



INTERNATIONAL CIVIL AVIATION ORGANIZATION
South American Regional Office

***SEMINAR/WORKSHOP FOR THE IMPLEMENTATION OF
NAVIGATION INFRASTRUCTURE TO SUPPORT PBN AND
GNSS PRECISION APPROACH OPERATIONS IN THE
NAM/CAR/SAM REGIONS***

SUMMARY

Lima, Peru, from 15 to 17 August 2016

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of ICAO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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HISTORY

ii-1 PLACE AND DURATION

The Workshop/Seminar for the Implementation of Navigation Infrastructure to Support PBN and GNSS Precision Approach Operations in the NAM/CAR/SAM Regions was held at the ICAO South American Regional Office, Lima, Peru, from 15 to 17 August 2016.

ii-2 OPENING CEREMONY AND OTHER MATTERS

Mr. Franklin Hoyer, Regional Director of the ICAO South American Office, greeted the participants and acknowledged their continuous support to the regional activities undertaken by the South American Regional Office, as well as the continuous support of civil aviation authorities of the South American Region.

ii-3 SCHEDULE, ORGANIZATION, WORKING METHODS, OFFICERS AND SECRETARIAT

The Workshop/Seminar was conducted from 08:30 to 15:00 hours.

The Meeting had two Secretaries: Mr. Onofrio Smarrelli, Regional CNS Officer of the Lima Regional Office, and Miss Mie Utsunomiya, Regional CNS Officer of the Mexico Regional Office.

ii-4 WORKING LANGUAGES

The working languages of the event were Spanish and English, with simultaneous interpretation services.

ii-5 AGENDA

The agenda is contained in Appendix A to this summary.

ii-6 ATTENDANCE

The event was attended by 48 participants from 18 CAR/SAM States (Argentina, Aruba, Bolivia, Brazil, Chile, Colombia, Cuba, United States, France, Jamaica, Mexico, Panama, Peru, Dominican Republic, Suriname, Uruguay, and Venezuela), one International Organization (COCESNA), as well as representatives from AERODATA AG, AEROLINEAS ARGENTINAS, BOEING, INVAP, HONEYWELL, MIRUS TECHNOLOGY, NAVBLUE, THALES ALENIA SPACE, and Universidad de la Plata (Argentina), in addition to ICAO Officers. The list of participants appears in **Appendix B**.

1 SUMMARY OF THE WORKSHOP

1.1 Objective

1.1.1 The objective of the workshop was to provide technical and operational information to the States, air navigation service providers (ANSPs), and users for the effective implementation of air navigation infrastructure to support PBN and GNSS precision approach operations.

1.1.2 The workshop was designed to support the implementation of Aviation System Block Upgrade (ASBU) B0 modules, mainly: B065/APTA-Optimization of approach procedures including vertical guidance, B0-10/ FRTO Improved operations through enhanced en-route trajectories, B0-05/CDO: Improved flexibility and efficiency in descent profiles, and B0-20/CCO Improved flexibility and efficiency in departure profiles - Continuous climb operations.

1.2 Introduction

1.2.1 The workshop was conducted in six sessions, as follows:

- Session 1: Global and regional implementation considerations of the navigation infrastructure to support PBN and GNSS precision approach operations in the NAM/CAR/SAM Regions
- Session 2: ICAO standards and recommended practices (SARPS) and documentation on the navigation infrastructure to support PBN and GNSS precision approach operations
- Session 3: Current status and evolution of GNSS
- Session 4: Ionospheric and tropospheric effects on GNSS
- Session 5: Ground and flight testing considerations
- Session 6: Final recommendations and conclusions

1.2.2 Twenty eight presentations were made and posted on the following website: <http://www2010.icao.int/SAM/Pages/MeetingsDocumentation.aspx?m=2016-PBNGNSS>

1.3 Global and regional implementation considerations of the navigation infrastructure to support PBN and GNSS precision approach operations in the NAM/CAR/SAM Regions.

1.3.1 In this session, two presentations were made: P/02, in which ICAO reported on Global Air Navigation Plan considerations on the navigation infrastructure to support PBN, including an explanation of the benefits of PBN implementation, the global status of PBN implementation and the way forward. This presentation focused on the global perspective of PBN, but also provided information on regional coordination and support, which would expedite PBN implementation in the CAR/SAM Regions.

1.3.2 In the other presentation (P/03), ICAO informed on regional planning, strategies and implementation of navigation infrastructure to support PBN and GNSS precision approach operations in the NAM/CAR/SAM Regions, according to the requirements of the Regional Air Navigation Plan (Document 8733 eANP), GREPECAS, and the Performance-based Implementation Plan.

1.4 ICAO standards and recommended practices (SARPS) and documentation on the navigation infrastructure to support PBN and GNSS precision approach operations

1.4.1 In this session, two presentations were made: P/04, in which ICAO presented its SARPs and the documentation on navigation infrastructure to support PBN. This presentation introduced ICAO SARPs and guidance materials related to PBN operations and navigation aid infrastructure to support PBN. Focusing on the performance-based approach and following the ASBU framework that assigns top priority to PBN, these documents are useful guidance for PBN planning, implementation and validation.

1.4.2 In the second presentation (P/05), ICAO shared some considerations regarding the frequency spectrum for navigation use, such as frequency registration and coordination, radio navigation frequency allocation, separation criteria, ICAO documents and results of the WRC 15.

1.5 Current status and evolution of GNSS

1.5.1 In this session, 12 presentations were made, 6 of them related to the ground-based augmentation system (GBAS), 4 on the satellite-based augmentation system (SBAS), and two on RAIM availability prediction.

Ground-Based Augmentation System (GBAS) presentations

1.5.2 Presentation P/06, by Benoit Roturier, of DSNA from France, dealt with the status of GBAS Cat I station deployment worldwide and the complexity of implementing Cat I GNSS procedures, compared to basic GPS approach procedures. The presentation reported that a small number of GBAS certified stations had been deployed so far (less than 10) and that the number was not expected to increase significantly in the near future (with the possible exception of Russia) due to: 1) current deployments of ILS systems in potential GBAS airports, and 2) additional GBAS infrastructure costs. On the other hand, major aircraft manufacturers have made huge efforts to equip different types of aircraft with GBAS, which has led to about 1200 users of GBAS-enabled avionics today.

1.5.3 Presentation P06 also introduced the new GBAS Cat II/III SARPs being developed by ICAO, and the regional efforts being made, such as SESAR in Europe. The ICAO Navigation System Panel (NSP) has been finalizing the first generation of Cat II/III standards based on the GPS L1 signal alone. To increase the robustness and availability of GBAS, especially in equatorial regions, consideration has been given to the possibility and need for a second generation of Cat II/III standards, based on dual frequency (L1/L5) and multi-constellation.

1.5.4 The presentation also showed a study conducted by France to assess the operational benefits of GBAS Cat II/III at Paris CDG, where currently 8 ILS units support A/L operations. The aim is to increase airport capacity under ILS operations using low visibility procedures and/or to reduce ILS infrastructure costs. Several scenarios were investigated, such as a segregated GBAS runway, or the need for specific approach sequencing tools, but the study could not quantify the benefits of introducing GBAS, since the level of fleet mix (ILS- vs GBAS-equipped) to be managed by still inexistent ATM tools played a major role there. CDG operational teams did not support the notion of a GBAS specialized runway due to its complexity, nor of removing ILS, until the fleet was 100% GBAS.

1.5.5 In P/07, Carlos Rodriguez from the FAA informed that GBAS CAT I had been implemented at Newark and Houston and was used on a daily basis by domestic and international air carriers. FAA was working closely with the international community to complete the validation of GAST-D (CAT III) standards, and with Honeywell on the design approval of their GAST-D system. In addition, FAA was reviewing the benefits of advanced GBAS capabilities (extended service volume, reduced RVR, RNP to GLS, variable glide path/displaced threshold operations). He noted that the FAA maintained a close relationship with international service providers and the user community by co-chairing the International GBAS Working Group with Eurocontrol.

1.5.6 Alessander Santoro from Brazil presented P/08, on the Brazilian experience with GBAS. He began by discussing the emergence of PBN as a way of addressing global air traffic growth, along with GNSS technologies, given that conventional nav aids had limitations to accompany this growth. He then explained the complexity and size of the Brazilian airspace, and described the evolution of GPS in Brazil, starting with the testing of the Honeywell SLS-2000 SCAT-I station up to the testing of the SBAS system within the context of ICAO project RLA/00/009. These tests revealed the severe behavior of the ionosphere around the geomagnetic equator and demonstrated that SBAS implementation did not have a favorable cost/benefit ratio.

1.5.7 In 2013, through an agreement with the FAA, DECEA (Airspace Control Department) installed a GBAS prototype station in SBGL (Rio de Janeiro) and equipped GEIV aircraft (Brazilian Flight Inspection Group) to test GBAS procedures. The flights showed the capacity, flexibility, and stability of GBAS for curved approaches, but data analysis was inconclusive due to data acquisition issues and the possible influence of the ionosphere. To eliminate variables, a Honeywell SmartPath SLS-4000 (certified by FAA) was installed in SBGL (Rio de Janeiro) to collect data during the peak of solar cycle 24 and check the behavior of the station. Since its installation, the availability of the station has been below the required level, forcing the disabling of monitors to allow for constant data collection.

1.5.8 Data collected from 180 GPS L1/L2 receivers installed throughout Brazilian territory and analyzed by a group of experts from DECEA, ICEA, FAATC, USTDA, Mirus Technology, SDTP, Stanford University, INPE, Boston College, UNESP, and KAIST, who measured S4, Kp and Dst indexes, revealed the occurrence of 127 severe ionospheric events. The result was a report submitted in March 2015, which concluded that the SLS-4000 station, at low latitudes, did not meet ICAO integrity and availability requirements. The report is posted in the ICAO website, together with all the presentations of the event.

1.5.9 He also reported on new technologies and procedures concurrent with GBAS GAST C, such as: GAST D (GBAS CAT II/III), GBAS MF/MC (multi-frequency, multi-constellation), LPV200 SBAS, SBAS MF, BARO VNAV and RNP-AR procedures. Finally, he noted that GBAS GAST C was operational in a few countries in mid-latitudes but was still a challenge in low latitudes. In 2003, Brazil tested GBAS stations in SBGL and the technology did not meet ICAO SARPs for availability and integrity. Brazil continues making efforts to set SLS-4000 operational at SBGL for public use, and new technologies were emerging to challenge GBAS GAST C.

1.5.10 Ricardo Abregu and Manuel Alvarez from ANAC (Argentina) informed in presentation P/09 that, in accordance with the ICAO strategy set forth in the Global Air Navigation Plan, ANAC opted for PBN implementation and GBAS as the best future option for CAT 1 precision approaches to replace ILS systems.

1.5.11 The presentation also described the CAT I GBAS implementation schedule, starting with the design, manufacture, implementation, and approval of a GBAS system at the San Carlos de Bariloche international airport in January 2014, the technical assessment conducted in the laboratory in 2014-2015, the on-site technical assessment model (2016), the certification and approval process (2016), and after that, the test period and initial manufacturing of 6 CAT I GBAS units. It also described the technical configuration of the GBAS and the test bench implemented for the correction algorithm.

1.5.12 Presentation P/10 by INVAP supplemented presentation P/09, providing more detailed technical information about the CAT I GBAS hardware and software and service provisions.

1.5.13 Patrick J. Reines from Honeywell presented P/17 on avionics support for GBAS and performance-based navigation. This presentation showed the cost-effectiveness of GBAS, since it could provide 48 possible approaches from a single ground station and enabled advanced PBN approach procedures. He also explained that GLS (GBAS avionics) equipage by airlines was being expedited and confirmed that GBAS and GLS were ICAO-compliant systems, in accordance with the following data: a. Formal approvals in multiple nations, b. In use on revenue passenger flights in IMC weather, c. GLS equipped airlines are already flying in the CAR/SAM Regions. In addition, he provided additional information, including that GBAS Cat I growth path to Cat II and Cat III was underway, that Brazil was leading the GBAS low latitude safety case, that the regional GBAS approval and implementation was an optimal approach, and that, so far, only the Honeywell GBAS was ICAO-compliant and was being used in revenue passenger service.

Satellite-Based Augmentation System (SBAS) presentations

1.5.14 Presentation P/11 by Benoit Roturier of France described the status of SBAS worldwide (EGNOS/Europe, MSAS/Japan, GAGAN/India, and WAAS). The vertical navigation service (LPV) is deployed over three regions, but not yet in Japan. Since SBAS does not involve local airport infrastructure costs, it is frequently considered a government-based multimodal infrastructure serving different user communities. SBAS represents a very low-cost infrastructure opportunity for aviation and supports a high rate of implementation of Cat I (LPV 200) or near-Cat I (LPV 250) approach procedures.

1.5.15 Using WAAS, more than 4000 approach procedures with vertical guidance were implemented during the last decade, and 440 were expected in Europe by 2018. The number of equipped aircraft is also increasing on a regular basis, with more than 80,000 SBAS users registered in North America. GAGAN has developed a specific ionospheric model that provides good availability of LPV in the equatorial region.

1.5.16 France showed how PBN was improving significantly the performance of its approach and landing national network, while also reducing infrastructure costs through an ILS phase out program. The second part of the presentation introduced 4 new SBAS programs: SDCM/Russia, SBAS/ASECNA, BDSBAS/China and KASS/South Korea. It was also developing new ionospheric algorithms for EGNOS in the equatorial region, with the support of the ASECNA ABAS program (see the Thales presentation).

1.5.17 Finally, the evolution of SBAS toward a dual frequency, multi-constellation system was described, showing long-term potential to cover all the land masses of the world with Cat I signals when current SBAS evolved to this technology and additional networks were deployed in the Southern hemisphere.

1.5.18 In P/12, Carlos Rodriguez from the FAA presented the status and evolution of SBAS. Related FAA activities included investments by the FAA in upgrades to the WAAS network to address obsolescence issues and to prepare the system for the implementation of the L5 (dual) frequency. The FAA continues to manage the acquisition of GEO satellite services to maintain optimum coverage and service level for the WAAS. The WAAS system provides the service required to meet ADS-B positioning requirements and to support PBN implementation. The FAA continues to support the development and publication of WAAS supported procedures and user equipage. The GPS follows the program for the development of the next generation of satellites and control segments and the FAA maintains close coordination for the implementation of aviation requirements in the GPS system.

1.5.19 In P/13, ICAO showed the results of the SBAS-type WAAS test bed trials conducted under technical cooperation project RLA/00/009 between 2001 and 2007 in the CAR/SAM Regions. Project activities were described, together with the recommendations made as a result of the trials.

1.5.20 In presentation P/14, COCESNA (Central American Corporation for Air Navigation Services) provided information about project RLA/03/902 SACCSA, in which several CAR/SAM States and agencies participated under the leadership of ICAO, and which consisted of three phases.

1.5.21 Its objective was to study the ionospheric behavior in the CAR/SAM Regions in order to find an SBAS solution for the development of an GNSS applicable to the CAR/SAM Regions, where ionospheric behavior is different from other regions that already have SBAS.

1.5.22 It was noted that phase III contemplated studies on the operation of the monitoring network and the Central Processing Unit, as well as a comparison of complementary solutions in areas of poor or limited performance. In addition, the meeting was informed that the project contractor, GMV, had enabled the link <http://magicgnss.gmv.com/sam/>, as a platform to analyze SACCSA benefits using its magic SBAS and MagicGemini tools.

1.5.23 In order to meet APV-I horizontal and vertical accuracy requirements, the system should take advantage of the multi-constellation of satellites (GPS/GLONASS and others) and dual frequency to minimize the impact of solar activity on the ionosphere, and particularly on the SBAS signal.

RAIM availability

1.5.24 Two presentations were made on this item: P/15, by ICAO, describing the reasons why the SAM Region had implemented a regional RAIM availability service called SATDIS, and its functionality in approach and terminal areas.

1.5.25 In P/16, NAV BLUE presented an overview of GPS operation and the errors and key parameters that affected RAIM (*e.g.*, geometry), a brief description of SATDIS, the SAM RAIM prediction tool, an overview of other regional solutions provided by NAVBLUE to AeroThai, CAAS and EUROCONTROL, and finally an overview of additional functionalities that could be added to SATDIS, including ADS-B, NOTAMs, and mapping capabilities.

1.6 Ionospheric and tropospheric effects on GNSS

1.6.1 Francisco Azpilcueta, from the University of La Plata, Argentina, presented P/18, on the ionospheric and tropospheric effects on GNSS. He showed a method to characterize the behavior of the

nominal ionosphere in Bariloche, which had favorable ionospheric conditions. The method was applied to characterize the behavior of the ionosphere in Argentinian territory and identify the different ionospheric regions of Argentina. In summary, University of La Plata is expecting to obtain results and conduct a statistical analysis based on the infrastructure installed at the Bariloche airport. At present, the first phase has been completed. The next step will be to characterize the irregular behavior of the ionosphere over Argentina, in order to define the parameters typical of an ionospheric threat model, and implement the management module.

1.6.2 In presentation P/19, Rich Cole (Mirus Technology) provided information on the effects of the troposphere and ionosphere on GNSS and an overview of the upcoming GBAS safety case project. He also summarized the findings of the low-latitude threat model project, comparing three ionospheric threat models from the U.S., St. Helena's Island (UK), and Brazil. The results of the Brazil threat model were dramatic compared to the U.S. and St. Helena. Then, a short description was given of the project sponsored by the U.S. Trade Development Agency (US TDA) for the development of a safety case for low-latitude GBAS operations. The safety case will provide the foundation for system design approval and allow DECEA to complete the commissioning of the GIG installation. It will also provide other nations in low-latitude regions the information required to approve GBAS in their respective airspace.

1.6.3 In P/20, Thales Alenia reported that the ionosphere was one of the main concerns in South America, where many low-latitude countries underwent the worst gradients and scintillation effects. Activities have been carried out in the past to deploy a test bed with an old version of “mid-latitude” WAAS algorithms (more than 10 years old). These studies did not lead to any conclusion as to the feasibility of conducting precise approaches with vertical guidance over South America. In addition, GBAS was facing the same kind of issue, as it was not able to separate ionosphere delays from other sources of GNSS ranging error, contrary to SBAS. Furthermore, the qualified GBAS threat model used for binding errors caused by the non-separation of ionosphere delay was not suitable to ensure integrity in low latitudes.

1.6.4 Other studies like SACCSA have been performed with new algorithms but fed by GLONASS, which unfortunately cannot be used today for safety purposes. (This is the reason why EGNOS does not provide GLONASS augmentation.) Thales Alenia Space, the prime contractor of the European SBAS - EGNOS, performed studies in low-latitude regions (in mid Africa – ASECNA countries) for several years. These studies allowed to understand ionosphere behavior in low latitudes (high gradients, depletion, bubbles, and scintillation) and to design a new generation of algorithms capable of operating even in severe equatorial ionosphere conditions. The results obtained in Africa during test campaigns showed that these algorithms were capable of providing at least APV-1 precision approaches (with vertical guidance, almost Cat 1 service) in Africa, even during geomagnetic storms, with the availability level required by ICAO SARPs (>99%).

1.6.5 These algorithms have also been run on the EGNOS network during severe geomagnetic storms, showing that they were not affected, contrary to current operational EGNOS and WAAS. These results show the huge improvement provided by Thales Alenia Space equatorial algorithms. Finally, preliminary studies have been performed in Brazil thanks to INPE and DECEA/ICEA, confirming the feasibility of APV-1 service, just as in Africa. To conclude, Thales Alenia Space invited South American countries to participate in new SBAS test bed campaigns, which will now use Thales equatorial algorithms. It will be a first step to support a future SBAS deployment over the South American region.

1.7 Ground- and flight-testing considerations

1.7.1 In P/21, Bob Stuckert, from the United States, presented GNSS flight inspections. GNSS flight inspections validate the data used in procedure design and ensure that the procedure delivers the

aircraft to the correct position for landing. Valid data depends on compliance with up-to-date survey standards developed for GNSS application. The United States performs Preflight Coding Validation. This is a comprehensive check of the procedure data and ARINC 424 coding. Once completed, flight inspection validates the procedure design, insures obstacle clearance, and confirms communications with air traffic control. An FAA program of flight inspection courses for international students scheduled for 2017 was also presented.

1.7.2 In P/22, Beniot Roturier reported on the status of PBN flight inspections in France. The presentation showed ICAO material applicable to PBN procedure design and validation, the logic behind it, and how this has been incorporated into French regulations. States should follow this process for procedure commissioning and when changes are made to the procedure. A description was then provided of the flight inspection structure in France, aircraft systems and teams, also showing several cases of interference on PBN procedures, which were detected thanks to the flight inspection teams and systems. This experience highlights the need for proper spectrum management and aviation tools to maintain high availability of PBN procedures.

1.7.3 In P/24, P26, P27, and P28, Argentina, Bolivia, Cuba, and COCESNA presented respectively the current status and expectations in terms of flight inspection of navigation infrastructure to support PBN. Additionally, Aerolineas Argentinas presented P/25, describing PBN flight validation procedures in Argentina.

1.7.4 In P/23, Frank Musmann, from AERODATA, provided information on Avionic Navigation Infrastructure to support PBN. When designing Instrument Flight Procedures (IFP), consideration should be given to many limiting factors, such as: terrain, obstacles, environmental constraints, and suitability for air traffic management. Accordingly, instrument flight procedures are increasingly based on area navigation (RNAV) or performance-based navigation (PBN), which permits the definition of a complex flight path. The capabilities of modern flight management systems (FMS) enable procedure designers to use new elements for the definition of the procedure path. Typical elements are radius-to-fix (RF) segments for the definition of arcs, and the final approach segment (FAS) for the definition of precision approaches with vertical guidance. This presentation highlighted some typical undesired effects that could be observed during flight validation of procedures based on RF and FAS. In order to simplify the validation process, software tools and functions have been developed. Based on case examples, it has been shown how such effects could be easily identified through an automated process.

2 FINAL RECOMMENDATIONS AND CONCLUSIONS

2.1 Based on the presentations and discussion, the participants agreed on the following conclusions and recommendations:

General aspects and development of SARPs

- a) PBN is the foundation for safety, operational and environmental improvements as described in the Global Air Navigation Plan, its technological roadmaps, and the ICAO ASBU methodology.
- b) The PBN framework is well established and there are a lot of SARPs and guidance materials related to PBN procedures to assist States in the: 1) implementation, including technical requirements of the navigation infrastructure to support PBN and GNSS operations, 2) validation, and 3) operation. Furthermore, ICAO is now providing more assistance to States in their planning and implementation, by providing guidance materials, offering CBT training, and conducting workshop and seminars.
- c) Follow-up activities are needed to allow the PBN concept to further mature and to provide adequate procedures and technical requirements to enable PBN-related ASBU modules B1 and B2.
- d) This includes assessment activities and the development of SARPs for GBAS Cat II/III operations by the Navigation System Panel (NSP). The development of GBAS Cat II /III SARPs is nearly complete, and the amendment of Annex 10 Volume I to introduce GBAS Cat II/III is scheduled to become effective in November 2018.
- e) It was noted that the NAM/CAR/SAM Regions had enough DME-DME coverage to support PBN procedures, but there were areas that were not yet covered and required the implementation of additional DME.
- f) In order to avoid the interruption of GNSS signals and interference, States should:
 - prohibit all actions leading to the interruption of GNSS signals;
 - develop and implement a strong regulatory framework governing the use of intentional in-band diffusers, including GNSS repeaters, pseudolites, spoofers, and jammers;
 - have particular care with off-band diffusers that are in a harmonically GNSS-related frequency, such as some television broadcast channels and other industrial applications;
 - support the position of ICAO at the ITU WRC;
 - protect the frequency spectrum for aeronautical use; and
 - coordinate frequency allocation with the respective ICAO Regional Offices

Ground-Based Augmentation System (GBAS)

- g) GBAS is being used as a satellite-based alternative to the Instrument Landing System (ILS) for precision approach and landing, providing differential corrections and integrity monitoring of global navigation satellite systems (GNSS), which are fundamental for PBN operation as described in ASBU modules.
- h) The implementation of GBAS CAT-I is underway worldwide and is already operational at several airports in mid-latitude States.

i) These operations and assessments confirmed various benefits of GBAS operations, including the high accuracy, availability, and integrity required for CAT I and, eventually, Cat II/III precision approaches. In addition, some assessments showed robustness under severe snow conditions and a good cost/benefit ratio, since a GBAS covers multiple runway ends, and provides up to 48 approaches per system.

j) However, it is important to note that these GBAS operations were conducted mainly in mid-latitude States and it is still a big challenge to operate GBAS in low latitudes because of the ionospheric effect.

k) Brazil was leading a low-latitude GBAS safety case, and it was recognized that the lessons learnt would provide great guidance for States interested in deploying GBAS in their States and who were facing the same challenges in their GBAS development and assessment projects.

l) It was also noted that several promising technical improvements were under development, such as multi-constellation and dual frequency GBAS, which was expected to provide enhanced robustness with respect to ionosphere anomalies and radio frequency interference.

m) Since many CAR/SAM States were located in equatorial regions, safety case assessments should be conducted if they intended to implement and operate GBAS in their States.

n) It was also recognized that the implementation of GBAS CAT II/III had to be carefully considered and assessed so that each State could decide whether the use of GBAS would allow them to achieve their particular goals and meet their operational needs, since those operations could depend on market demand, maturity of standards/regulatory requirements, availability of infrastructure and other business factors.

o) A cost-benefit analysis based on the operational demand of each State was needed to identify those airports suited for the installation of GBAS CAT I stations.

p) For each eligible airport, a GBAS ionosphere threat model would be required for certification and commissioning purposes.

SBAS

q) States were encouraged to continue assessing the technical, operational, and financial feasibility of SBAS systems in a multi-constellation and dual frequency environment. But it was noted that an ionospheric model that supported a good availability of LPV in the equatorial region (low latitude) had been developed through GAGAN, the African SBAS test campaigns, and SACCSA in the CAR/SAM Regions.

r) Studies conducted under the SACCSA project have shown that an augmentation solution for the CAR/SAM Regions is feasible and its interoperability with other systems is based on the SARPs/MOPS. In addition, the use of multi-constellation (GPS+GLONASS+Others) and multi-frequency (dual frequency) is recommended to minimize the impact of solar activity on the ionosphere and the SBAS signal.

s) SACCSA studies are consistent with recommendations 6/5 and 6/9 of the 12th Air Navigation Conference.

t) As a result of the SBAS-type WAAS test bed developed in the CAR/SAM Regions, the following recommendations were made:

- i) The SBAS-type WAAS tests carried out in the CAR/SAM Regions between 2001 and 2007 concluded that, because of the severe ionosphere conditions in the geomagnetic equatorial region (+/- 20° degrees around the equatorial line), it was recommended that the CAR/SAM Regions consider the possible implementation of an SBAS only for lateral navigation (LNAV) or non-precision approach (NPA).
- ii) In the future, GNSS-based precision approach services in the region should be provided only after a Cat I capable ground-based augmentation system (GBAS) that can account for ionosphere error as recorded at/near the geomagnetic equator, or a global second civil GPS signal at L5, is available.

RAIM availability prediction

u) In the SAM Region, where a RAIM availability prediction tool has been implemented, the following recommendations were made:

- The aeronautical community should be aware of SATDIS functions in support to the GNSS-based navigation (basically GNSS - ABAS). In this respect, an AIC should be issued.
- For the approval of PBN by the aeronautical authority, users must be required to implement an availability prediction system (RAIM) (SATDIS is a service that meets the requirement, as stated in the advisory circulars issued in the Region, for the approval of PBN operations).
- Any State that has published in its AIP the PBN procedures at an aerodrome should also publish a NOTAM in case availability prediction for that aerodrome is not available (SATDIS makes 24-, 48-, and 72-hour predictions).
- Additional functionalities that can be added to SATDIS include ADS-B, NOTAMs, and mapping capabilities.

Ionospheric and tropospheric effects on GNSS

- a) GBAS operations in low latitude cannot meet ICAO integrity requirements using the mid-latitude threat model.
- b) To support GBAS operations in low-latitude regions, a safety case is required to ensure compliance with ICAO Annex 10 and overall system safety criteria. The safety case is a critical part of the certification process and requires rigor, structure, and a process to make sure that the highest level of safety is maintained.

Ground and Flight Testing Consideration

- a) The validation process and the flight testing experience of States have underlined the need for proper spectrum management to avoid interference and for aviation tools to maintain high availability of PBN procedures.
- b) It is recognized that GNSS flight testing is important for validating the data used in PBN procedure design and making sure that the procedure delivers the aircraft to the correct position during operations.

- b) Instead of only validating the signal-in-space, States should take into account the validation process described in the PBN Manual and in Doc 9906, which highlight the importance of a full validation process, including validating the data used in the PBN procedure design.
- d) The PBN Manual, the Quality Assurance Manual for Flight Procedure Design (Doc 9906) and the Manual on Testing of Radio Navigation Aids (Doc 8071), Volume II, Testing of Satellite-based Radio, should be referred to when performing PBN procedure validations.
- e) It was confirmed that the technical requirements and specifications for the GNSS flight testing were described in the Manual on Testing of Radio Navigation Aids (Doc 8071), Volume II, Testing of Satellite-based Radio Navigation Systems.

APPENDIX A

AGENDA

WORKSHOP/SEMINAR FOR THE IMPLEMENTATION OF NAVIGATION INFRASTRUCTURE TO SUPPORT PBN AND GNSS PRECISION APPROACH OPERATIONS IN THE NAM/CAR/SAM REGIONS

(Lima, Peru, 15 to 17 August 2016)

MONDAY, 15 AUGUST 2016		
HOURL	SUBJECT	EXPOSITOR
08:30-09:00	Registration	
09:00-09:150	Opening ceremony	SAM ICAO RD Franklin Hoyer
09:15-09:30	Introduction workshop/seminar	ICAO Onofrio Smarrelli
SESSION 1: GLOBAL AND REGIONAL IMPLEMENTATION CONSIDERATION OF NAVIGATION INFRASTRUCTURE TO SUPPORT PBN AND GNSS PRECISION APPROACH OPERATIONS IN THE NAM/CAR/SAM REGIONS		
09:30-10:00	Global air navigation plan consideration on navigation infrastructure to support PBN	ICAO Mie Utsunomiya
10:00-10:30	Regional air navigation plans implementation consideration on navigation infrastructure to support PBN in the NAM/CAR and SAM Regions	ICAO Onofrio Smarrelli Mie Utsunomiya
10:30-11:00	<i>Coffee break</i>	
11:00-11:30	<i>Questions / Session 1 summary</i>	
SESSION 2: ICAO SARPS AND DOCUMENTATION OF NAVIGATION INFRASTRUCTURE TO SUPPORT PBN AND GNSS PRECISION APPROACH OPERATIONS		
11:30-12:00	ICAO SARPS and documentation on navigation infrastructure to support PBN	ICAO Mie Utsunomiya
12:00-12:30	Spectrum consideration of navigation infrastructure	ICAO Onofrio Smarrelli
12:30-13:30	<i>Lunch break</i>	
13:30-14:00	<i>Questions / Session 2 summary</i>	
SESSION 3: CURRENT GNSS SITUATION AND EVOLUTION		
14:00-14:30	GBAS world implementation and France GBAS Cat III opportunities and challenges at Paris Charles de Gaulle experience	France Benoit Roturier
14:30-15:00	GBAS current situation and evolution	United States FAA Carlos Rodriguez

TUESDAY, 16 AUGUST 2016		
HOUR	SUBJECT	EXPOSITOR
SESSION 3: CURRENT GNSS SITUATION AND EVOLUTION		
9:00-10:00	Brazilian GBAS experience	Brazil Alessander de Andrade Santoro
10:00-10:30	GBAS future vision and other CNS development	Argentina (ANAC) Ricardo Abregu and Manuel Álvarez
10:30-11:00	<i>Coffee Break</i>	
11:00-11:30	GBAS development in Argentina	INVAP Isidoro Vaquilla and Oscar Bria
11:30-12:00	PBN and EGNOS implementation status in France and other SBAS world implementation (Current situation and evolution)	France Benoit Roturier
12:00-12:30	SBAS current situation and evolution	Estados Unidos FAA Carlos Rodriguez
12:30-13:30	<i>Lunch break</i>	
13:30-14:00	SBAS type WAAS test bed Project in CAR/SAM Region	ICAO Onofrio Smarrelli
14:00-14:30	SBAS NAM CAR SAM experience SACCSA Project	COCESNA Rony Montenegro
14:30-14:45	RAIM availability prediction tool in SAM Region SATDIS	ICAO Onofrio Smarrelli
14:45-15:15	GNSS integrity	NAVBLUE John Wilde
15:15-15:45	Avionic navigation infrastructure to support PBN	Honeywell Patrick Reines
15:45-16:15	<i>Questions / Session 3 summary</i>	

WEDNESDAY, 17 AUGUST 2016		
HOUR	SUBJECT	EXPOSITOR
SESSION 4: IONOSPHERIC AND TROPOSPHERIC EFFECTS ON GNSS		
09:00-09:30	Ionospheric and tropospheric effects on GNSS	Universidad La Plata (Argentina) Francisco Azpilcueta
09:30-10:00	Regional ionospheric update and low-latitude GBAS threat model synopsis	United States Rich Cole
10:00-10:30	Latest SBAS performances under severe and equatorial ionosphere conditions	Thales Alenia Space Franck Haddad
10:30-11:00	<i>Coffee Break</i>	
11:00-11:30	<i>Questions / Session 4 summary</i>	
SESSION 5: GROUND AND FLIGHT TESTING CONSIDERATION		
11:30-12:30	GNSS Flight Inspection	United States Bob Stuckert
12:30-13:30	<i>Lunch break</i>	
13:30-14:00	PBN flight inspection status in France	France Beniot Roturier
14:00-15:00	CAR/SAM GNSS flight inspection	ARGENTINA BOLIVIA COCESNA CUBA
15:00-15:30	Avionic navigation infrastructure to support PBN	AERODATA Frank Musmann
15:30-16:00	<i>Questions / Session 5 summary</i>	
SESSION 6: FINAL RECOMMENDATIONS AND CONCLUSION		
16:00-16:30	Workshop/Seminar final recommendation and conclusion	ICAO/STATES
16:30	Closing ceremony and delivery of certificate	

APÉNDICE B / APPENDIX B

Seminario/Taller para la Implementación de infraestructura de navegación para soportar PBN y las operaciones de aproximación de precisión GNSS en las regiones NAM/CAR/SAM

Workshop/Seminar for the implementation of navigation infrastructure to support PBN and GNSS precision approach operations in the NAN/CAR/SAM Regions

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