



SAM/IG/5  
WP/12  
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**International Civil Aviation Organization  
South American Regional Office**

**Agenda Item 3: Implementation of performance-based navigation (PBN) in the SAM Region**

**Revision proposal to ICAO documents 8168 and 9613 regarding DME limitations**

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**Summary**

This paper presents a proposal to review ICAO documents 8168 and 9613 regarding the DME limitation in elevation angles above 40° and inclusion angles less than 30° and greater than 150°.

**References:**

- Document 8168 Volume II PANS-OPS
- Document 9613 Performance Based Navigation Manual

**1 Background**

1.1 In several documents issued by ICAO and specifically in the two mentioned above, there is a restriction in the use of DME for elevation angles above 40° and in the case of DME/DME navigation the use is limited to inclusion angles smaller than 30° and bigger than 150°. This is a paragraph extracted from the ICAO Document 9613:

*“3.2.1.4 The navaid infrastructure should be validated by modelling, and the anticipated performance should be adequately assessed and verified by flight inspection. The assessments should consider the aircraft capability described in this chapter. For example, a DME signal can only be used if the aircraft is between 3 NM and 160 NM from the facility, below 40 degrees above the horizon (as viewed from the facility) and if the DME/DME include angle is between 30 degrees and 150 degrees. The DME infrastructure assessment is simplified when using a screening tool which accurately matches ground infrastructure and aircraft performance, as well as an accurate representation of the terrain. Guidance material concerning this assessment can be found in PANS-OPS (Doc 8168), Volume II and the Manual on Testing of Radio Navigation Aids (Doc 8071).”*

## 2 Discussion

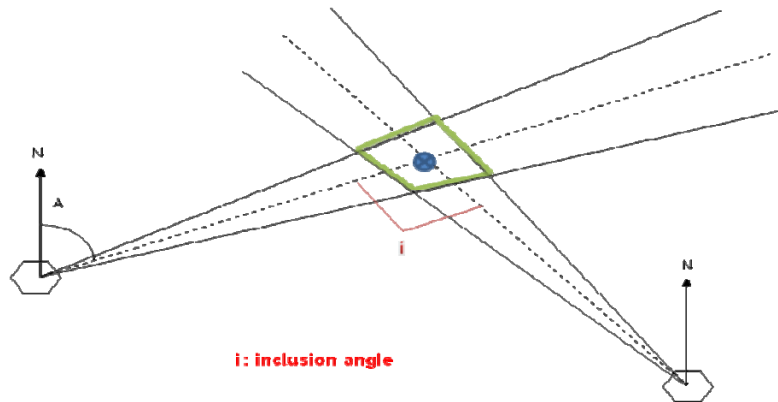
2.1 Elevation angle restriction for DME above  $40^\circ$  makes sense to diminish the error caused by the aircraft altitude, because RNAV computer (usually Flight Management System) executes the triangulation assuming the lineal distance when in fact DME calculate the slant distance. However this error could significantly increase when triangulation is executed using two DME stations with different altitude levels. For example in the Andes Mountains there are DME stations installed at sea level and DME stations 10.000 feet above sea level.

2.2 Regarding inclusion angle limitation for DME/DME Navigation, assuming two DME stations at the same altitude level, doing the calculations and flight checks the reason to restrict DME to inclusion angles smaller than  $30^\circ$  and bigger than  $150^\circ$  is not understood. This restriction is valid for VOR/VOR navigation because the VOR error is angular and in fact for inclusion angles smaller than  $30^\circ$  and bigger than  $150^\circ$  the calculation error is so that it may not be tolerable even for the navigation specification RNAV 5. Furthermore for inclusion angles near to  $0^\circ$  and  $180^\circ$  there is not solution to calculate the position. However this is not the case for DME/DME navigation because the error does not depend upon the angle and it is almost independent from the distance for the latest versions of DME equipment.

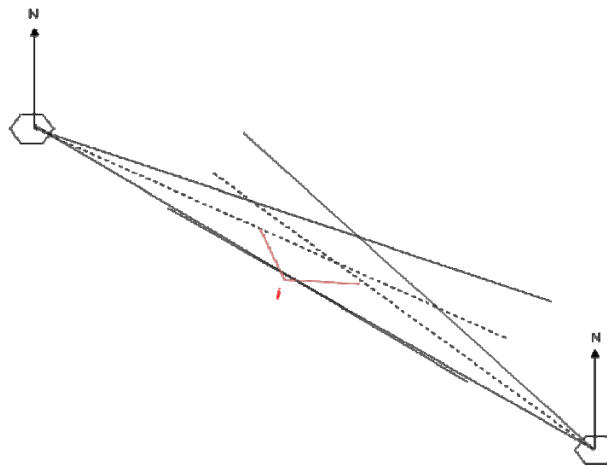
2.3 Even though DME operation principle is completely different to GPS, the triangulation method of these systems is similar, since both are based on distance measuring and position calculation by intersection of circumferences. GPS calculates distance by synchronization method, that is transmitter clock (satellite) should be synchronized with receiver clock and the distance is calculated by measuring the time that signal takes from the transmitter to the receiver; at least 4 satellites are required to compute position in the space 3D (latitude, longitude and altitude). DME calculates distance by interrogation-reply method, that is, a transponder A (aircraft) interrogates another transponder B (station), which replies to the interrogation. The distance is function of the time from the interrogation to the reception of the reply; at least 3 DME stations are required to compute position in the plane 2D (latitude and longitude), although FMS use only 2 stations because the ambiguity of the circumferences intersection can be eliminated with other sensors.

2.4 Taking into account the above mentioned, if the limitation of the inclusion angles smaller than  $30^\circ$  and bigger than  $150^\circ$  using DME/DME navigation is reasonable, should be reasonable also to limit the use of GPS satellites to a mask angle of  $30^\circ$ ?

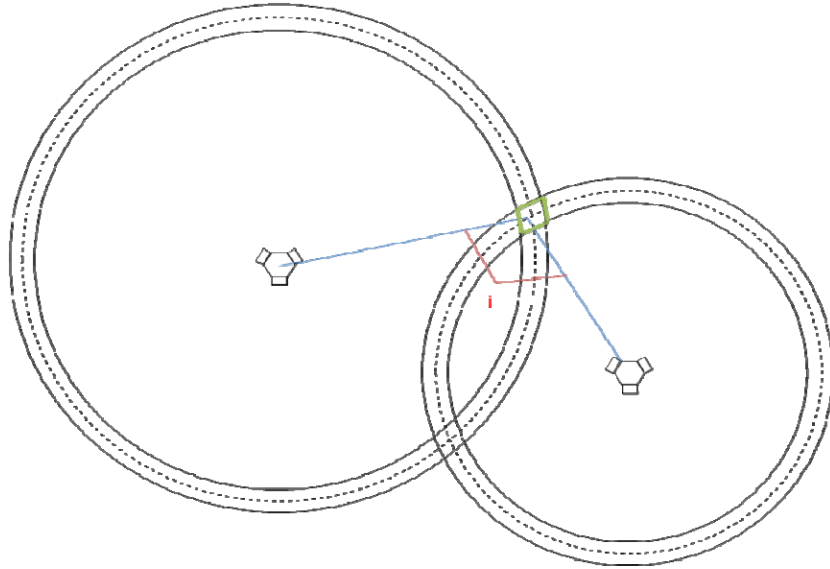
2.5 It could be mathematically demonstrated, nevertheless a graphic method has been used to explain why the inclusion angle limitation is applicable to VOR/VOR navigation, but it is not so significant to DME/DME Navigation. The next picture shows the error area around the intersection of the two VOR radials with an inclusion angle of  $90^\circ$ . The dotted lines are the measured radials and the continue lines delimitates the error (approximately  $\pm 2^\circ$ ). It is clear that error linearly increases with the distance to the station.



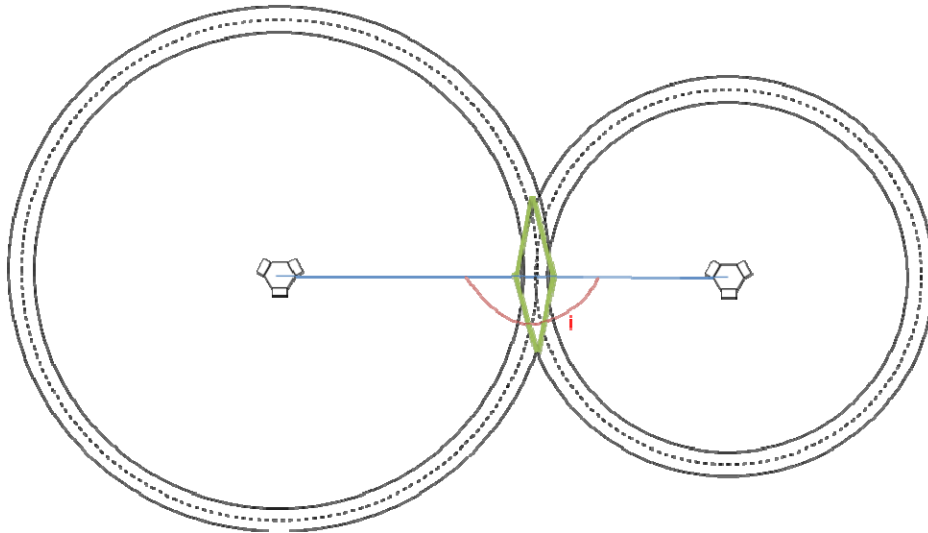
If the inclusion angle increases, the error area also increases and when it is near to  $180^\circ$  the position cannot be calculated as can be seen in the next picture.



For DME the error is not angular but radial that is, the error does not depend upon the distance. This error is bordered by a circumference slightly bigger and another circumference slightly smaller. There is ambiguity because two circumferences intersect in two points. In the next picture is shown the error area around the intersection of the two circumferences with an inclusion angle near to  $100^\circ$ .



In the next picture is shown the worst case with an inclusion angle near to  $180^\circ$ , where there is no ambiguity because the circumferences are tangent and the error increases but not significantly.

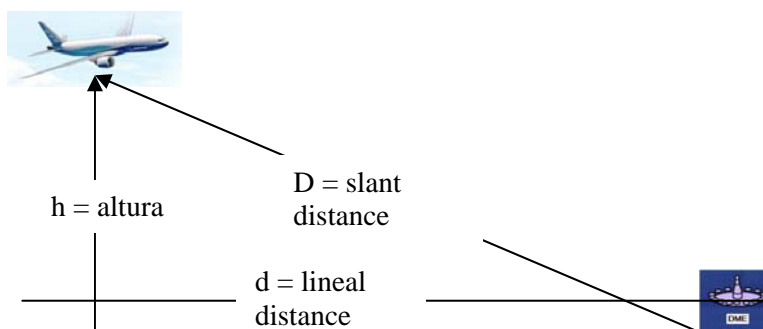


In all above pictures, the error is magnified in order to clearly show the error area, but in fact this error is much smaller, especially in the DME/DME navigation.

### 3 Suggested Action

3.1 It is suggested to reduce the inclusion angle limitation from  $30^\circ$  and  $150^\circ$  to inclusion angles smaller than  $10^\circ$  and bigger than  $170^\circ$ . This limitation could be reduced taking into account that DME error is not angular but radial and this angle has almost not influence in the error area as demonstrated above.

3.2 It is recommended to include aircraft altitude in the DME/DME method to reduce the error induced because the FMS computer assumes the lineal distance  $d$ , but in fact DME calculates the slant distance  $D$  (see next figure). In this way the FMS computer can easily calculate the real distance at terrain level simply by  $d = \sqrt{D^2 - h^2}$



3.3 Furthermore, the elevation angle limitation ( $40^\circ$ ) and the minimum distance limitation (3 NM) could also be suppressed because even when the aircraft is exactly on the DME station distance  $D$  is equivalent to altitude  $h$  and the FMS computer calculate  $d$  as 0.

3.4 Complementing the recommendation in 3.2, it is suggested to include in the Navigation data bases the altitude of the NAVAIDs stations to use it in the calculation based on DME/DME navigation. In this way the error could be reduced due to the difference in altitudes of DME stations, which in some cases can reach 10.000 feet.

3.5 The DME/DME Navigation is without a doubt the most accurate after GNSS Navigation. With the suggested changes, the use of this navigation could be spread out (reducing the current limitations) and improving the accuracy. This navigation is an excellent back up for the GNSS with the additional advantage that each state controls its own NAVAIDs, which is not the case of the GNSS systems.

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