

ELEVENTH AIR NAVIGATION CONFERENCE

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Agenda Item 6 Aeronautical navigation : issues

TOOLS AND FUNCTIONS FOR GNSS RAIM/FDE AVAILABILITY DETERMINATION

(Presented by Germany)

SUMMARY

This paper highlights the need for GNSS receiver autonomous integrity and availability prediction functions and for notification systems. As a result of an initiative of the ICAO GNSS Panel tutorial prediction software has been provided by the German Air Navigation Services provider, DFS to ICAO.

1. INTRODUCTION

1.1 State air traffic services (ATS) agencies have the responsibility to monitor and to report the status of navigation services. To support this requirement, navigation service providers must provide status information to ATS. If the status of a navigation service changes, ATS must advise pilots via direct communications and/or via a NOTAM system (*Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444)).

1.2 In the case of global navigation satellite system (GNSS), when a system element (e.g. a Global Positioning System (GPS) satellite or a satellite-based augmentation system (SBAS) reference station) fails, neither ATS nor the pilot can relate the failure to a loss of service. GNSS service providers must therefore determine the effects of such failures through suitable systems and provide information on service outages to ATS. This information must be presented to ATS operational staff in such a way that it supports the requirement to advise pilots of service interruptions. The information must also be used to generate a NOTAM. AN-Conf/11-IP/14 (GNSS Manual) refers.

1.3 Additionally, organizations may need to determine the availability of GNSS services in their area of responsibility before decisions about transition towards GNSS are made. This information paper gives background information about availability prediction functions and a tutorial software tool for GNSS receiver

autonomous integrity monitoring (RAIM)/fault detection and exclusion (FDE) calculations that has been donated from DFS Deutsche Flugsicherung to ICAO and is accessible on the ICAO web site.

2. GPS RAIM/FDE AVAILABILITY

2.1 The core GNSS satellite constellations such as GPS or GLObal NAVigation Satellite System (GLONASS) were not developed to satisfy the strict requirements of IFR navigation, particularly in regard to integrity monitoring. Receiver autonomous integrity monitoring (RAIM) requires redundant satellite range measurements to detect faulty signals and alert the pilot. RAIM algorithms require a minimum of five visible satellites in order to perform fault detection and six visible satellites for fault detection and exclusion (FDE).

2.2 The RAIM algorithm computes a horizontal protection level (HPL) that is based on the geometry of satellites at a given point in time. The HPL is the radius of a circle in the horizontal plane, centered at the true aircraft position that is assured to contain the indicated horizontal position, with a given probability of missed detection and false alert. The FDE algorithm performs a similar computation to determine the horizontal exclusion level (HEL).

2.3 There can be occurrences when the number and/or geometry of the visible satellites is not sufficient to allow detection of a failure even when the satellite constellation is fully operational. Also, satellites occasionally are taken out of service for maintenance, thereby further reducing the availability of RAIM. Since FDE requires one additional satellite measurement than RAIM, its availability will be even lower.

2.4 The availability of RAIM and FDE is predictable based on the knowledge of the current status of the core constellation and any planned satellite outages.

2.5 There are several factors that can affect RAIM availability, in particular the:

- a) number of operational satellites in the constellation;
- b) satellite mask angle;
- c) avionics capable of barometric altimeter aiding;
- d) availability of ranging signals from geostationary satellites; and
- e) receiver capability to account for GPS selective availability (SA) off.

3. NEED FOR GNSS AVAILABILITY PREDICTION

3.1 GNSS is fundamentally different from traditional ground-based navigation aids. If a satellite is taken out of service for maintenance or the satellite system status has changed, it is not explicitly known whether or not this change will have an impact on service availability. It is for this reason that GPS RAIM approvals need to consider the use of a prediction function, which should support both flight planning and NOTAM services.

4. APPLICATIONS OF AN AVAILABILITY PREDICTION FUNCTION

4.1 In general, such an availability prediction function can be used on two levels:

- a) flight planning and NOTAMs; and
- b) equipment certification and (strategic) planning of navigation services

Availability prediction in flight planning

4.1.1 A number of States have granted operational approvals for the use of GPS/RAIM equipment for en-route and approach operations. Independent from the built-in integrity monitoring functions of the onboard receivers, it is important to note that pre-flight planning is required to ensure availability of all needed navigation aids, including GNSS. In some States, NOTAM services have been established that cover this requirement, while some others have delegated authority to aircraft operators to perform availability checks using a prediction service.

4.1.2 If prediction is used in flight planning, then from an operational perspective, there remains only a continuity risk associated with the failure of necessary system components between the time the prediction is made and the operation is conducted.

NOTAMs

4.1.3 NOTAM information for Basic GNSS receiver RAIM outages are required and will continue to be issued for the foreseeable future where Basic GNSS receivers are expected to be used. Before approving operations based on a satellite-based augmentation system (SBAS) or ground-based augmentation system (GBAS), a State is expected to provide a status monitoring and NOTAM system. To determine the effect of a service element failure on service, a software (service volume) model should be in place.

4.1.4 SBAS receivers revert to RAIM or FDE operation if there is a loss of SBAS service or the aircraft is operating in a region outside the SBAS service area. There is a need to distinguish in the NOTAMs between Basic GNSS receiver RAIM outages and SBAS receiver RAIM or FDE outages that may occur with use of SBAS receivers. Therefore, in the situation where SBAS receivers revert to RAIM or FDE operation, a RAIM or FDE outage will be issued as an SBAS NOTAM by the navigation service provider.

Equipment certification and operational approval

4.1.5 Notification systems (including NOTAMs on GNSS service) should reflect the current status. This requirement is complex in realisation for GNSS. Availability predictions are based on constellation simulations and include assumptions about receiver parameters laid down in the certification documentation (e.g. FAA TSO C129 or JAA TGL 3). In the planning stage of GNSS implementation, service providers or certification authorities may wish to investigate the results of specific parameter setups on availability figures. As an example, the “mask angle” limits the reception of satellites for the receiver and varies between 7.5 and 0 degrees, depending on equipment. The variation of mask angles and analysis of resulting availability figures

is a typical application for offline simulations and can be used to assist organisations in their decision making process.

4.1.6 An additional certification requirement for Basic GNSS receivers is barometric aiding for non-precision approach. This type of aiding provides an additional ranging measurement and therefore improves GNSS availability. RAIM prediction software can support organisations in the examination of the use of barometric aiding for other phases of flight.

4.1.7 The switching off of GPS SA raised questions about consequences for existing operations. Theoretically, SA off improves GPS/RAIM availability. However, existing Basic GNSS receivers have “hard coded” assumptions on GPS signal performance including SA and do not reflect actual developments. As a consequence, these types of receivers are conservative in their performance and provide less navigation availability than theoretically possible. Differences in availability figures with and without SA can be calculated using offline prediction tools, thus enabling estimates on service availability for different receiver types.

Planning of navigation services

4.1.8 States willing to implement navigation services based on GNSS are likely to examine the possible implications before approving such operation. Also, availability of service predictions is essential for future planning of navigation services.

4.1.9 It is worthwhile to examine GNSS availability and compare the results with operational needs. Availability figures of 95 per cent may be sufficient for some type of operation but may cause major problems for scheduled operations. A comparison of the percentage of availability against absolute numbers in terms of minutes per day or duration and number of outages should be performed and results discussed with affected operators before deciding about approvals. Use of offline prediction software gives the opportunity to compare the nominal 24-satellite GPS constellation with the actual constellation regarding availability results. The inclusion of SBAS geostationary satellites in the availability calculation may facilitate further steps towards GNSS implementation.

4.1.10 With GNSS, most States rely on a navigation system that is not operated and maintained by themselves. In the planning stage of GNSS implementation, it is therefore helpful to base decisions not only on nominal constellations (respectively availability figures) but on actual, worst and best case performance, so that the range of the GNSS availability within the area of interest becomes better understood. This may include the identification of “critical” satellites which have an outstanding impact on availability figures for the area. GNSS satellites undergo scheduled and non-scheduled maintenance or may suddenly fail. Using offline prediction software can give an estimate about operational consequences before “things happen”.

5. IMPLEMENTATION OF PREDICTION FUNCTIONS AND SYSTEMS

5.1 A number of States have developed GNSS prediction capabilities and introduced them into operation to support flight planning and NOTAM generation. These efforts have been primarily related to prediction of RAIM/FDE availability, but are now expanding to support introduction of SBAS and GBAS operations. Other States have run extensive simulations using non-operational tools. The GNSS Panel has

taken extensive discussions on service availability and availability prediction and used its expertise to develop standards and recommended practices for the implementation of GNSS related NOTAM services. This effort will ensure a harmonized distribution of critical GNSS services information independent from technical realisations.

6. INITIATIVE OF THE ICAO GNSS PANEL

6.1 During 1998, the John A. Volpe National Transportation Systems Centre (under the US DoT) supported the German Air Navigation Services Provider, DFS in the implementation of a GPS RAIM prediction system. This system was designed for operational use and is now directly linked to the national German NOTAM system. As this system is operational, variations of input parameters such as mask angle, use of different satellite constellations, etc. are not possible. For the operational system, these parameters are fixed to match with national certification requirements. Consequently, a PC-based version of the German GPS RAIM prediction system was developed which can be run independent from the operational system, thus enabling the analysis or prediction of scenarios without interfering with the operational system.

6.2 Some States as well as the GNSS Panel were presented analysis results and capabilities of this PC-based system and members expressed interest in the distribution of such tool.

6.3 The Secretariat of the International Civil Aviation Organization considered the initiative of the Global Navigation Satellite System (GNSS) Panel and supported the request to use the above mentioned software for tutorial and demonstration purposes. As a result of this initiative, DFS recently donated the PC based software to ICAO, and this software was posted on the secure ICAO Web site of the Navigation Systems Panel, “Links” directory (New users: go to <http://icaosec.icao.int>, click “New user,” follow directions for group name “NSP”). The software can be downloaded through an authorization and verification process. It is anticipated that the provided documentation for this software is sufficient to support the handling of this non-operational software. Questions regarding further details or on operational implementation issues are welcome by ICAO, Volpe NTSC and DFS.

7. CONCLUSIONS

7.1 The conference is invited to take notice of the issues regarding the provision of NOTAMs and prediction functions for GNSS and their operational implications as well as the tutorial software available on the ICAO Web site.

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