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Requirements for RNAV Flight Inspection

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ABSTRACT

While various forms of RNAV procedures have been in use for many years, only the recent emphasis on public use RNAV procedures with relatively tight accuracy requirements for use in Terminal Control Areas (TMA) makes it necessary to review the resulting need to develop additional flight inspection capabilities. This is reflected in the current efforts on P-RNAV in Eurpope, U.S. RNAV in North America and the associated harmonization effort at the ICAO level (RNAV-1). As this paper focuses on RNAV with a 95% accuracy of ±1NM, it will consistently refer to RNAV-1 when discussing requirements.

Although much of today's flight inspection fleet is capable to complete assessments of the Signal-In-Space (SIS) supporting RNAV procedures, the process is inefficient and can be difficult to accommodate in a TMA. The work builds on recent experience with P-RNAV implementation by skyguide in Zurich, Switzerland [1] and formulates what capabilities flight inspection equipment should evolve to in order to efficiently cope with a multi sensor environment.

INTRODUCTION

The current RNAV implementation effort for TMA's supporting a maximum 95% Total System Navigation Error of ±1NM foresees the use of GNSS and DME/DME sensors. Some limited use of VOR is also envisioned for crosscheck and fallback purposes. Both DME and GNSS can be additionally supported by inertial navigation (INS). While GNSS (TSO C129a and C145 equipment with appropriate integration) does cater for such navigation requirements comfortably, establishment of sufficient performance is more demanding with multiple DME ranging. Because there are still a considerable number of aircraft not equipped with GNSS sensors, it is very desirable to make DME based RNAV possible, even if it requires some reversion to INS coasting. Consequently, the main subject of this paper is to show which flight inspection capabilities are suitable for multi DME signal inspection.

Additionally to the establishment of the claim that navigation sensors meet SIS standards, RNAV procedures also need to undergo procedure validation, which uses flight inspection and other methods to verify database coding issues, obstacle information, flyability, etc. This will require an appropriately trained flight inspector and relatively advanced navigation equipment. Procedure validation may alternatively be carried out by a regular aircraft without a flight inspection system. Consequently, while some aspects of procedure validation may well be carried out by flight inspection aircraft in order to maximize resource use, this work focuses on the required capabilities for the verification of a suitable RNAV SIS.

EVOLUTION OF ROLE OF FLIGHT INSPECTION FOR RNAV PROCEDURES

Before turning to pure SIS aspects, it is valuable to highlight the need for increased interaction among the parties associated with the flight inspection of RNAV procedures. In a non-RNAV environment, flight inspection generally caters to an individual Navaid. While operational factors are certainly taken into account for example by putting priorities on inspecting those radials of a VOR facility that are used by published procedures, it is still a process that is primarily driven by the technical engineering and maintenance staff of a service provider, as illustrated in figure 1 below.

The process can be described as follows. In particular in a developed service provision environment under the customary cost pressures, the commissioning of new facilities has become relatively rare. Either based on a new operational need or simply due to the lifecycle replacement of old equipment with new generation equipment, the project engineering staff requests a commissioning check. After the flight inspection, the report is being evaluated by the Designated Engineering Authority (DEA) to verify that the flight inspection results provide sufficient evidence to grant the clearance for operation. Additionally, the DEA will also define the interval and scope of the periodic maintenance inspection. Once the facility is in the operation & preventive maintenance mode, no additional interaction with the operational services is necessary except to accommodate changes in the operational environment.

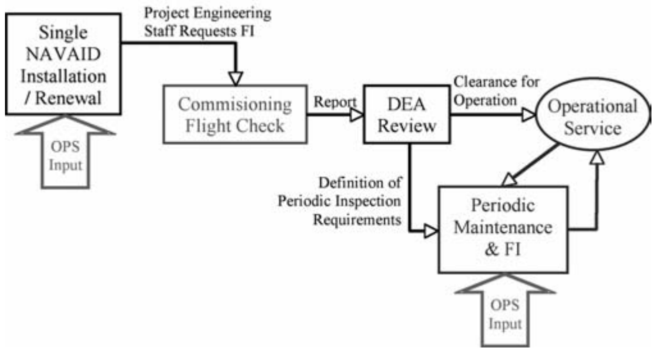

Figure 1: Current Single Navaid SIS Assessment Process

When evaluating the suitability of the available facilities to support a new RNAV procedure, the interactions between technical and operational staff need to be increased as illustrated in figure 2. It starts with the operational experts requesting the DEA to conduct an initial analysis if the available DME facilities are able to support the envisaged procedure. This is done based on standard error budgets and a geometry analysis taking terrain limitations into account.

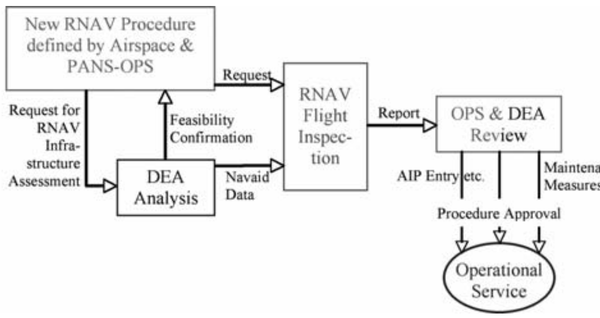

Figure 2: Signal-in-Space Assessment Process for RNAV Procedures

The analysis identifies which DME pairs support the procedure, if there are any critical DME facilities and if INS coasting may be required for some portions of the procedure. The analysis should also identify which DME facilities could have a negative impact on the position solution (suspected multi-path etc.). Depending on the altitude profile of the procedure, the terrain environment and the experience with a particular DME facility, an inspection of some facilities may also be considered excessive. When the feasibility of the procedure is confirmed by the DEA, the operational experts (procedure designers, airspace planners, …) typically request the flight inspection, while the DEA findings need to be taken into account in the planning of the flight inspection activities. Once the flight inspection report is available, the DEA adjusts the feasibility analysis findings if necessary and consults with the operational experts to determine what implementation measures are necessary before activating the new RNAV procedure. These measures include procedure chart and AIP entries, possibly maintenance actions or cross-border agreements on maintenance procedures.

As the RNAV infrastructure assessment matures, the roles of the individual staff may further evolve, but at least initially, a lesson learned from the Zurich assessments is that all parties need to realize the interdependencies in RNAV and increase their coordination. For flight inspection organizations serving customers unfamiliar with the approval process for public TMA RNAV procedures, this point should be emphasized early on.

NEEDED CAPABILITIES FOR RNAV INFRASTRUCTURE ASSESSMENT

For supporting Navaids other than DME, the requirements are straightforward:

1) Ability to record GNSS performance and spectrum to confirm absence of interference.
2) Ability to record VOR radials at specific points along the procedure

These capabilities should be available in parallel with the DME functionalities and require as little interaction by the flight inspector as possible.

For the DME capabilities, a more detail discussion of SIS aspects is necessary. Multi-DME inspection serves two primary goals. The first is to establish that the DME facilities identified by the DEA as capable of supporting the RNAV procedure do meet field strength and accuracy requirements. The second aim is to verify that there are no DME signals that could harm the position accuracy and would consequently need to be identified as requiring de-selection by the pilot, which is a feature that is required for RNAV-1 approval. While most flight inspection systems can indirectly estimate field strength and other parameters with some accuracy of at least one DME facility, RNAV requires that this can be done reliably with multiple DME facilities in the same run. Otherwise, flight inspection aircraft will need to complete a large number of runs of the same procedure, which can be difficult to accommodate in a high density TMA. Additionally, multiple runs are not cost effective.

In order to make the suitable / unsuitable decision required by the two goals identified in the preceding paragraph, it is necessary to establish that boundary with some precision. For a DME to be suitable for RNAV ranging, the signal needs to both have sufficient field strength and be free of excessive distortions. Current, traditional readouts in flight inspection receivers of a calibrated Automatic Gain Control (AGC) voltage suffer from the following disadvantages:

- At low signal levels, the noise figure of the receiver chain becomes a significant limiting factor, especially with older generation front end amplifiers.
- AGC does not reveal anything specific about signal distortions, other than being able to observe when the AGC gets unstable (jumping back and forth due to searching between good and bad returns).
- The AGC alone is an incomplete indicator. Up to 12dB and more inaccuracy can result from the combined variations in the incident 3D installed antenna gain pattern and due to impedance mismatches.

If the 3D installed antenna gain pattern gets calibrated as described in [3], the maximum accuracy of a distortion free field strength measurement that can reasonably be achieved is about 3dB. This is certainly acceptable as avionics receivers generally work quite well even below the required minimum field strength. However, it is important to note that there are other good indicators of DME performance becoming marginal:

- Indication of reply efficiency.
- Indication of AGC lock status. This may take the form of lock / AGC unlock, memory mode / full unlock.

Consequently, it is recommended that the corresponding data bits are recorded by the inspection system. Furthermore, it is important to realize that entering memory mode is not acceptable, as the sensor accuracy is permitted to degrade to ±1NM (Section 2.2.13. of RTCA DO-189), which is well above the airborne receiver allocation of the Navigation System Error (NSE). If memory mode events occur within the normal service coverage of a particular DME facility, that DME is not suitable to support RNAV in the identified area. If this leads to there not being enough DME's to provide sufficient navigation performance, the procedure needs to be specified as only available to DME / DME / Inertial – equipped aircraft (or GNSS). The precise locations of the beginning and the end of insufficient DME coverage need to be known in order to allow the DEA to assess whether coasting through the outage on inertial navigation will be possible.

In addition to establishing the areas where the minimum field strength requirement is satisfied, propagation problems such as significant multipath reflections need to be identified. Again, the reply efficiency is a good indicator of when too many interrogator replies are rejected due to distortions. However, if the nature of the distortions is to be analyzed in order to identify the possible source, it is necessary to see the actual shape of the pulse pairs, as demonstrated in [2]. Looking at the actual pulse pairs will give an indication of reflection lag time and desired to undesired signal power ratio (reflector distance and properties). Significant signal in space reflections that have been observed were due to large objects such as a mountainsides or lakes. In such a case, there is not much a service provider can do other than declare the DME as unsuitable in the affected area. In other cases, where near field objects have a strong impact, it may be possible to correct the situation with maintenance actions.

Finally, it is also the duty of the flight inspection system to establish ranging accuracy, in particular to identify biases in the ground transponder stations. While such data is usually known from the regular maintenance of the individual facilities under the control of the service provider, this may be more critical if cross border DME facilities are needed to support an RNAV procedure. In particular for older analog DME ground facilities, it may be necessary to realign the reply timing to zero bias, since the requirements on the ground segment for RNAV-1 are tighter (0.05NM) than what is today required in ICAO Annex 10 (0.081NM). Such was the case with DME Hochwald (HOC) in 2005, which is an older analog facility that still met Annex 10 requirements as shown in figure 3, but needed to be readjusted for supporting RNAV-1.

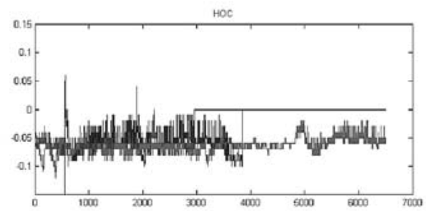

Figure 3: Ground Facility Bias Needing Readjustment for RNAV-1 [in NM versus Samples]

For the truth reference system this implies that the measurement accuracy needs to be at least 0.01NM or 20m, which is something that can be readily achieved with either commercial regional differential GPS or SBAS and is consistent with ICAO Doc 8071. In particular with older DME interrogators, it may be difficult to do much better than this due to limited resolution of the data output bus.

POSSIBLE REALIZATIONS IN FLIGHT INSPECTION EQUIPMENT

There are basically two possible approaches to integrate an efficient RNAV-1 inspection capability into a flight inspection system. One is to integrate a multi-channel or scanning DME and associated RNAV avionics into system. The other is to augment the existing DME interrogators with an advanced SIS analysis capability as described in [2], termed Signal-In-Space Monitoring System (SISMOS). The latter feeds off the same DME receive antenna and uses direct sampling and advanced parallel baseband signal processing. Figure 4 shows an example of pulse pair distortions visualized by this method. It is an example from DME St. Prex on Lake Geneva, where the lake reflection is stronger than the direct signal.

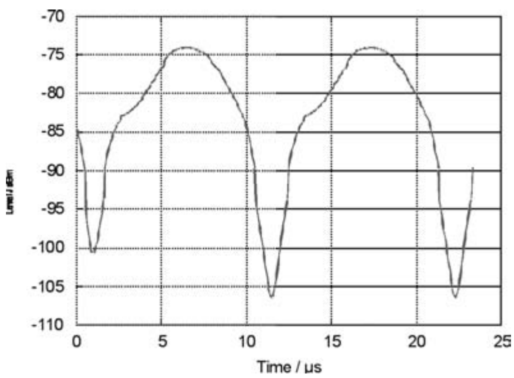

Figure 4: Distorted DME Pulse Pair Visualized with SISMOS

Since the pulse pair video is available from the samples, the pairs can then be further analyzed to see if the assumptions in the standards with respect to the statistical distribution of the errors, such as standard deviation, hold true. This is illustrated in figure 5, which is the result from looking at the half amplitude points of DME pulse pairs, the standardized timing reference point. It can be observed that this particular DME ground transponder can support a standard deviation of about 0.02NM.

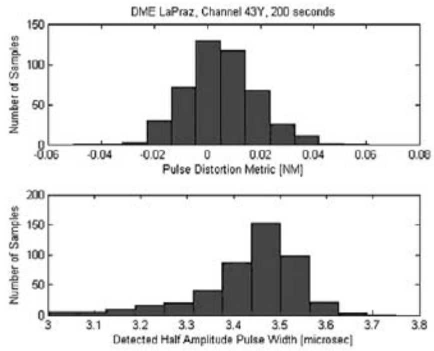

Figure 5: DME Pulse Pair Distribution Statistics

Currently, a multi-channel DME capability is being integrated in SISMOS. Further work will focus on assembling standard application interfaces and procedures in order to generate the kind of data that the DEA needs to complete its assessments of DME infrastructure for RNAV-1. The strength of a tool that complements traditional flight inspection equipment with a capability to look at the true SIS lies in all the extra analysis that can be completed flexibly to validate assumptions specified in the appropriate standards and to evaluate much more easily if and how particular propagation or maintenance problems can be solved.

CONCLUSIONS

Traditionally, the role of DME has been to complement a VOR radial with distance to station information, essentially enabling navigation in polar coordinates. With the widespread introduction of RNAV, DME is evolving into a multi-ranging navigation system that is in principle quite similar to GNSS, where the VOR is becoming less and less important. Due to this evolution and the increased application of RNAV procedures in busy TMA airspace, SIS quality needs to be well understood, such that the promulgated procedures support airspace users safely and reliably. This paper showed what sort of technical capabilities are needed in a flight inspection system that can effectively cater to this need. It is the hope of the author that the various providers of flight inspection services will take these requirements into account in their system evolution planning.

ACKNOWLEDGEMENTS

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