Space Weather Effects on Air Navigation Systems

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AGENDA

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III. SPACE WEATHER
IV. IONOSPHERE EFFECTS OVER GNSS IN LOW LATITUDE (PROPOSALS)
V. CONVENTIONAL WEATHER AND ITS EFFECTS
VI. REMARKS
I. INTRODUCTION

LAYERS OF THE ATMOSPHERE

- **Exosphere**: High as 2000 °C
- **Thermosphere**: 1500 °C
- **Mesosphere**: -85 °C
- **Stratosphere**: 0 °C
- **Troposphere**: -60 °C

**Principal layers**

**Temperature**

**Transport and Natural phenomena**

- Satellite
- Aurora
- Spacecraft
- Meteors
- Radiosonde
- Aircraft
- Clouds
- Mt. Everest
Space weather is related to the behaviour of the Sun, the nature of Earth’s magnetic field and atmosphere, and our location in the solar system. The active elements of space weather are particles, electromagnetic energy and magnetic fields, rather than the more commonly known weather contributors of water, temperature and air. Magnetic fields, radiation, particles and matter which have been ejected from the Sun can interact with the Earth’s magnetic field and upper atmosphere to produce a variety of effects.
EFFECTS OF IONOSPHERE AND SPACE WEATHER
ICAO CONCEPT FOR GNSS

A worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation. (Ref. ICAO Annex 10, Vol. I).

There are four essential criteria: i) Accuracy, ii) Integrity, iii) Continuity, and iv) Availability, in correspondence with the new PBN (RNAV/RNP) procedure which permits flying direct routings, precise navigation capability and permits efficient operations in terrain constrained or congested airspace.

GNSS Segments:
1) Space: satellite constellations (GPS, GLONASS, GALILEO, BEIDOU)
2) Control: monitor, control and synchronization of satellites
3) Users: receivers, aircraft

There are Augmentation Systems like SBAS (Satellite) and GBAS (Ground), to improve performance of GNSS systems
EXAMPLE OF CURRENT NAVIGATION (BASED ON RADIO-AIDS)

CASE: LIMA - CUSCO

APPROACH (DEPARTURE)

SURFACE

ILS CAT III

EN-ROUTE (CRUISE)

VOR / DME

APPROACH (LANDING)

SURFACE

VOR/DME

CUSCO

Conventional Procedure

ILS: (Instrument Landing System)
VOR: Very High Frequency Omnidirectional Range
DME: Distance Measurement Equipment
ICAO Concept for GNSS
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**GNSS Segments:**
1) Space: satellite constellations (GPS, GLONASS, GALILEO, BEIDOU)
2) Ground: Control, monitor and synchronization of satellites
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There are Augmentation Systems like SBAS (Satellite) and GBAS (Ground), to improve performance of GNSS systems
Local Area Augmentation System (LAAS)

Wide Area Augmentation System (WAAS)

Global Positioning System (GPS)

GBAS Architecture:
- GNSS satellites
- Satellite signals and navigation messages
- VHF data broadcast signal
- VHF transmit antenna
- Reference receivers and antennas

GBAS ground subsystem

SBAS Architecture:
- Master Station
- Reference Stations
- Uplink Station
- SBAS Station

Wide Area Augmentation System:
- Communication Satellite
- GPS Satellites
- L1 signal

Ground Earth Station

Local Area Augmentation System (LAAS):
- Ranging Sources
- Integrity Data and Path Definition
- Status Information

Omnidirectional VHF Data Broadcast (VDB) Signal

GBAS Ground Facility

GBAS Reference Receivers
The PBN is a shift from sensor-based navigation to performance-based navigation (Doc 9613-AN / 937 "Manual Navigation Based Performance") ICAO. There are two kinds of Navigation Specifications:

**RNAV (Req. Area Navigation):** It is based on area navigation that does not include the requirement for monitoring and alerting board performance, e.g. RNAV 5, RNAV 1.

**RNP (Req. Navigation Performance):** It is based on area navigation that includes the requirement for monitoring and alerting board performance, e.g. RNP 4, RNP APCH.
Lima-Peru is the Geomagnetic Equator in the South America region (low latitude), that is why the airports at this region have an intense ionosphere activity, as well as countries located between $20^\circ$ N and $20^\circ$ S (aprox) from the geomagnetic Equator, especially during periods of maximum solar activity (Panama is at the border).

At the end of 2013 and 2014 it was the maximum solar cycle Nr 24. Next cycle would be in 2025.
Principal impacts of ionospheric scintillation on GPS performance:

- Loss of lock / outages
- Induced ranging errors

Consequences of these effects on GPS positioning accuracy depends on constellation geometry.

For example, losing multiple satellites in the same region of the sky can lead to large errors.

Figure Courtesy of C. Carrano, BC

Scintillations generate fading over GNSS signals.

TEC generates delays, measurements made by LISN (Low-latitude Ionosphere Sensor Network) – Courtesy of Boston College.
Proposals

1) Test Bed SBAS/WAAS/GPS - Regional Project RLA/00/009 (ICAO – FAA)

The main objective was to develop a plan of test bed (trials) and evaluation of the technical and operational benefits of SBAS Augmentation System/GNSS based on GPS / WAAS for CAR/SAM

The GPS receivers used the L1 and L2 frequencies

Results of Project RLA/00/009:
- The Scintillation generated loss of messages and data in collection stations
- Lack of an algorithm more robust to interference or ionospheric scintillation, especially in the equatorial region (low latitude)
- It may also be considered as an aspect of risk in the development of SBAS systems for procedures of accuracy or vertical guidance.
Reference: Results of ionosphere impact evaluation on GBAS operation in Brazil (Published in SAM/IG/15-20)

- GBAS system, in accordance with ICAO Annex 10, Volume 1, allows performing precision approach Category I with increasing values of GPS signals accuracy and integrity.
- The purpose of the evaluation was to study the impact of the ionosphere on the operation of the SLS-4000 station (Rio de Janeiro – Southamerica region) during solar cycle 24 by using a mid-latitude ionosphere threat model. Software is in process of updating/test.
- As result of the ionosphere impact evaluation on GBAS (operations in Brazil): It was concluded that the mid-latitude ionosphere threat model is not directly applicable to low latitudes like Equatorial Region. Like the mentioned Regional Project RLA/00/009, the receivers used the L1/L2 GPS frequencies.

Using this model, the most critical situation for GBAS operation would be an aircraft on approach (landing) receiving wrong correction from the ground station caused by different ionosphere delay received by aircraft and ground station.
Cusco Airport

Elevation: 10745 ft.
Minimum approach (DA 14500’, visibility required 8Km) often higher than actual weather conditions.

EXAMPLE OF PERUVIAN EXPERIENCE:
The first operational approach procedure based on GNSS and RNP Baro - VNAV information was authorized at the Cusco Airport in 2008.

Caxamarca Airport

Shorter Flight distance/Best minimum of approach

Saving per flight

<table>
<thead>
<tr>
<th>Distance</th>
<th>Time</th>
<th>Fuel</th>
<th>CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.8 nm</td>
<td>11.6 min</td>
<td>375.9 gal</td>
<td>1186 kg</td>
</tr>
</tbody>
</table>
SBAS O GBAS SYSTEM FOR SOUTHAMERICAN REGION?

- Equatorial region (Low Latitude) is hostile for the GNSS signals, requires more investigation.
- Less air traffic in Southamerica than Northamerica (Medium Latitude).
- Brazil is doing the study and testing of a national GBAS Augmentation system, which could be a model extended for the South America Region.
- Continuous study of the scintillation in more detail as the main constraint on the use of two frequencies (L1 and L5) for vertical guidance.
- The scintillation can seriously affect the continuity and availability of GNSS.
- Cost - benefit analysis
- In service from September 2003 for fixed communications
- For international links: ATS voice and aeronautical messaging AMHS/AFTN
- Administered by ICAO: Regional Project RLA/03/901 “Sistema de Gestión de la REDDIG y Administración del Segmento Satelital”
- Capacity for transmitting Radar and GNSS data
- In 2016 it will be installed Node Nr. 17 in Brazil
There is currently 1090 ADS-B technology that works in S Mode format and with capacity to provide information for air traffic control.

**ADS SYSTEM - Automatic Dependent Surveillance by Satellite**

It is broadcasting the position (latitude and longitude), altitude, speed, aircraft identification and other information obtained from the onboard systems. Because their coverage is satellite (GNSS), the ADS nicely complements the current radar information (ground) giving coverage to remote areas, low flight level and oceanic areas, which is integrated with the radar data.

There is currently 1090 ADS-B technology that works in S Mode format and with capacity to provide information for air traffic control.
CONCLUSIONS
- There are benefits (VSAT, GBAS, ADS) for air navigation around the world, by using the satellite technology in accordance with ICAO recommendations.
- Most countries in South America would have to base their national airspace on GNSS/GBAS and/or SBAS.
- Development of a valid Ionosphere Threat Model for Low Latitudes (Equatorial region) is key to GBAS for the national or regional aviation community.
REMARKS

- No SBAS and GBAS operation in CAR/SAM Regions, No infrastructure deployed in these Regions
- Ionospheric effects over the GNSS signals (Low Latitude)
- Need of strategy analysis to identify SBAS/GBAS implementation.
- Opportunity: Aircraft would be equipped with SBAS/GBAS capability
- For example in Peru, use of GNSS is currently limited to supplemental navigation of “No-Precision” like GPS/RAIM on board and it is not enough.
- Space Weather effects happen in the Ionosphere between 50 to 600 Km aprox.
CONCLUSIONES

Modo SSR - S
RED DE TELECOMUNICACIONES AERONAUTICAS

Comunicaciones: entorno actual

Estaciones terrestres
Radio en VHF
Servicio de Tráfico Aéreo

Voz y Datos
Satellite

Comunicaciones: entorno futuro

Servicios de tráfico aéreo
Radio VHF
Radio HF

Data y voz
Radar secundario de vigilancia (SSR) con antena de datos en Modo S

Navegación: entorno actual

Servicios de tráfico aéreo
GNSS

Sistema de alertaje por instrumentos (ILS) y sistema de aterrizaje por microonda (MLS)

Navegación: entorno futuro

Informes de posición orales
Servicios de tráfico aéreo

Sistemas de aterrizaje por comunica (SEAS/BEAS/GRAS)

Vigilancia: entorno actual

Informes de tráfico aéreo
Radar primario/ secundario

Servicios de tráfico aéreo

Vigilancia: entorno futuro

Informes de tráfico aéreo
Radar secundario de vigilancia (SSR)
CONCLUSIONES

1. Esta presentación trató sobre la importancia de la tecnología satelital en los servicios de aeronavegación a nivel internacional tales como Redes VSAT, Sistemas de Navegación Global (Global Navigation Satellite System - GNSS) y la Vigilancia Dependiente Automática (Automatic Dependent Surveillance - ADS) que se han convertido en pilares del Tráfico Aéreo.

2. Se han visto los potenciales beneficios para la aviación civil en las Regiones CAR/SAM, del uso de la tecnología satelital para los sistemas de navegación aérea.
THANK YOU!!

Note: The opinions expressed here are solely those of the author.