level scattering. Pure DME beacons (Vesta / VES, Elbe / LBE) only scatter within 1dB across the time slot whereas the TACAN beacons (Schleswig / SWG, Skrydstrup / SKR, Hamburg / HAM) vary over 10dB since the pulses are Amplitude Modulated (AM) at 15Hz and 135Hz to broadcast the bearing information. The former TACAN functionality of Helgoland (DHE) was supposed to be removed to operate as a DME only. However, the measurements revealed that the 135Hz AM was still turned on and, as a result, the pulses scatter within 5dB.

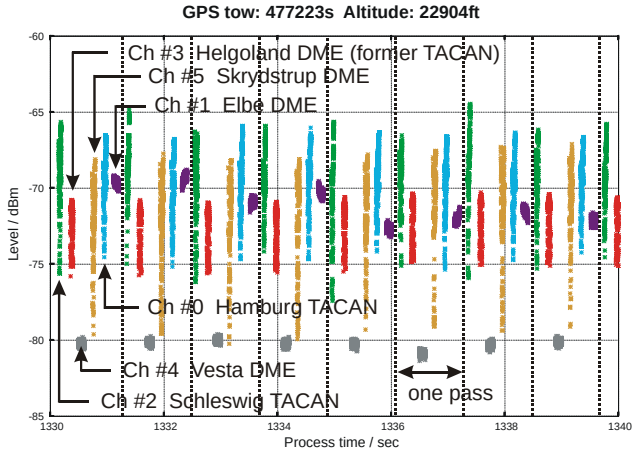

Figure 1: Levels of Six Channel Pseudo-Simultaneous DME Reception

To get a detailed impression of the signals-in-space one must deeply zoom into the time scale of figure 1 for making the DME pulse shapes visible. As an example, the logarithmic pulse videos of all six channels around process time 1332.s are shown in figure 2. The signal processor catches the time-stamped pulse pairs which are displayed as a sequence for each channel per row of figure 2. Since the time between the relevant pulse pairs mainly consist of the base noise floor, this gap is omitted and the following pair is directly appended, separated by a blue vertical line. A corresponding time label on the x axis indicates the temporal gap between the separated pulse pairs. Multipath activity of a pulse-based system as DME can generally be observed as a reflected pulse reaching the receiver later than the direct signal. Visually, this can be observed by a succeeding weaker pulse such as can be seen on the Elbe DME (channel 1, 2nd row of figure 2).

In most cases the reflection has its source in the near vicinity of a DME beacon such that its energy deforms the falling edge of the direct pulse making it wider or arriving shortly after the first pulse from the receiver's point of view. A specific TACAN multipath characteristic can be observed on channel 5 (TACAN Skrydstrup, last row of figure 2) where an obvious strong reflection affects the rising edge of the 2nd pulse. This is due to the bearing AM of which an example is given in figure 3, generated by the Skydstrup beacon.

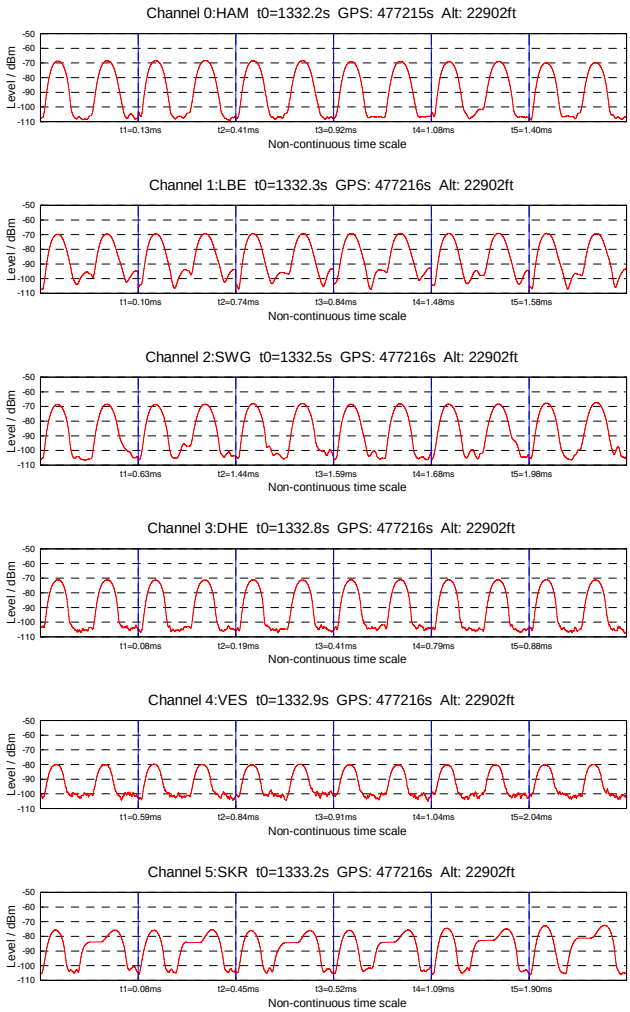

Figure 2: Pulse Pair Video of Six Channel Pseudo-Simultaneous Reception

During 67ms or one 40° period of the TACAN 15Hz coarse bearing signal, the full scale difference level shift of 10dB is reached when the minimum of the 135Hz fine bearing signal meets the minimum of the 15Hz AM and vice versa 40° after. When a momentary minimum points to the aircraft and a +10dB maximum illuminates a reflector offset 40° in azimuth, the pulse reaches the receiver's antenna 10dB higher than the level provided by the coefficient of the reflector alone. Hence, such strong reflection effects do not occur in DME ranging. The strongest DME reflections were observed at about 25dB below the direct signal.

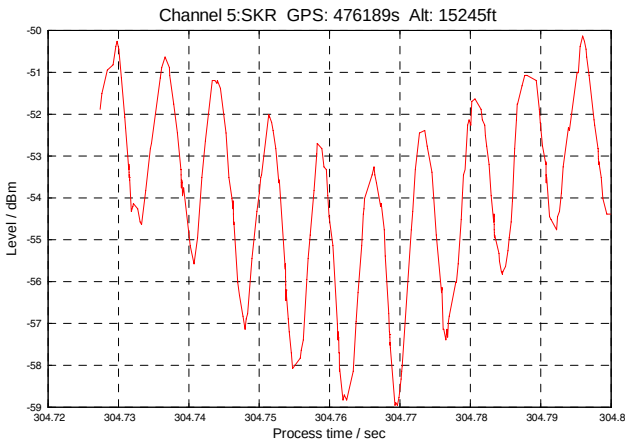

Figure 3: Level Distribution of a TACAN AM Signal

So far, it has not been considered necessary to derive acceptance criteria for permissible pulse shape distortions, which would enable an automatic assessment of the collected pulse shapes. While this could easily be added, it would only be sensible to screen out "clean" pulse pairs. As the infrastructure assessment is primarily an engineering activity, it is expected that multipath effects are too varied to permit a simple automated pass/fail evaluation. Since "a picture is worth more than a thousand words", the pulse pair video gives the flight inspector and the engineering authority a clear view of what is going on with the signal-in-space, which is the purpose of the infrastructure assessment. By evaluating the delay and amplitude of the reflected pulse contributions, suspects for problematic reflections can be quickly identified by analysis.

The results show that multi-channel DME flight inspection is possible. More precisely, the SISMOS/DME receiver represents an ideal tool to achieve the second objective of the infrastructure assessment process in a single flight inspection run, which is to identify any DME that could potentially degrade the RNAV solution. While an estimate of the range measurement accuracy can also be derived from such samples, it is expected that SISMOS would still be complemented by traditional single channel DME receivers dedicated to those two to three DME transponders within DOC that establish the feasibility of an RNAV solution. Ideally, such capabilities would be integrated into flight inspection systems as part of a new flight inspection aircraft acquisition, but even as a retrofit application integration is possible within reasonable effort.

DME FIRST INSTALLED PRIOR TO 1989

A particular detail issue that remained a part of the infrastructure assessment discussion was the question whether DME first installed prior to 1989 could support P-RNAV. This is due to changes in Annex 10 requirements that took effect on 1 January of that year, requiring that all new installations use the first pulse as a timing reference. This was to reflect advances in integrated circuitry, which permitted the elimination of the more multipath-prone RC (analog) delay circuits. While the new standard included a variety of other requirements, the pulse reference is the one that is most relevant for RNAV performance. Airborne equipment certifications of DME sensors supporting RNAV require the use of first pulse timing. It was noted that in Europe, a good number of DME using second pulse timing are still in operation, even if it proved difficult to identify exact locations and numbers. The EUROCONTROL Navigation Subgroup considered if it was necessary to force a Europe-wide upgrade of such DME to ensure P-RNAV support, in order to avoid any complications brought about by the fact that such DME could easily be used by avionics on procedures in a neighboring state. The neighboring state may not be aware of such DME types and consequently could be affected if airspace users encounter insufficient P-RNAV performance.

In order to determine if such DME could pose a threat to P-RNAV requirements, it was decided that such a facility should be evaluated. A FACE FSD-15 was identified near Esbjerg, Denmark. The FSD-15 was designed a little prior to 1989 and anticipated the new ICAO requirements. As some ANSP customers were still unfamiliar with first-pulse operations, the manufacturer decided to make the timing reference configurable: a jumper setting permits ANSP maintenance staff to change between first and second pulse reference. This provided the ideal testing ground for second pulse effects, as it was possible to evaluate the signal-in-space both during first and second pulse operation in an identical environment. The relatively unproblematic flat environment of Denmark further supported the assessment in nominal conditions, e.g., without having to differentiate between specific anomalies. The VESTA VOR/DME and its environment are shown in figures 4 and 5, respectively.

Figure 4: VESTA DME near Esbjerg, DK

Figure 5: Environment of VESTA DME

Description of Test Campaign

The primary concern with using second pulse timing in RNAV positioning was that the higher multipath levels could be inconsistent with the agreed accuracy error budget, thus causing unacceptable track deviations of aircraft. Consequently, all available DME and TACAN interrogators were tuned to the VESTA DME. The Flight Inspection System (FIS) used by the Flight Calibration Services (FCS) test aircraft, a Beech B300 Super King Air tail-numbered D-CFMD, is equipped with two Honeywell RNZ-850 DME Interrogators and two Collins TCN-500 TACAN. While these avionics boxes are not certified to TSO-C66C (as is common for a number of aircraft approved for P-RNAV), they do meet the stipulated accuracy requirements. The measurement uncertainty for

these calibrated receivers is ±0.02NM, just sufficient for evaluating compliance to the P-RNAV error budget for the Signal-in-Space contribution of an individual DME of 0.1NM (95%). The test program consisted of a 10NM orbit, a 20NM radial over water (202°) and a 10NM radial over land (118°), all at 3000ft QNH. This test program was flown once while in first pulse timing mode and once while in second pulse timing mode. Even though SISMOS is independent from the transponder time reference, the VESTA DME signal was recorded in parallel with SISMOS to get a good view of the multipath environment.

VESTA DME Test Results

It was shown that in both timing modes, the FACE FSD-15 is able to support P-RNAV accuracy requirements. The signal-in-space environment was benign in both cases, as evidenced both by the FIS measurements and SISMOS pulse pair analysis, with no discernible difference in measurement noise. Thus, even pre-89 DME operating on second pulse timing reference can support P-RNAV, provided that the DME is well calibrated and that there are no specific multipath issues, just as with any other current DME. The only additional consideration with second pulse DME is then that in the case of a multipath-prone environment, the additional multipath mechanism of a first pulse reflection corrupting the second pulse needs to be taken into account.

While the SISMOS analysis only measures the uplink, the potential corruption of the second pulse would take place on the downlink. However, apart from a negligible frequency shift, the uplink experiences the same free space conditions and multipath influences as the downlink per the reciprocity theorem. Consequently, the pulse distortions visualized by SISMOS are also representative of the downlink. While some of the trailing edge pulse distortions are showing the typical and relatively strong ground plane reflections documented earlier [8], they remain on the order of a few microseconds, sufficiently below the 12µs X-channel pulse pair spacing. Nonetheless, it was noted that even in this benign environment, some multipath fading is present in locations that cannot be expected from simple engineering observations of the terrain environment. Such a fade, created on the 10NM orbit over land near radial 090°, is shown in figure 6, along with some secondary returns (reflections).

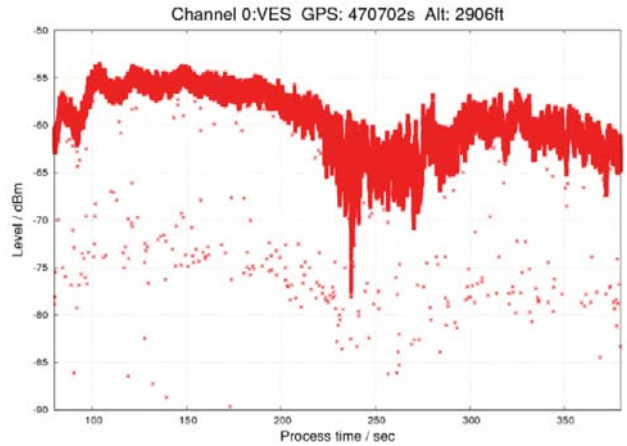

Figure 6: Flat – Terrain DME Fading Effect

Scenarios for DME Pulse Multipath

For significant effects using first pulse timing, the multipath scenario would most likely include a line of sight attenuation of the direct signal. For second pulse timing, reflection paths causing a delay of near 12µs are of concern for X-channel DME. It has been shown in this and related test efforts that nominal reflection delays in a normal environment typically do not exceed 6µs. Consequently, a 12µs path delay is actually quite difficult to “create”. It certainly does not appear possible in the near field of the transponder, and thus reflectors need to be quite large as the reflector distance increases. In addition to propagation delay, standard criteria such as Snell’s Law (angle of incidence equals angle of reflection), the reflection coefficient of the reflector surface (building, water, earth, etc.), and phase shift need to be taken into account when judging multipath scenarios. Figure 7 illustrates the locations of potential reflectors for two points on the over-water radial that was flown in the flight test. The ellipses represent the loci of reflection points on the ground between the aircraft position and the transponder with an equal reflection path delay of 12µs. It can be quickly seen that such potential reflectors could be identified by simple inspection.

Figure 7: X-Channel Spacing Critical Multipath Ellipses

Interoperability Issue

Finally, the test results did still include an unexpected effect. Even if it should have been obvious from theoretical analysis, a measurable bias was noted between the two flight inspection programs. This is due to the differences in timing reference between the aircraft and the ground facility, as the downlink is delayed by the pulse spacing of the ground facility and the uplink is advanced by the pulse spacing of the interrogator. Consequently, both the ground and aircraft pulse spacing tolerances become relevant in the time delay measurement. This is illustrated in the timing diagram shown in figure 8.

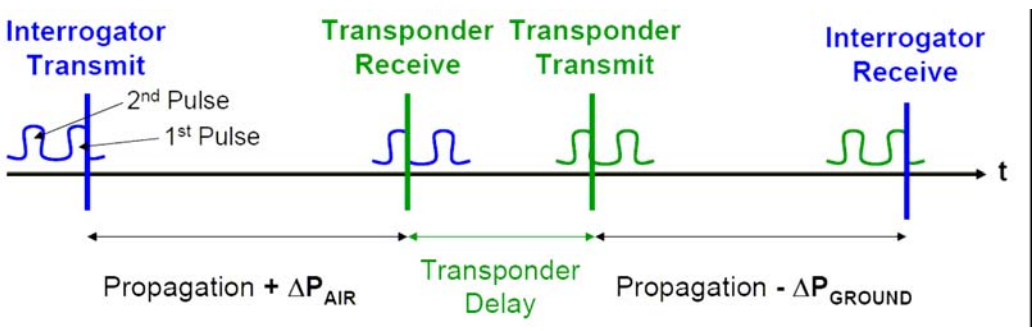

Figure 8: Timing Diagram of Mixed Pulse Reference DME Ranging

The pulse spacing tolerances for both aircraft and ground equipment are given in ICAO Annex 10 [10], as follows:

Table 1: DME Pulse Spacing Tolerances

Interrogator	Requirement	**0.5μs**
Interrogator	Recommendation	**0.25μs**
Transponder	Requirement	**0.25μs**
Transponder	Recommendation	**0.1μs**

In subsequent laboratory testing, it has been verified that some avionics manufacturers take full advantage of the pulse spacing tolerance. This is understandable as the pulse spacing - when using identical timing references - only serves as a gating function in order to filter out unwanted interrogator replies. Consequently there is normally no significant need to achieve a smaller tolerance, even if this is typically the case for ground transponders. For example, the equipment specifications for both the FACE FSD-10 and the FSD-15 already require the equipment to meet 0.1μs.

Guidance Material Update

While the effects of this interoperability issue turn up in the avionics, it is clearly due to the ground transponder difference in timing reference. Consequently, the airborne pulse spacing tolerance needs to be accounted for in the signal-in-space portion of the accuracy error budget. While such biases should typically result more in a uniform distribution rather than a normal distribution, there are numerous independent biases that contribute to DME range errors. By invoking the central limit theorem, they can be treated as independent, normal distributions, and thus this new error term is added into the signal-in-space (SIS) allocation using the root-sum-square formula:

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

The pulse spacing tolerance term has been fixed to 0.02NM in line with the ICAO interrogator requirements. The transponder term is equally derived and amounts to 0.04NM. The remainder is available for propagation effects. Note that even if this would result in errors greater than the nominal 0.05NM (1-Sigma) SIS allocation, the infrastructure assessment could still be accomplished with such an increased signal-in-space contribution. The size of the transponder pulse spacing tolerance has been considered negligible, but could easily be added in a similar manner if so required. This approach has been agreed by European stakeholders and integrated into the guidance material described earlier. While this approach is feasible, it is also hoped that the additional complications will cause ANSP operating second pulse timing reference DME to upgrade these more than 20 year old systems.

CONCLUSIONS

The guidance material for P-RNAV infrastructure assessment summarizes the associated work over the last several years on the subject, and is available to the aviation community free of charge. It highlights in particular the evolving role of flight inspection for RNAV, which is first that the flight inspection program should be designed through a cooperation of operational and technical ANSP staff with the support of appropriate Software tools. Second, the results obtained during the flight inspection should then be fed back to the engineering authority in order to fully substantiate and complement the assessment of the proposed RNAV procedure. While this process has principally been laid out for the assessment of specific procedures or routes, it should also be applicable for area assessments. It is further recommended that such an evolving flight inspection role should be complemented by appropriate signal-in-space analysis tools such as the one described and tested in this paper. The importance of such analysis tools is further underscored by that fact that the avionics capability gap between small corporate or general aviation aircraft typically used in flight inspection and highly integrated digital systems on airline aircraft is expected to increase further, emphasizing the need to fully understand the interface between ANSP and operator or aircraft certification responsibilities. Further investigations, in particular in cases of relevant multipath cases where a direct comparison between signal-in-space and receiver effects is possible, would be valuable.

Finally, even if the effects of the analyzed scenario have been found to be minor, an interesting interoperability issue arising from differing pulse timing references in air and ground equipment has been described. More generally, as the body of knowledge of flight inspection of RNAV procedures is still relatively limited both for initial inspections and specific problem cases, flight inspection organizations and ANSP are invited to report their experiences to the authors. This will permit to take those experiences into account in any future updates of the guidance material.

ACKNOWLEDGMENTS

The authors would like to thank NAVIAIR, ANSP of Denmark, for their support of flight tests of the VESTA DME at Esbjerg.

REFERENCES

[1] For a comprehensive collection of documents relating to P-RNAV, please refer to www.ecacnav.com

[2] Performance Based Navigation Manual; Doc 9613, Final Working Draft 5.1, ICAO, Montreal, March 2007. Available on www.icao.int/pbn

[3] Guidance Material for P-RNAV Infrastructure Assessment; EATMP Doc 08/04/17-05, Version 1.2, Eurocontrol, Brussels, April 2008

[4] Global Navigation Satellite System Manual; Doc 9849, 1st Edition, International Civil Aviation Organization, Montreal, 2005

[5] Distance Measuring Equipment (DME) Operating within the Radio Frequency Range of 960-1215MHz; TSO C66C, Federal Aviation Administration, Aircraft Certification Service, Washington DC, January 1991

[6] Ashton, K.; Use of DME Below Station Height; Working Paper 45 by UK NATS, ICAO Navigation Systems Panel Working Group 1 & 2 Meeting, Brussels, May 2006

[7] Goto, K.; Shinpuku, T.; TACAN Signal Received at Negative Elevation Angles: Information Paper 22 by Japan Civil Aviation Bureau, ICAO Navigation Systems Panel Working Group 1 & 2 Meeting, Brussels, May 2006

[8] Berz, G.; Bredemeyer, J.; Requirements for RNAV Flight Inspection; Proceedings of the 14th International Flight Inspection Symposium, Toulouse, 2006

[9] Bredemeyer, J.; Berz, G.; Monitoring a Navaid's True Signal-in-Space; Proceedings of 13th International Flight Inspection Symposium, Montreal, June 2004

[10] Radio Navigation Aids; Annex 10 to the Convention on International Civil Aviation, Volume I, 6th Edition, ICAO, Montreal, July 2006

Biographies

Gerhard E. Berz
Eurocontrol DAP / APN
Rue de la Fusee 96
B-1130 Bruxelles
Tel direct +32 2 729 3734
Tel APN +32 2 729 3783
Fax +32 2 729 9003
gerhard.berz@eurocontrol.int
www.eurocontrol.int

Job Title: Senior Specialist, Navigation

Topics of Studies:

Bachelor of Science, Avionics Engineering Technology, Embry-Riddle Aeronautical University, 1996 (Magna Cum Laude)

Master of Science, Electrical Engineering, Avionics Engineering Center, Ohio University, 1998

Professional Experiences:

Swiss Federal Aircraft Company (now RUAG), Electrical Systems Group, Emmen, Switzerland:

- Implementation support for fuselage fatigue monitoring systems and small technical upgrades to fighter fleet

Naval Air Systems Command, Satellite Navigation, ATC and Landing Systems Division, Patuxent River MD, USA:

- Validation, testing and standards development for Ground Based Augmentation System (supporting FAA through RTCA SC159, Global Positioning System)

Skyguide, Air Navigation Service Provider, Systems Planning Group, Zurich Airport, Switzerland:

- Development of GBAS (Implementation in Switzerland, international harmonization, siting criteria) and GNSS in general
- Coordination of flight inspection development and test and evaluation capabilities

Eurocontrol, Directorate of ATM Programmes, Airspace, Network Planning and Navigation Division, Brussels, Belgium:

- ILS Sustainment, RNAV Infrastructure and 4D Navigation
- Technical Advisor to ICAO Navigation Systems Panel

Dr. Jochen Bredemeyer
FCS Flight Calibration Services GmbH
Hermann-Blenk-Straße 32A
D-38108 Braunschweig, Germany
Tel: +49 531 23777-85
Fax: +49 531 23777-99
E-mail: brd@flightcalibration.de

Job Title: Head of Research

Topics of studies :

Diploma degree in electrical engineering (Dipl.-Ing.), 1996, Doctoral degree in electrical engineering (Dr.-Ing.), 2001, both from Technical University of Braunschweig, Germany

Research focus on RF engineering and electromagnetic multipath wave propagation

Professional experiences:

1996 – 2000:	Research assistant at Technical University of Braunschweig
Since 2000:	Research work for FCS and its shareholders DFS, Skyguide, Austrocontrol
	Focus on signal-in-space synthesis and analysis for Navaids and Radar systems
Since 2005:	Lecturer at University of Hannover, Germany, for measurement engineering and topics related to research work

Memberships:

DGON (German Institute of Navigation)

IEEE Aerospace & Electronic Systems Society (AESS)