LIMITS AND FUTURE GNSS SOLUTIONS FOR AIRCRAFT LANDING IN LOW VISIBILITY CONDITIONS

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ABSTRACT

The growing demand for air transportation in Brazil and all over the world pushes for improvements on communication and navigation in direction to safety and efficiency of flights. ICAO has currently worked to implement the standards for new satellite based precision landing system for situations where the runway visibility is limited. The ILS is the most used system in such situations up to today, but this is changing with the arrival of new and less costly technologies. The next generation system for precision landings will be GNSS based. This paper aims to give a brief review of ILS and GNSS, pointing out advantages and limitations of this new technology being supported by ICAO. The results show that despite the economic advantage, the GNSS could suffer from ionospheres' errors. However, it is expected that in the future new techniques could be applied to increase the precision, availability, integrity and continuity of GNSS.

Keywords: Aircraft landing system, GNSS, ionosphere scintillation

1. INTRODUCTION

The air transportation demand growth around the world and especially in Brazil increases airport operations. Adverse climate conditions that can limit the full capacity of airports due to low visibility of the runway are therefore of increasing concern.

The ability to land an aircraft in low visibility is often required to avoid delays and queues, which in turn, represent large economic losses. In this case a specific instrumentation requires high precision level, availability, integrity and continuity.

The ILS (Instrument Landing System) is nowadays the main system that can provide such navigation in the final approach phase and landing. But this equipment is quite expensive, both in terms of acquisition and in terms of maintenance (Chujo, 2007).

The system based on satellite positioning GNSS (Global Navigation Satellite System) is an economic alternative for aircraft navigation approaching the runways in low visibility conditions. But this system depends on some patches to have accuracy and reliability to keep the safety of a flight. The main source of errors in these systems based on satellite signals is the ionosphere. In countries near the equatorial region this error is even more pronounced due to the ionosphere anomaly that occurs mostly between latitudes 20 and -20 (in relation to the magnetic equator) (Monico, 2008).

GPS was originally designed as a military navigation and positioning system for rendezvous and for precision weapon aiming. It has become a vital utility for transport infrastructure because of its inherent accuracy and ease of use. The history of GNSS related to the massive expansion of civilian applications started in the 1990s. However in 1988, the International Civil Aviation Organization (ICAO) announced that the Future Air Navigation System (FANS) would be based on satellite navigation systems. On 8 December 1993, the US Global Positioning System (GPS) reached Initial Operational Capability (IOC) with 24 Block I and II satellites in six orbital planes, and the Standard Positioning Service was declared available for civil use (Bonnor, 2012). Since that, despite the Russian, European, Japan, Chinese, or Indian GNSS related initiatives, GPS is the most used source in civil GNSS applications.

1.1. Study Goals

Given the conditions presented in the introduction of this paper, the aim of this work is to offer the reader a brief explanation about the concepts of ILS and GNSS, which are used to guide the landing of aircraft in low visibility runway conditions. Subsequently, the paper shows some sources of error that are still impeding the full implementation of GNSS in many countries, especially in Brazil.

2. ILS CONCEPTS

The ILS was accepted as a standard tool to aid the precision landing by ICAO (International Civil Aviation Organization) in 1947. Until now, the ILS is still the main instrument in support of precision landing (Landing Systems, 2013).

The basic elements that make up the system are:

- VHF (*Very High Frequency*) localizer transmitter;
- UHF (*Ultra High Frequency*) glide slope transmitter;
- Marker beacons;

One of the main components of the ILS is the localizer, which handles the aircraft guidance in the horizontal plane. The transmitter is located at the axis of the runway, at the opposite threshold with respect to the direction of approach, and

indicates if the aircraft is on the right, left or on the exact runway axis.

The UHF glide slope transmitter determines the angle of descent of the aircraft, thus guiding the aircraft in the vertical direction during landing. The glide slope transmitter is usually installed beside the airstrip, and indicates whether the aircraft is above, below or on the exact standard ramp approach.

The Marker beacons indicate how far the aircraft is from the runway threshold. They are composed of outer, middle and inner markers, and are usually positioned at around 11000, 1000 and 60 meters from the runway threshold, respectively.

Figure 1 shows a simplified illustration of ILS layout and its horizontal and vertical marking provided for the aircraft.

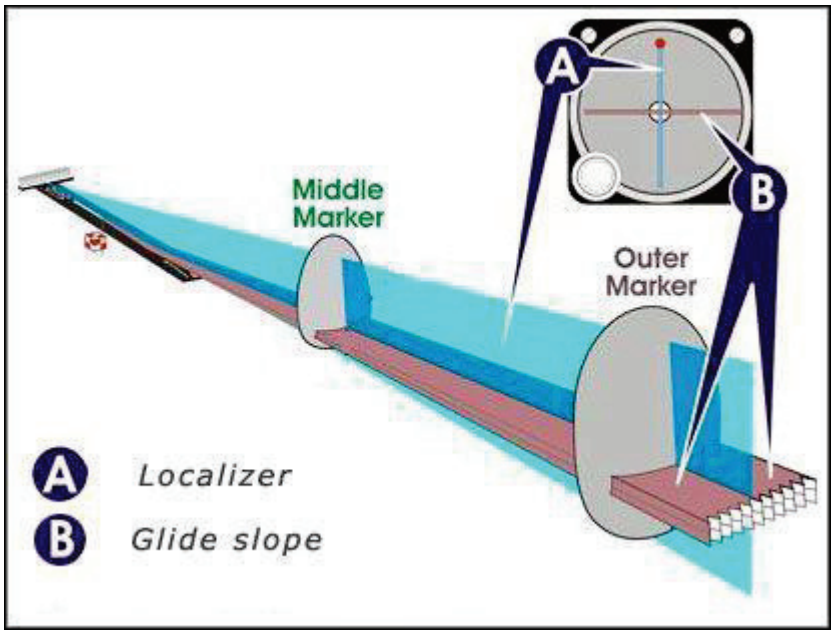


Figure 17: ILS layout (Wikispaces, 2013)

A decision height for an ILS approach is a point on the glide slope where a decision must be made to either continue the landing or execute a missed approach. In particular, precision land systems have been categorized as follows:

Cat I: Decision Height (Min.): 60 m / Visibility: Between 800 and 550 m

Cat II: Decision Height (Min.): 30 m / Visibility: Not less than 300 m

Cat III:

A: Decision Height (Min.): 30 m / Visibility: 175 m

B: Decision Height (Min.): 15 m / Visibility: 175 m

C: Ceiling ZERO / ZERO Visibility

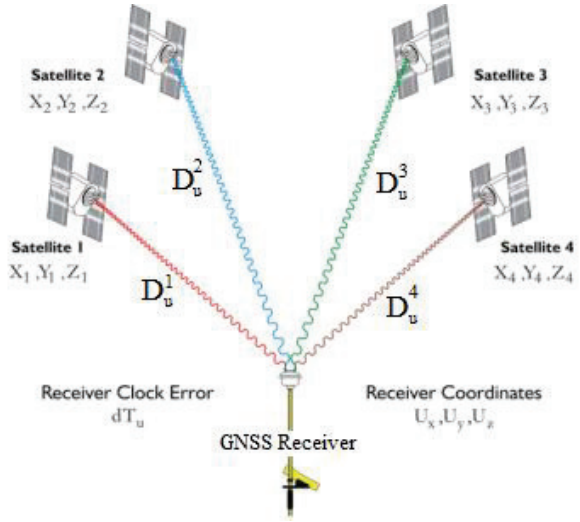
A complete ILS unit provides coverage for navigation to a single direction of landing at one runway. Therefore, to provide precision landing in both directions of a runway it is necessary to double the number of installed equipment. Thus, the application of this method at multiple runways or many airports significantly increases the costs involved, since a single ILS CAT I could cost 1,332,000 euros (EUROCONTROL, 2003).

According to EUROCONTROL (2003) the current Instrument Landing System (ILS) also suffers from a number of technical limitations such as, VHF interference,

multipath effects (for example due to new building works at and around airports), as well as ILS channel number limitations.

3. GNSS CONCEPTS

The basic principle for the GNSS navigation, according Monico (2008), consists of measuring distances (pseudoranges) between the receiver and at least four satellites. Knowing the coordinates of three satellites in a suitable reference system, it is possible to calculate the coordinates of the receiver antenna in the same reference system of the satellite. A fourth measurement is necessary because the receiver and satellite clock are not perfectly synchronized, so a variable *c(dTu)* and an equation is added to the problem.



$$D_u^1 = \sqrt{(X_1 - U_x)^2 + (Y_1 - U_y)^2 + (Z_1 - U_z)^2} + c(dT_u)$$

$$D_u^2 = \sqrt{(X_2 - U_x)^2 + (Y_2 - U_y)^2 + (Z_2 - U_z)^2} + c(dT_u)$$

$$D_u^3 = \sqrt{(X_3 - U_x)^2 + (Y_3 - U_y)^2 + (Z_3 - U_z)^2} + c(dT_u)$$

$$D_u^3 = \sqrt{(X_3 - U_x)^2 + (Y_3 - U_y)^2 + (Z_3 - U_z)^2} + c(dT_u)$$

Figure 2: Basic calculations in GNSS (Geospatial Revolution, 2013)

The distances D_u in fact are not very accurate (about 15 m) even with the receiver clock corrections. There are some delays in the satellite signal that could be corrected. A technique large implemented is the Differential GNSS which promotes an accuracy of 0,5 to 3m (Monico, 2007).

3.1. GROUND BASED AUGMENTATION SYSTEM

One of the concepts employed in the differential GNSS is called GBAS (Ground Based Augmentation System) and it involves the use of a stationary receiver at a reference station with known coordinates, tracking all visible satellites. The processing of the data in this reference station allows the calculation of a most accurate distance between visible satellites and the GBAS reference stations.

The difference between the distances calculated using the known base station coordinates and calculated using the equation in Figure 2 is the correction to be applied in airplane boarded receiver coordinates.

The reference station being located near the region of interest (region near the airport) makes a stronger correlation between the errors involved in the reference station and the position of the aircraft to be determined. Thus, if the aircraft receives those corrections, it can improve the accuracy of its position.

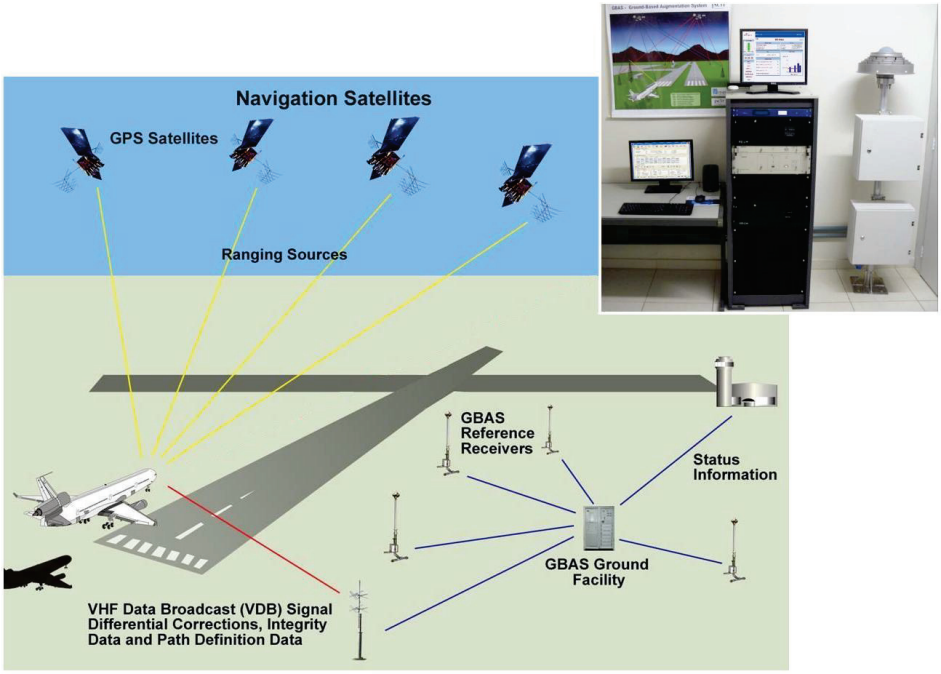


Figure 3: GBAS architecture (source http://www.faa.gov) and the equipment in Rio de Janeiro SBGL (ICAO, 2013)

Figure 3 shows that the GBAS ground station is formed by reference receivers with their antennas installed in precisely surveyed points. The information generated in the receiver is sent to a processor that computes the corrections for each navigation satellite in view and broadcasts these differential corrections, besides integrity parameters and precision approach path data, via a Very High Frequency (VHF) Data Broadcast (VDB) (ICAO, 2013).

The main advantages the GBAS application can provide are:

- Reduction of critical and sensitive areas;
- Curved approach;
- Positioning service;
- Provision of service to several runways of the same airport;
- Provision of several approach glide angles and to displaced threshold;
- Guided missed approach; and
- Adjacent airports use.

4. IONOSPHERE

The effect of the ionosphere is the largest source of systematic error in the signals transmitted by the satellites of GNSS (Global Navigation Satellite System), which mostly affects the accuracy of positioning and navigation when using single frequency receivers, such as the receptors embedded in the aircraft. This systematic error is directly proportional to the TEC (Total Electron Content) present throughout the signal path in the ionosphere, and inversely proportional to the square of the frequency of this signal (Monico, 2008).

The determination of the aircraft location has a strong influence from the electron density variation at the ionosphere due to the heterogeneity of the ionosphere overall structure. It changes with latitude, due to sun's zenith angle variation, which directly influences the radiation level, which, in turn, also alters the electron density in the ionosphere. The equatorial regions are characterized by a high level of electron density and the mid latitudes regions are considered relatively free of ionosphere

anomalies, while the polar regions are not very predictable (Webster, 1993). Figure 4 shows a sample effect of equatorial ionosphere anomaly. The TEC Map has a contribution of INPE (National Institute For Space Research) and the stations of Brazilian Network for Continuous Monitoring (RBMC). The blue areas represent low electron density (TEC), and the red areas are those with high level density.

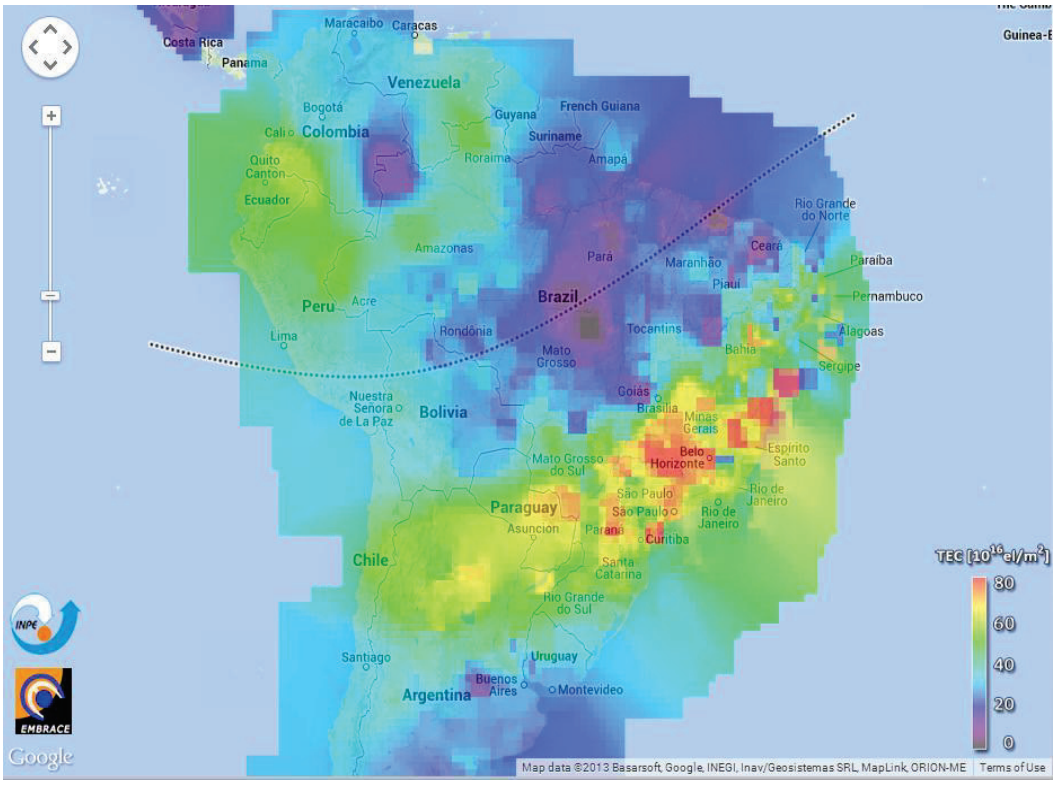


Figure 4: Map of equatorial ionosphere anomaly (INPE, 2013)

For civil aircraft navigation application only the signals transmitted on L1 frequency (1575.42 MHz) are available to be used in Radio Navigation Satellite Service (RNSS) in both North American GPS (Global Positioning System) and the Russian called GLONASS (Global'naya Navigatsionnay Sputnikovaya System). In the precision applications of aircraft navigation it is necessary to apply the ionosphere delay fixes provided by GBAS reference stations.

Several models have been developed to estimate the ionosphere electron density. However, it is difficult to find one that accurately estimates the TEC properly to precision positioning. An alternative for the correction is obtained based on simultaneous observations of the signals transmitted by GPS satellites on two different frequencies, L1 and L2 (1227.6 MHz).

Seeber (1993) demonstrates that higher frequency signals are less affected by the ionosphere, because the error is proportional to the square of the frequency. Table 1 shows how the ionosphere affects the propagation at different frequencies and it indicates the vertical positioning residual error for the cases where measurements with two different frequencies are available, making it possible to obtain a linear combination properly.

Table 1: Propagation effects caused by the ionosphere (Monico, 2008)

Single frequency	400 MHz	1600 MHz	2000 MHz	8000 MHz
Average effect	50 m	3 m	2 m	0,12 m
90% lower than:	250 m	15 m	10 m	0,6 m
Highest effect	500 m	30 m	20 m	1,2 m
Dual frequency	150/400 MHz	2000 MHz	1227/1572 MHz	2000/8000 MHz
Average effect	0,6 m	0,9 cm	0,3 cm	0,04 cm
90% lower than:	10 m	6,6 cm	1,7 cm	0,21 cm
Highest effect	36 m	22 cm	4,5 cm	0,43 cm

Currently civilian aircraft are equipped only with single frequency receiver, and L2 frequency is reserved for military use. But the future GNSS satellites will provide an additional frequency for civilian use called L5 (1176.45 MHz). Thus the frequencies L1 and L5 within the ranges already approved by Aeronautical Radio Navigation Service (ARNS) may be used in the future for dual frequency receivers, therefore allowing to directly fix the ionosphere delay, without the need for reference stations to send differential corrections. However, for precision guidance, GBAS would still be required to assume integrity.

4.1 IONOSPHERE SCINTILLATION

In the ionosphere the effect called ionosphere scintillation can also occur. It is amplitude or phase fluctuations in radio waves as a result of propagation through a region where there are irregularities in the electron density. The ionosphere scintillation causes weakening in the signal received by the GNSS, furthermore in many cases it can cause the signal loss (Webster, 1993).

The electron density variation over long periods, with cycles of approximately 11 years (Figure 5), is associated with sunspots occurrences. The increased ionization is proportional to the number of sunspots. We are currently in the middle of the cycle 24, which is showing lower ionization than previous cycles 22 and 23.

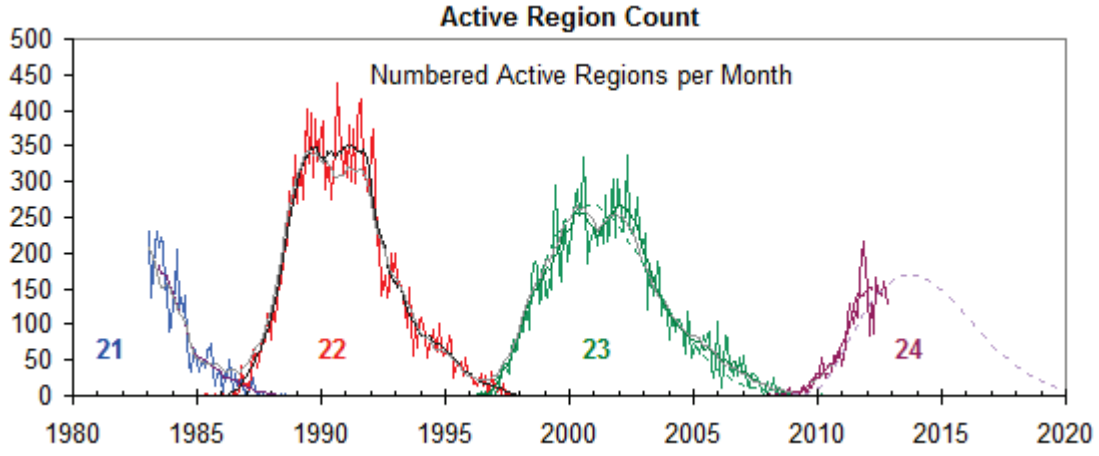


Figure 5: Sunspots active region count since 80`s (WUWT, 2013)

In Brazil, there are monitoring stations provided by INPE (National Institute For Space Research). The mapping of ionospheric scintillation is done through S4 index values. The S4 index is a metric for indicating the amount of variation in the amplitude of a signal. In this situation the S4 index is an indicator of the standard deviation of the GPS satellites received signal power as seen on the ground (INPE, 2013). The Figure 6 shows the actives monitoring stations and the S4 index in Brazil.

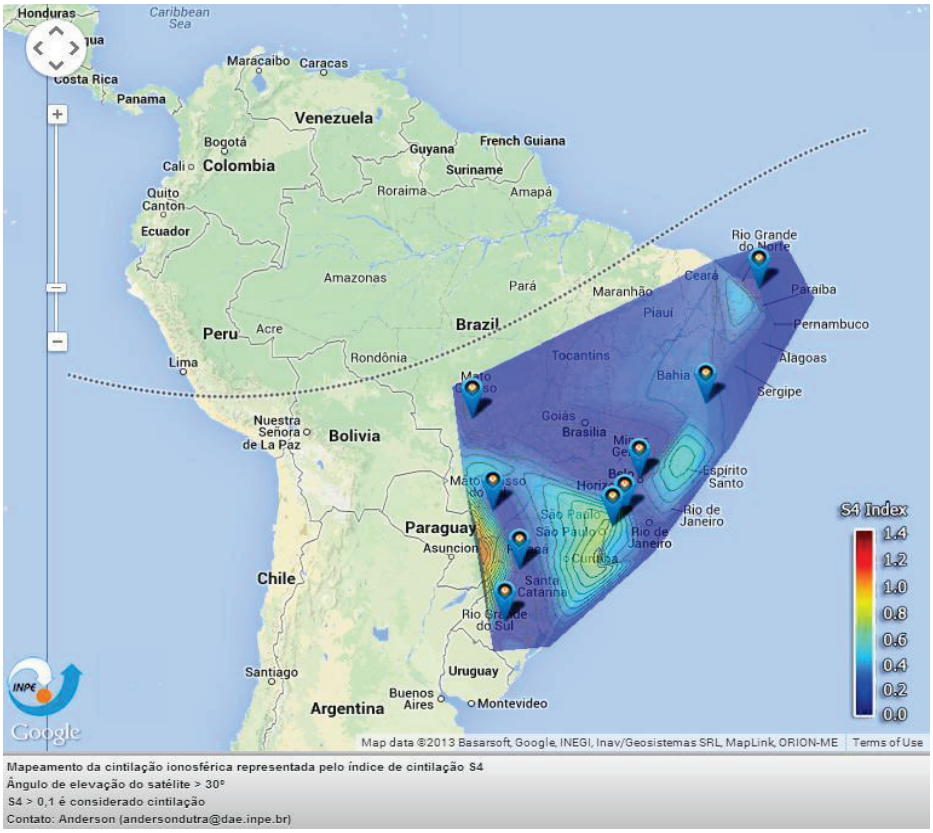


Figure 6: S4 Index across monitoring stations in Brazil (INPE, 2013)

Analyzes made by Seo (2010) showed that the signal quality that arrives into GNSS receivers can be affected drastically during the ionosphere scintillation. The worst scenario in this study was on data obtained in the year 2001. It presented weakening signal on 7 of 8 satellites tracked by a receiver in a period of 45 minutes.

Based on the observed data and signal availability analysis, a new requirement is being proposed for future on-board dual frequency receiver performance standards to mitigate the impact of scintillation. This is a faster reacquisition requirement after a brief interruption of signal capture by the receivers. Currently this requirement is been discussed in the Special Committee 159 of EUROCAE.

With this requirement, an on-board dual frequency receiver provides 50% more availability than the current standards on runway approach during a severe scintillation. It was shown by Seo (2010) that with the new requirement it is possible to achieve a high availability level (over 99%) even during severe scintillation.

5. CONCLUSION

Currently the ILS is still the main instrument for guidance of landing aircraft in low visibility. Approved in the 1940´s, it still fulfills its functions when inspected and maintained under appropriate conditions. But its cost may restrict the equipment purchase in order to install it at multiple airports.

ICAO is currently working to homologue worldwide the GNSS, an economical alternative when compared to the ILS. The use of this system based on satellite positioning still has restrictions in countries located near the equatorial region. The main reason for that is the effect of the ionosphere anomaly that causes positioning errors, satellite signal weakness and loss.

However, since the GBAS allows the aircraft positioning with increased accuracy, it can be

used at airports located in countries free of ionosphere anomaly. In Brazil it still needs further studies to ensure the signal availability for GNSS receivers, because the ionosphere scintillation can affect the satellite signal quality.

Dual frequency GNSS receivers will eventually be part of the equipment on board the aircraft. Furthermore, the L5 frequency addition and a faster signal reacquisition will enable an availability greater than 99% of the GNSS even during in a severe ionosphere scintillation occurrence.

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