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Agenda Item 4: **RNAV/RNP Issues related to the Safety and Airspace Monitoring Working Group (SAM/WG)**

Infrastructure required to Implementation of the RNAV/RNP concepts in the CAR/SAM Regions

(Presented by CARSAMMA)

Summary

This working paper presents a view of the infrastructure required for the implementation of the RNAV/RNP concepts in the airspace of the CAR/SAM Region and some recommended actions

References

- Annex 10 to the Convention on International Civil Aviation.
- RTCA DO-236.

1. Introduction

1.1. The Caribbean and South American Air Navigation Planning and Implementation Regional Group (GREPECAS) established the Caribbean and South American Monitoring Agency (CARSAMMA) as a safety oversight function to support RVSM/RNP implementation in the Caribbean and South American Region. The CARSAMMA is a service provided by the Brazilian Air Navigation Management Center.

1.2. Along with maintaining a registry of State RVSM/RNP approvals of operators and aircraft using CAR/SAM airspace, the CARSAMMA will produce readiness and safety assessments in conjunction with the Safety and Airspace Monitoring (SAM) Working Group of the RNAV/RNP Task Force.

1.3. The CARSAMMA will apply the internationally accepted safety assessment process with the introduction of the RNAV/RNP into CAR/SAM airspace. The basic collision risk model (CRM) will be used to estimate the overall system risk attributable to all causes prior to implementation of the RNAV/RNP. To define the separation minima that will be applied in the airspace of the CAR/SAM region, and that will affect the safety level, one of the tasks is to verify the infrastructure available in support of the navigation in the airspace where is or will be planned the implementation.

1.4. The International Civil Aviation Organization (ICAO) has recognized a need for dramatic improvements to the existing air navigation system. To obtain the benefits of the CNS/ATM concept, aircraft will need to achieve accurate, repeatable and predictable navigation performance. This is referred to as Required Navigation Performance (RNP).

1.5. The purpose of this paper is to present a summary of navigation system requirements and infrastructure characteristics in connection with the implementation of the RNAV/RNP concepts in the CAR/SAM airspace.

2. Background

2.1. A navigation system with the infrastructure addressed in this WP provides the functions of position estimation, path definition, path steering, and situation indications and alerting to the flight crew. The system may also provide the optional speed control function to support Vertical Navigation and Time of Arrival Control. These functions and the operational interface to the system affect the level of navigation performance that can be achieved. This paper provides a general description of the infrastructure required and explains the relationship between the various errors of the navigation system.

2.2. Position estimation is a means of determining the aircraft’s position over the surface of the earth. Data is used, either from radio sensors (with signals from ground-based NAVAIDS or from satellites) or from onboard autonomous navigation sensors, to derive an estimated position. The position estimation function obtains information concerning any ground-based Navaids that are being used from a navigation database. An important consideration for the aircraft system is that most air transport aircraft incorporate multi-sensor navigation systems. Such systems can utilize the information simultaneously from various available aids such as VOR, DME, GPS and IRU, to provide the best estimated position and aid in continuity of performance. The function also provides position data for display of parameters such as estimated position, estimate of position uncertainty, ground speed and track angle, based on the sensor data being processed.

2.3. The future CNS/ATM operating environment is expected to be based on navigation defined by geographic fixes. Routes and instrument procedures will not be restricted to the location of ground-based navigation aids. This concept, known as Area Navigation (RNAV), is not new. The critical benefit of RNAV is that it eliminates the strict dependency on over-flight of ground NAVAIDS, thus aiding flexibility in the designation of routes and procedures. However, an element that has been missing is the level of confidence of navigation accuracy in flying such routes and procedures. The standards defined in the MASPS integrate the concepts of Required Navigation Performance with that of Area Navigation to provide this level of confidence.

2.4. The RNP concept as written in the ICAO Manual also states:

While the navigation performance accuracy is the basis for defining an RNP type, the other navigation performance parameters of availability, coverage, reliability, capacity, time to recover and integrity determine the utilization and limitations of the individual navigation systems, both ground and airborne, and characterize the means by which a user derives navigation information within an RNP type airspace, as described in this paper. Numerical values for these parameters will be quantified by the appropriate technical bodies.

2.5 Work is in progress in the ICAO respective bodies. One expected product is a new manual that will update the concepts of the RNP Manual, as well as provide implementation guidance for States. It is expected that this new manual will address many of the points discussed here, as well as many others.

2.6 It must be reminded that All navigation data published by a State is assumed to be referenced to the WGS-84 earth model in accordance with ICAO Annex 15 for lateral and precision landing path points. All altitude data will be referenced to the MSL geoid and standard atmospheric pressure model.

3. **Discussion**

3.1 This section describes one consensus on the sensor performance that is assumed to be provided by each type of navigation facility if it is to be used to promulgate a route for RNP RNAV, and with Vertical Performance requirements, where appropriate. This performance must be assumed by the aircraft when demonstrating compliance to the system requirements**.** It is also provided information for the airspace planner in assessing what RNP RNAV types may be supported by a particular navigation infrastructure.

3.2 Integrity of the infrastructure is not considered as part of the airborne evaluation; the Signal-in-Space **(**SIS**)** are assumed to have the error distributions described below. The only exception is GPS, which has a SIS failure rate that must be compensated by an augmentation.

3.3 Infrastructure continuity is not considered as part of the airborne evaluation, but must be considered by the State prior to defining RNP RNAV airspace predicated on a particular navigation infrastructure. It is assumed that an RNP RNAV operation will not be initiated unless the SIS continuity is sufficient.

3.4 In addition, it is assumed that the State publishes the correct location for each navigation facility, so that any error arising from inaccurate survey of a navigation facility is consistent with the following accuracy assumptions.

3.5 This guidance was developed with two purposes. One was to establish a generalized baseline of aircraft performance and capability. In doing so, the requirements do not consider all possible implementations and the potentially better levels of performance that can be achieved. The second purpose was to enable the State to focus on the types of NAVAIDS in their infrastructure, including numbers, locations, and their ability to support performance required.

3.6 Navigation Facility Assumptions for the Airborne System

3.6.1 VHF Omni-directional Range (VOR)

The basic expression for VOR accuracy is:
$\sigma_{VOR}^2 = (\sin(\text{GS error}) * D)^2 + (\sin(\text{airborne error}) * D)^2$

where

GS error = ground station alignment and bend error,
D = distance to the VOR, and
airborne error = standard deviation of airborne error, including receiver noise

When demonstrating compliance to the MASPS, the airborne system shall assume that the VOR infrastructure will provide a radial signal with a Gaussian angular error that has a mean of zero and a standard deviation of 0.7 degrees. VOR signals shall not be used at ranges greater than defined in the table below.

Range	max. D
P-0.3 to RNAV RNP 0.9	20 NM
RNAV RNP- 1 to RNAV RNP- 1.9	40 NM
RNAV RNP-2 and above	100 NM

Table 1 - Maximum VOR Ranges

When designating RNAV RNP airspace based upon a VOR infrastructure, the State may assume that the VOR contribution to error (in the perpendicular direction from the track to the VOR) is equal to:

$$\sigma_{VOR}^2 = (0.0122 * D)^2 + (0.0175 * D)^2$$

Note: This assumes that VOR equipment has an airborne error contribution of 1 degree (95%).

VOR facilities are assumed to have a mean time between failures of 10,000 hours.

3.6.2 Distance Measuring Equipment (DME)

The basic expression for DME error is:

$$\sigma_{DME}^2 = (\text{GS Error})^2 + (\text{Air Error})^2 + (K*D)^2$$

where

GS Error = ground station timing error
K = constant
D = distance to the DME

When demonstrating compliance to the MASPS, the airborne system shall assume that the DME infrastructure will provide a ranging signal with a Gaussian slant range error that has a mean of zero and a standard deviation of 0.05 NM. DME signals shall not be used at ranges greater than defined in the table below.

Range	**max. D**
RNAV RNP-0.3 to RNAV RNP 0.9	25NM
RNAV RNP- 1 to RNAV RNP- 1.9	55 NM
RNAV RNP-2 and above	140 NM

Table 2 - Maximum DME Ranges

Note **:** *The DME range error will be less than 0.2 NM (95%) for systems installed after 1 January 1989 (ICAO Annex 10). Before this date, accuracy was addressed in Annex 10 as a recommended 0.25 NM + 1.25% indicated range.*

When designating RNAV RNP airspace based upon a DME infrastructure, the State may asume that the DME contribution to error (slant-range to the DME) is equal to:

$$\sigma_{DME}^2 = (0.05\ \text{NM})^2 + \text{MAX}\ \{ (0.085)^2, (0.0125 * D)^2 \}$$

DME facilities are assumed to have a mean time between failures of 10,000 hours.

3.6.3 Inertial Reference System (IRS)

Since an IRS is not dependent upon external signals, no external error allocation is necessary.

3.6.4 **Global Positioning System (GPS)**

When demonstrating compliance to the MASPS, the airborne system shall assume that the GPS infrastructure will provide a signal with a Gaussian pseudorange error that has a mean of zero and a standard deviation of 33 meters.

When establishing compliance to the containment requirements, GPS satellites shall be assumed as having a major service failure rate of 10^{-5}/hour/satellite. A major service failure is defined to be a pseudo-range error greater than 150 meters received from a satellite not designated "unhealthy". The overall failure rate shall also be assumed to be 10^{-5}/hour/satellite (the failure rates are equivalent because the major service failure rate is conservative).

Note: GPS provides a unique signal-in-space in that it is not directly monitored to a level commensurate with aviation requirements (time-to-alarm and probability of *missed detection). In order to use GPS for IFR navigation, augmentation is required to provide the monitoring function [airborne augmentation such as fault detection and exclusion (FDE), space-based augmentation, or ground-based augmentation]. The requirements for the augmentation must be based upon the potential effect of a GPS satellite failure on multiple users. These requirements will be determined for each type of augmentation, and will be more stringent than that required to satisfy the containment requirements of a single aircraft. For GPS systems using FDE as the requisite augmentation, the probability of missed detection and failed exclusion have both been established as 10^{-3} (RTCA/DO-229, FAA Notice 8110. 60).*

Note: As implementation of RNP proceeds, it should be recognized that the assessment of performance and capability, and the approval will consider the total system. The total system i.e. multiple sensors and navigation computer will be evaluated in determining how continuity of performance and integrity is provided in the event of sensor failure and loss of signal in space, as described further in 3.7.3.

3.7 Effect of Position Estimation Error (PEE) to Route or Procedure Airspace Design

It is assumed that RNAV RNP procedures will not be developed unless the navigation infrastructure supports the procedure. In order to assess whether or not a particular infrastructure supports RNAV RNP-(x), the State will identify the desired RNAV RNP type and assess the feasibility of the desired RNAV RNP type. The assessment of feasibility involves the following steps:

1) Determine the maximum σ_{PEE} that supports the desired type: $\sigma_{PEE} = 0.3(x)$,
2) Identify the navigation facilities which support the σ_{PEE}, selecting at least one type of airborne integration, and
3) Assess continuity of the selected navigation infrastructure.

These steps are discussed in detail below. Alternatively, the entire process can be reversed by assessing a particular navigation infrastructure and determining the RNAV RNP type that it supports.

3.7.1 Determine Maximum σ_{PEE}

The maximum standard deviation of position estimation error is defined as

$$MAX \{ \sigma_{PEE} \} = 0.3(\text{desired RNP Value})$$

By allocating a fraction of the allowable total system error to the signal-in-space, the remaining error budget is allocated to the aircraft. The value of 0.3 was based upon an evaluation of reasonable airborne errors, so that the effective error allocation is:

$$\sigma^2_{TSE} = \sigma^2_{PEE} + \sigma^2_{PSE}$$

$$(\text{RNP Value})^2 = (2*0.3*\text{RNP Value})^2 + (0.8*\text{RNP Value})^2,$$

where the path definition error is assumed to be zero for this feasibility assessment. The aircraft has been allocated an error of
$2\ \sigma_{PSE} = 0.8 * \text{RNP Value}$.

3.7.2 Identify Navigation Facilities Which Provide Required Accuracy

The State should identify the facilities within range of the intended procedure. Because the airborne equipment assumes that the SIS have the characteristics defined in this paper, the State must also use these assumptions in assessing the RNAV RNP type supported by an infrastructure. The past section provides sufficient information to determine the error distribution for each navigation aid. These error distributions are combined depending upon the type of airborne integration. The following assumptions provide a reasonable baseline for the resulting standard deviation of PEE (in the worst-case cross-track dimension). Additional types of airborne integrations may be specified as appropriate.

Collocated VOR/DME Position

$\sigma^2_{PEE} = \sigma^2_{VOR} + \sigma^2_{DME}$

DME/DME Position

$\sigma^2 PEE = (\sigma^2 DME,1 + \sigma^2 DME,2) / \sin(\alpha)$

where α is the angle between the DMEs.

Note: The effects of slant-range have not been separately considered, based upon the assumption that the error is small for terminal operations and not signficant for en route operations.

GPS Position

$\sigma_{PEE} = 50$ meters

Note: The performance of RNAV RNP systems which utilize GPS is typically constrained by the containment integrity requirement, not the accuracy requirement. While the accuracy is suficient to support all envisioned RNAV RNP types, it should be recognized that additional augmentation is required to meet the containment requirements with high availability.

3.7.3 Assess Infrastructure Continuity

Depending on the type of facilities provided and the intended operation, the State may elect to have redundant facilities to ensure that the continuity is consistent with air traffic requirements. If multiple facilities are required to satisfy the air traffic service requirements, then the worst-case operational configuration should be used for the assessment in item 3.7.2.

For example, an RNAV RNP procedure may be created based on a DME/DME environment. Although only two DMEs are required to provide navigation, the State may determine that three DMEs are necessary to achieve the desired continuity and account for DME ground station maintenance and failures. In this case, the two DMEs with the worst geometry should be used (the third DME should be assumed to be out of service).

4. Summary

4.1. This paper provided a summary of the required infrastructure to implement the RNAV RNP concepts and the errors associated with the possible NAVAIDS to be used to provide the envisaged navigation performance.

4.2. It was seen that the knowledge of the infrastructure is one of the main aspects during the process of definition of the RNAV RNP type to be implemented.

4.3. Also, it was seen that the avionics assume some limits to the amount of error for each available means of navigation.

4.4. The correct definition of the RNAV RNP type to be applied is a key issue in the safety assessment of the system.

4.5. It was verified that the States must be compliant with the WGS 84 system, before the RNAV RNP implementation as well as keep the NAVAIDS working properly.

5. Recommended actions

5.1 States are requested to take note of the information provided in this paper as guidance when assessing the RNAV RNP type to be applied.

5.2 The Secretariat is requested to confirm the status of WGS 84 implementation in the CAR/SAM Regions.

5.3 The RNAV RNP TF is requested to create a specific task in its task list related to the definition of the RNAV RNP type to be applied in the en-route structure of the CAR/SAM airspace or in a particular area.

5.4 States are requested to keep their NAVAIDS with the performance required to support the RNAV RNP implementation.