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CAR/SAM Regional Planning and Implementation Group (GREPECAS)
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Punta Cana, Dominican Republic, 28 March – 1 April 2011

Agenda Item 3: Performance framework for Regional Air Navigation Planning and Implementation

3.1 Global, inter-regional and intra-regional activities concerning air navigation systems in the CAR/SAM Regions

IMPLEMENTATION OF NAVIGATION ELEMENTS IN SUPPORT OF PBN

(Note presented by Spain)

SUMMARY

This working paper delves further into the analysis being carried out by the CNS/ATM Subgroup on the use of DME/DME for RNAV operations, the implementation of PBN and the SBAS and GBAS systems. Regarding the use of DME/DME to support RNAV operations, the paper states that it has a direct impact on the sizing of the ground infrastructure of such systems, based on the precision to be achieved and the geometric factors that condition its achievement.
PBN implementation shall take into account all aspects related to navigation systems that might have an impact on it. In this sense, SBAS and GBAS systems permit SoL operations, but are affected by problems in the ionosphere. The combination of the two will minimise such issues in GBAS systems, which are responsible for CAT I operations (and CAT II/III operations in the future), and minimise the risk of service failure in a given area, which reduces PBN capabilities therein.

References:

- ICAO Annex 10, Vol. I
- Project RLA/03/902 – SACCSA
- ICAO Doc 7300/8
- ICAO Annex 11 (RNP routes – Annex B)
- ICAO Doc 9613, RNP manual
- JAA TGL 10, Section 4c
- NSP navigation infrastructure assessment in support of PBN
- Performance-based navigation roadmap for the CAR/SAM Regions
- ICAO PBN Manual - Doc 9613
- Performance-based navigation manual, Volume I- Concept and implementation guidance
- Reports of the first and second meetings of the CNS/ATM Subgroup, Lima, March 2010, and Mexico, Nov. 2010

1. Introduction

1.1 PBN implementation entails an analysis of ground radio aid infrastructure, mainly DMEs, which will have a significant impact on State plans concerning their deployment, and the corresponding investment plans. This working paper presents some aspects to be taken into account, and an analysis of possible alternatives in this regard.

1.2 Currently, there are two augmentations for SoL operations. One is SBAS, that enables APV 200, and the other one is GBAS, which permits up to CAT I, and CAT II/III in the future. The combination of these augmentations would constitute a robust system *vis-a-vis* ionosphere disturbances, providing warnings on the arrival of these disturbances, and giving sufficient time to adjust traffic and take timely measures to minimise the impact. RAIM should be added to these augmentations to ensure en-route integrity.

2. Discussion

Impact of DME/DME in support of PBN

2.1 RNAV procedures should permit the use of GNSS. However, since some aircraft lack the GNSS capability, and since GNSS can fail, it is necessary to have an alternate infrastructure based on DME/DME or DME/DME/INS.

2.2 The CNS/ATM/SG/1 meeting, in paragraph 4.61 *"took note of the need to establish the necessary actions to assess DME coverage in the States and determine the number of new facilities required for the implementation of RNAV procedures"*. In order to do this assessment, it is necessary to delve further into the assessment of the impact of DME/DME coverage.

2.3 Since GNSS, in its basic forms (GPS, ABAS and RAIM), is available worldwide, no specific investments in infrastructure are needed. Nevertheless, it should be noted that the responsibility for the provision of GNSS-based service falls upon the State that is responsible for the airspace. Consequently, air navigation service providers must make sure that the level and quality of service, as well as the level of interference, is appropriate for the provision of the service, in keeping with the planned or authorised procedures. This can be achieved by various means, such as measuring interference on board the aircraft and/or on the ground (see ICAO Doc 9846, GNSS Manual, Doc 8071 and Annex 10), or through GPS augmentations, such as SBAS or GBAS.

2.4 Furthermore, the ground aid network can support RNAV operations through proper deployment of DME stations, and shall cover the DOC (Designated Operational Coverage) area, which is the term that defines the boundaries of the area covered by a navigation aid. In this sense, we must take into account that, given the implementation of DMEs to be used in RNAV by the FMS, the DME shall not be used if located more than 160 NM or less than 3 NM, regardless of the published DOC; furthermore, if the elevation between the station and the aircraft exceeds 40 degrees, it shall also be excluded. These conditioning factors have a direct impact on the precision obtained in a DME/DME operation, as well as on the sizing of the DME network for the provision of the RNAV services required for PBN implementation.

2.5 Obviously, these aspects have an impact on DME/DME coverage and precision. When determining precision, we must consider that, while the precision of a single DME may be consistent with that specified in ICAO Annex 10, Vol. I, when we talk about the precision obtained from the joint use of two or more DMEs, we must take into account geometric aspects, as explained above. In this sense, the overall precision of the system for RNAV-1 (total system error, TSE) must be equal to, or less than, +/-1 NM 95% of the flight time. This includes navigation error (NSE), position estimation error (PEE), as well as the flight technical error (FTE). The PEE is made up by the signal-in-space error and the airborne receiver error.

2.6 The first level of position precision is between the FTE and the NSE, which, in the case ofRNAV-1, is 0.5 NM (95%) for the FTE, a value that is recommended when using the flight director or autopilot, although it can be achieved under manual flight. Since the FTE and the NSE are treated as independent errors, the FTE provides a maximum allowable NSE of ± 0.866 NM (95%), obtained from the root sum square formula. These errors will be treated as circular errors and no error assignments will be made along longitudinal or transverse paths.

2.7 When analysing the precision obtained when using DME/DME, we may consider that the NSE can be divided into two parts: one that comes from the airborne equipment (interrogator) and the other from the ground equipment (transponder), including signal-in-space propagation effects. Since at least two DMEs with an acceptable geometry and an adequate range (160 NM – 3 NM) are needed to provide RNAV, the following formula will be used to determine precision (PBN manual):

$$2\sigma_{DME/DME} \leq 2\,\frac{\sqrt{\left(\sigma^2_{1,air} + \sigma^2_{1,SIS}\right) + \left(\sigma^2_{2,air} + \sigma^2_{2,SIS}\right)}}{\sin(\alpha)}$$

where:

σ_{SIS} = 0.05 NM
$\sigma_{air}$is maximum (0.085 NM, 0.125 % of the distance)
α must be between 30º and 150º

2.8 This formula is used for determining if a given pair of DMEs is capable of supporting a given procedure by assessing the two $2\sigma_{DME/DME}$ *versus* a maximum NSE of 0.866 NM.

2.9 With these data, we can analyse the infrastructure required to support a given RNAV procedure based on the use of DME/DME. To this end, it is advisable to use SW tools to expedite calculations, and take into account all the variables and station combinations. The process to be followed can be divided into six items:

1. Collection of the necessary data
2. Identification of individual DME stations that may be used
3. Definition of the DME pairs to be used
4. Identification of specific elements
5. Preparation and conduction of flight inspection
6. Completion of implementation studies

2.10 When determining what DMEs can be used, it will be necessary to have a terrain modelling tool in order to see what DME will be on the line of sight along each point within the service volume of a given procedure, and thus capable of being used by an FMS (a range of less than 160 NM and more than 3 NM with an angle of less than 40 degrees). Once the list of DMEs is available, those coupled to the ILS or that share channels must be eliminated. This will result in a final list from which pairs will be selected.

2.11 With the resulting list of DMEs, pairs can be selected based on the identification of all possible combinations within the service volume of a given procedure. For each possible combination of DME pairs, compliance with angle requirements must be assessed and estimated (within 30 to 150 degrees). Then, for each pair obtained, the resulting NSE must be calculated, checking for compliance with the precision requirements of ± 0.866 NM (95%).

2.12 When conducting this analysis, the number of new DMEs that need to be added can be determined, taking into account a new parameter, which is up to what flight level is DME/DME coverage required. The implementation cost of the new facilities and the maintenance cost of the resulting network will need to be assessed, and then conduct the corresponding cost-benefit analysis.

2.13 Amongst these activities, it will be necessary to conduct a parallel analysis for the implementation of RNAV using GNSS, in order to rationalise costs and optimise the infrastructure serving the airspace.

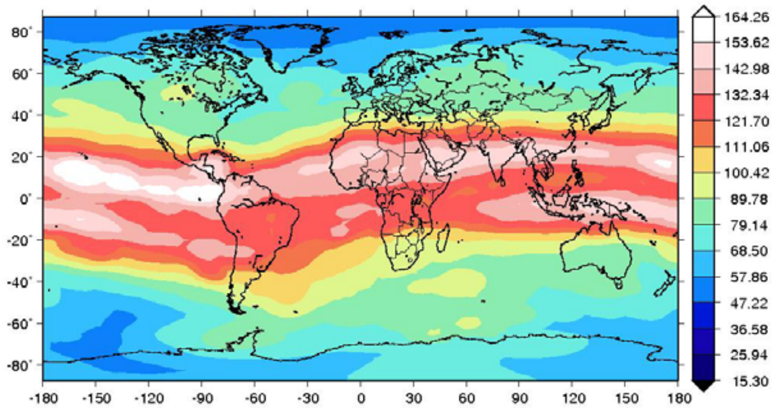
Impact of the SBAS and GBAS on GNSS implementation

2.14 The implementation of GNSS systems involves the use and combination of all its elements and, based on the GPS reference constellation and/or other satellite constellations, adding augmentations and functionalities to supplement it and to meet ICAO requirements. Accordingly, the RAIM function is added to airborne receivers, together with ABAS, SBAS and GBAS augmentations.

2.15 In this sense, the CAR/SAM PBN implementation roadmap cites both augmentations as examples of air navigation systems that can support PBN implementation. This is reflected in the PBN Manual, Doc. 9613, which specifies that integrity shall be provided by the SBAS or RAIM systems (operators must check for RAIM signal availability in case of failure or lack of coverage of the SBAS). Likewise, the manual specifies the use of GBAS and/or SBAS for achieving a better precision than GPS, around 2 m.

2.16 All these augmentations are aimed at achieving one of the most important parameters for the definition of SoL systems: system **INTEGRITY**, without which it will be very difficult to obtain an aeronautical certification for precision operations.

2.17 However, depending on the latitudes in which we are flying, this is more or less simple (or difficult, depending on how we see it), and in the case under discussion, which involves the CAR/SAM Regions, things become significantly more complicated due to the effects of the ionosphere in most part of the Regions (mainly between20º N and 20º S from the geomagnetic equator).

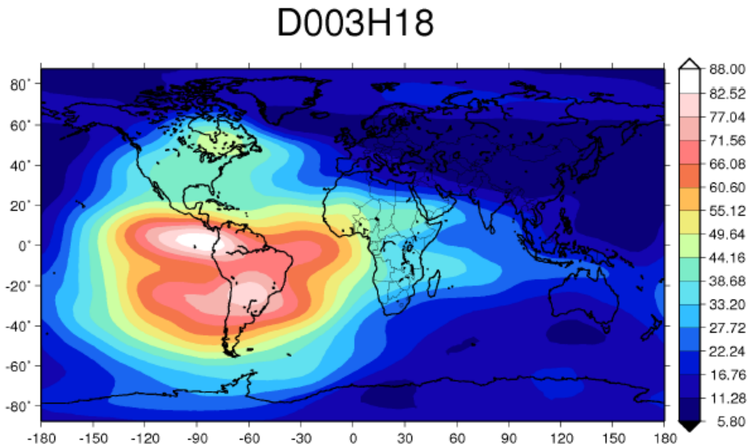


2.18 Both Regions are currently conducting programmes for the development/implementation of SBAS systems (regional project) and GBAS (national projects). Both systems are aimed at improving the provision of GPS and ensuring integrity, one at regional level (SBAS), with services that reachup to APV 200, and the other (GBAS) with local coverage and some services that initially reachup to CAT I but which are evolving to reach CAT II/III.

2.19 However, the two systems suffer from the same problem: **the ionosphere**. This problem has different effects that go from a slight interference in the reception of the L1 signal to the loss of such signal and code delays, which significantly alters service provision, and for which either system can only issue a flag activation message and stop providing the intended service.

2.20 SBAS systems permit en-route, terminal, approach and landing operations up to APV 200, which make them quite befitting for airports with little traffic and where a GBAS would not be profitable, or for those whose terrain layout may hinder GBAS installation. GBAS systems, on the other hand, are suited for high-traffic airports that require CAT I operationsor greater.

2.21 When determining the effects of the ionosphere, the working method is completely different, since the SBAS is based on a reference station network that enables it to detect the arrival of a disturbance and follow its entire path (disturbances are East-West, and bubbles have an approximate size of 1000 KM N/S by 100 KM E/W). The GBAS is based on local detection using the four antennae of the station, which enable it to detect but not foresee the disturbance, since it lacks "far-field monitoring".When the disturbance is detected, and if the effects are serious, flags are activated and the precision landing operation is interrupted.



2.22 Consequently, both systems work properly, but there is a difference between knowing that there will be a problem within a given period of time, and having to "suffer" the problem all of a sudden. The difference is that if we know that we will have this problem, we can make traffic adjustments and take operational measures for its arrival, but if we have to face it all of a sudden, it is like when an ILS fails abruptly, only that in this case, several runways are affected at the same time (we must recall that a GBAS can serve several runways).

2.23 In this sense, we must distinguish the way we address ionosphere issues in a GBAS and in an SBAS. In an SBAS, the processing centre calculates some corrections and an associated integrity. In the GBAS, it is assumed that the ionosphere does not change "much" between the reference station and the user, and in terms of integrity, a statistical behaviour *vis-à-vis* that change (ionosphere gradients) is assumed. The GBAS is absolutely valid in a mean ionosphere, since the ionosphere nominally has a good behaviour, and the likelihood of a "bad" behaviour is small. Accordingly, the GBAS takes into account a maximum gradient (or equivalent) to ensure integrity. This entails a loss of availability, in the sense that the gradient is not estimated in real time, but rather a Stamford University (ionosphere threat) model is used, establishing a maximum for the ionosphere gradient. In the CAR/SAM Regions, this could be valid for Cat I, where there is some margin, and maximum values can be used. In this respect, a study—independent, if possible--would be fundamental to really see if the model can be used in the area in question (AENA is currently conducting a study of this type for the Canary Islands). The study should involve several stations around each GBAS station (approximate separation of 50km) for a long period of time that includes a solar maximum. However, *a priori,* in the case of CAT II/III, it is not valid to use this model of "maxima" since there seems to be no margin of availability, and the use of an SBAS (or real-time ionosphere monitoring device) is more appropriate.

2.24 How can this be resolved? If an SBAS system is available, we can know what is happening hundreds of kilometres east of our airport, since, thanks to the reference station network, we monitor large areas (a whole region). This allows us to know when we will have ionosphere disturbance sufficiently in advance so as to take measures to mitigate its impact on traffic. Obviously, when the disturbance reaches our airport, it will affect the GBAS, but since we were aware of its arrival, we will have had sufficient time to take timely measures (for example, to warn aircraft that precision operations will be cancelled during a certain period of time, and that NPA or baro VNAV operations will be applied). Accordingly, we can structure the airspace surrounding the airport based on these operations, thus avoiding a collapse.

2.25 That is why it is recommended that the various GNSS projects underway in the CAR/SAM Regions consider SBAS and GBAS iteration in order to take into account mutual impacts and find an optimum solution to ensure the highest possible level of service under any circumstance. In this regard, we should clarify that, if it were decided that ionosphere disturbances are an obstacle to the implementation of a given augmentation, these will be more serious for GBAS than for SBAS. Therefore, a conclusion in this sense would affect GBAS implementation plans more than SBAS implementation plans. Consequently, any assertion or decision in this respect should be carefully analysed.

2.26 The CNS/ATM/SG/1 meeting, in paragraph4.62*"noted that the use of SBAS monitoring capacity over wide or regional area could alert with sufficient anticipation the air navigation service providers regarding the proximity and arrival of a disrupt in the ionosphere (especially in cases of scintillation) that moves East to West of an airport equipped with GBAS, in such a way to contribute with authorities in applying the corresponding and timely measures to mitigate these problems produced to GBAS when arriving to the corresponding local ionosphere zone of this system, interrupting its service. The use of this SBAS capacity will contribute to establish operational criteria on the GBAS"*. Also, in paragraph 4.63, it stated that the *"Secretariat will transmit this issue to the ICAO Navigation Systems Panel (NSP) for its consideration"*.

Considerations about PBN implementation

2.27 In previous paragraphs, we have seen the impact of the DME/DME solution on ground infrastructure, which could impair its implementation on a large scale, given the large number of new stations that would be required, at a high cost. Likewise, we have seen that the GNSS solution, using SBAS and GBAS augmentations, could mitigate this aspect, but in the case of the CAR/SAM Regions, there is the problem of the ionosphere, which must be taken into account when defining a final solution.

2.28 The information contained in this working paper will have to be taken into account when planning PBN implementation, based on the level of service that is to be attained, the flight levels to be used (it is different to say "starting at 280" than "up to PA", or "RNP 5" instead of "RNP 0.1"). The corresponding cost-benefit analysis should also be conducted, based on the level of service to be attained, analysing the various navigation service solutions and seeking the highest possible level of efficiency.

3. Suggested action

3.1 The Meeting is invited to:

a) Take note of the information provided in this working paper;

b) Identify the actions required to assess DME coverage in the States, and determine the number of new facilities needed for the implementation of RNAV procedures;

c) Promote the conduction of the corresponding cost-benefit studies;

d) Analyse regional GNSS implementation alternatives;

e) Include the independent GBAS ionosphere model study for use in the CAR/SAM Regions;

f) Analyse the implementation of the cited solution, and recommend that it be taken into account in national GBAS plans and SBAS project activities;

g) Consider participating in the SBAS Regional Project (SACCSA in the case of the CAR/SAM Regions)and in national GBAS projects, in order to have visibility of this type of solutions; and

h) Take into account the foregoing when drafting PBN implementation plans.

– END –