International Civil Aviation Organization

THE TWELFTH MEETING OF PERFORMANCE-BASED NAVIGATION IMPLEMENTATION COORDINATION GROUP (PBNICG/12)

(Beijing, China, 16-18 December 2025)

Agenda Item 6: RAIM Understanding and Implementation

RAIM Understanding and Implementation in Indonesia

(Presented by Indonesia)

SUMMARY

To discuss the understanding and implementation of RAIM (Receiver Autonomous Integrity Monitoring), which ensures the accuracy and reliability of PBN systems by monitoring the integrity of satellite-based navigation signals in PBN systems.

1. INTRODUCTION

1.1 The objective of this paper is to thoroughly discuss the understanding and implementation of RAIM (Receiver Autonomous Integrity Monitoring) in the context of Performance-Based Navigation (PBN) systems.

1.2 RAIM is a vital component of satellite-based navigation systems, particularly when utilizing Global Navigation Satellite System (GNSS) signals, which are the backbone of modern air navigation. This session will explore the technical aspects of RAIM, its role in ensuring the integrity of navigation signals, the implementation challenges it presents across various states, and how RAIM can be effectively integrated into existing navigation infrastructure, as well as:

- RAIM ensures the accuracy and reliability of PBN systems by monitoring the integrity of satellite-based navigation signals.
- It is crucial for enhancing safety in PBN operations, particularly when using GNSS (Global Navigation Satellite System) as the primary means of navigation**.**

1.3 PBN is a navigation system that allows aircraft to fly more direct routes, increasing efficiency and reducing operational costs. However, for PBN to function optimally, GNSS signals must be reliable and accurate. RAIM ensures that this level of reliability is maintained by continuously verifying the integrity of the GNSS signals.

2. DISCUSSION

2.1 Since 2012, Indonesia has published the SID/STAR RNAV 1 of Soekarno-Hatta Airport, followed by the entire airport and en route in Indonesia is now using the PBN procedure as the primary means of navigation. This makes RAIM play a pivotal role in

ensuring that aircraft remain on the intended flight path. Without RAIM, aircraft relying on GNSS would be vulnerable to signal degradation (satellite constellation) which could result in navigation errors. RAIM thus serves as a safeguard, ensuring that the aircraft stays on the correct flight path.

2.2 RAIM works by using the aircraft's GNSS receiver to analyze the incoming satellite signals. It checks whether the signals are consistent and accurate. If any signal is suspected to be faulty, RAIM will generate an alert, warning the flight crew about the loss of integrity. The system relies on a minimum number of visible satellites to perform its validation checks. Typically, a minimum of five satellites is required for a receiver to perform RAIM, although more satellites are recommended for better accuracy.
To both **detect and exclude** a faulty satellite (called *Fault Detection and Exclusion*, or FDE), RAIM requires **at least six satellites**.
The algorithm compares redundant measurements, performing statistical consistency checks (residual analysis) to determine if one or more satellites are providing out-of-family data.

2.3 The primary function of RAIM is to detect faults in the navigation signals. It does not correct the fault but rather provides an alert to the aircraft's avionics or flight crew. This allows the crew to take corrective action, such as switching to an alternative navigation source, if available. RAIM is considered a key technology in achieving safety-critical navigation in PBN operations, which rely heavily on GNSS.

2.4 Although RAIM is widely used in many regions, there are numerous challenges in its global implementation, particularly in diverse states with varying infrastructure, resources, and airspace management systems. Implementation Challenges in Different States can be identified as follows:

- Variations in the availability and reliability of GNSS signals across different regions.
- Infrastructure and technology limitations hinder the deployment of RAIM.
- Challenges in aligning RAIM requirements with existing navigation systems,
- etc.

2.5 Technical Discussions on RAIM Validation and Integration can be pictured as below:

- How RAIM validates the integrity of navigation signals.
- Integration of RAIM with current airspace systems and technology.
- The role of RAIM in supporting flight operations, especially during low-visibility and adverse conditions.
- etc.

2.6 RAIM validation is a technical process that ensures the accuracy and reliability of GNSS signals before they are used in PBN navigation. The receiver continuously monitors the integrity of the signals coming from the satellites, comparing the signal's data with the expected values. If the data from one or more satellites deviates beyond predefined thresholds, RAIM will issue an alert, indicating a potential issue with the satellite data. The validation process involves several key steps:

- Satellite Visibility: RAIM requires that a minimum number of satellites be visible for accurate integrity checks.

- Signal Comparison: RAIM compares the signals from multiple satellites to detect any inconsistencies or faults.
- Error Detection: If a signal is determined to be erroneous, RAIM flags it and issues an alert to the flight crew.
- Actionable Alerts: The crew receives the alert, and depending on the severity of the fault, they can decide whether to continue relying on GNSS or switch to an alternative system.

Challenges and Lessons Learnt

2.1 The implementation of RAIM is particularly important in the context of PBN procedures in Indonesia, such as RNP (Required Navigation Performance) and RNP AR (Required Navigation Performance Authorization Required). These procedures require high accuracy and integrity from GNSS systems, and RAIM is a critical component in meeting these demanding performance standards.

2.2 One of the primary challenges States face when implementing RAIM in Indonesia is the variability in GNSS signal availability. In some areas, the satellite coverage is not always optimal, and aircraft may not always have access to a sufficient number of visible satellites for RAIM to perform its checks. This is particularly problematic in areas in remote, oceanic regions, where satellite geometry may be less favorable.

2.3 Moreover, the geometry of satellites plays a crucial role in the reliability of RAIM. In order to ensure accurate signal processing, the satellites must be spread across the sky in such a way that no one satellite's signal dominates. In regions like Indonesia, which lies in the equator, where there is ionosphere disturbance or poor geometry, RAIM may be unable to verify the integrity of the signals, leading to potential navigation risks.

2.4 Aviation infrastructure may encounter significant challenges when trying to implement RAIM. Indonesia's challenges could include inadequate ground-based support, poor communication networks, or limited access to advanced navigation technologies. In some cases, older navigation systems may not be fully compatible with RAIM technology, requiring costly upgrades to onboard and ground equipment.

2.5 Furthermore, the implementation of RAIM in Indonesia demands that both aircraft and ground systems are capable of supporting the necessary processing power for real-time analysis of GNSS signals. This requirement could be a significant hurdle in deploying RAIM technology across Indonesia's fleet.

2.6 Moreover, Indonesia has implemented PBN operations may lack the experienced personnel required to troubleshoot RAIM-related issues or implement the necessary regulatory frameworks to ensure safe operations.

2.7 Integrating RAIM into existing navigation systems in Indonesia can be challenging. However, the benefits of RAIM far outweigh the integration costs, as it improves the overall reliability and safety of the airspace. The integration process may involve software updates, hardware changes, and the implementation of new operational

procedures. This can be complex and costly, but it is necessary to ensure that the aircraft can accurately detect and handle GNSS signal failures.

2.8 One of the key challenges in integration in Indonesia is ensuring that RAIM alerts are communicated effectively to pilots and air traffic controllers. Since RAIM issues alerts based on real-time analysis of GNSS signals, these alerts must be timely and accurate. This requires coordination between the aircraft's avionics, air traffic management systems, and ground support personnel.

2.9 Looking ahead, RAIM will continue to evolve, particularly with the advent of multi-constellation GNSS systems. These systems, such as Galileo, GLONASS, and Beidou, will provide greater satellite availability and improve RAIM's performance. With these advancements, states will be able to implement RAIM with fewer limitations, increasing the overall reliability of PBN operations.

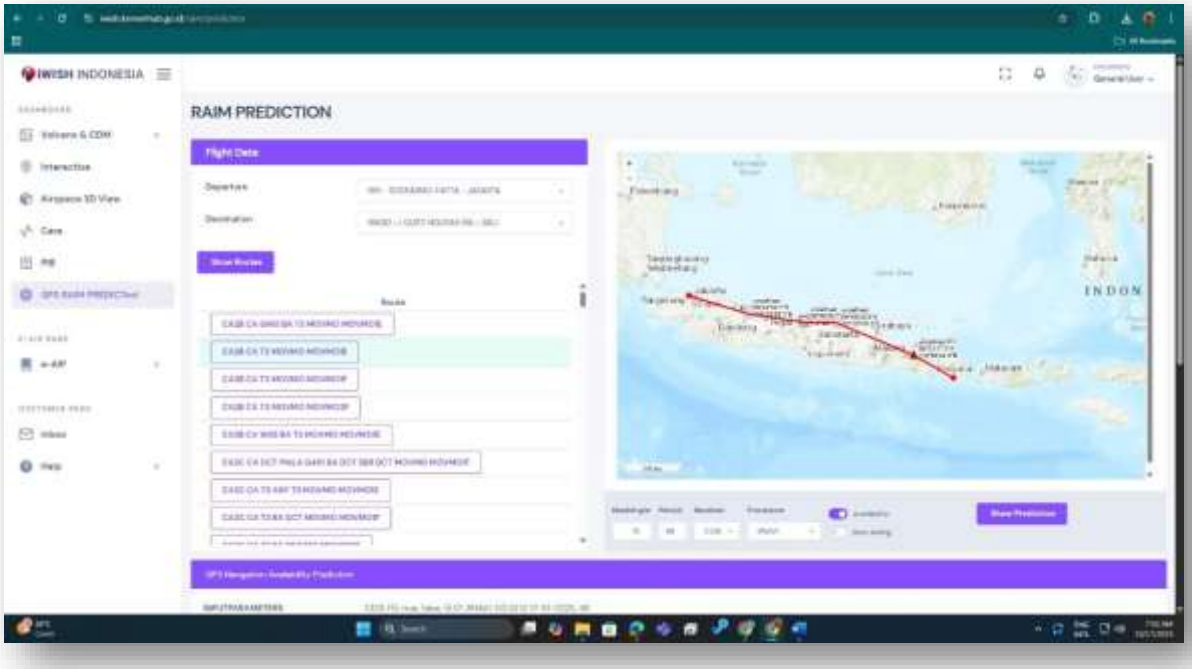
2.10 In addition, as Satellite-Based Augmentation Systems (SBAS) become more widely available, RAIM will work in conjunction with these systems to provide enhanced navigation integrity. The integration of RAIM with SBAS and GBAS technologies will allow for even higher levels of accuracy and reliability in air navigation.

3. CONCLUSION AND RECOMMENDATION

3.1 RAIM is a fundamental component of Performance-Based Navigation that ensures the integrity of GNSS signals used in modern air navigation. It provides critical support in maintaining the accuracy and safety of PBN operations, particularly in regions where satellite signals may be subject to degradation.

3.2 However, implementing RAIM across various states, especially in Indonesia, presents significant challenges, including variability in GNSS signal availability, technological limitations, and the need for robust training programs. To overcome these challenges, we must prioritize collaboration and share best practices, while also investing in the necessary infrastructure and training to support RAIM adoption.

3.3 As aviation continues to embrace more advanced PBN procedures, RAIM will remain a critical safeguard for ensuring safe and reliable navigation in increasingly complex airspaces.



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4. ACTION REQUIRED BY THE MEETING

The meeting is invited to:

a) Note the information contained in this paper; and
b) Discuss any relevant matters as appropriate.

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