Global Navigation Satellite System Overview and Support for PBN Implementation

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Outline

1. Air Navigation Evolution
2. What is GNSS?
   - ICAO Concept for GNSS
   - GNSS Concept development in ICAO
   - GNSS Elements
3. GNSS SARPS and General considerations
   - Reference documentation and GNSS related Standards
   - GNSS Policy Issues
   - Performance requirements
Air Navigation Evolution

- Visual Navigation
- Estimated Navigation
- Astronomic Navigation
- Radio Navigation (Ground Based – Conventional)
- Global Navigation Satellite System (GNSS)
Navigation - The Beginning

VFR

- Visual Flight Rule!

- And Rivers
- And Railroads
- And Buildings
- And Telephone Lines
- And Whatever Else I Can See
Air Navigation Evolution

Night and Weather!

1910s
- First Bonfires and Beacons

Early 1920s
- Lighted airport boundaries
- Spot-lit windsocks
- Rotating lighted beacons on towers
- Lighted Airways
  - 1923 Dayton to Columbus, Ohio (USA) – 72 km
Radio! Late 1920s - 1930s

- Weather Updates
- Request Help With Navigation
- Radio Marker Beacons
- 4-Course Radio Range System

Pilots Listen for Navigation Signals
Air Navigation Evolution

1930s - 1940s

VOR!

Static-Free VHF Omni-directional Radio Range

- Pilots Navigate by Instrument

VOR (with improvements) becomes a primary NAVAID for decades

- Defines Routes
- Supports Approach Procedures
Air Navigation Evolution

**ILS!**

1929: First system tested

1946: (Provisional) ICAO selects ILS as primary landing air for international “trunk” airports

Today ILS:

- Cat I,
- Cat II,
- Cat III
Air Navigation Evolution

From 1950s

**DME!**

1961: first regular civil use (pilot tuned)

In PBN, DME use is based on automatic tuning
The 1970's Cockpit

- Ground-based navigation aids (NAVAIDs)
  - Aircraft Overfly NAVAID or Intersection
- Display Accuracy is a Function of Distance
  - Protected Area Grows
  = Limited Design Flexibility
First Generation Digital Avionics

Appeared in early 1970s

- Basic ‘cruise control’
- Capable of storing 4 manually inserted ‘waypoints’
- Provided guidance on Course Deviation Indicator (CDI)
- Flew to waypoint before switching to next leg

Conventional ATS Routes:

- Defined by NAVAIDs
- NAVAID coordinates loaded into computer
- Automatic route guidance provided from computer

Air Navigation Evolution
Evolution to Area Navigation

- Long Range Navigation (LORAN)**
- Omega Radio Navigation System*
- Inertial Navigation
- VOR/VOR and VOR/DME

* Terminated in 1997
** US system terminated in 2010
WHAT IS GNSS?

ICAO Concept for GNSS

GLOBAL NAVIGATION SATELLITE SYSTEM

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)*

Key enabler of the initiatives in the Global Air Navigation Plan

Enabler of PBN

Not only purely GNSS navigation but other GNSS-based services (ADS-B/ADS-C)

Annex 10, Vol I / GNSS Manual (Doc 9849)
During the 10th Air Navigation Conference, the Air Navigation Commission request the beginning of an agreement between ICAO and the GNSS Provider States with respect to the quality and duration of GNSS (1991).

In 1993, the ICAO GNSS Panel (GNSSP) was established, whose principal task was the development of SARPS in support of GNSS Aeronautical Applications.

In 1994/1996 the United States and Russia offered ICAO to provide GPS/GLONASS services for free at a continuous and global basis.

By 1999 the GNSSP completed the developments of GNSS SARPS, applicable for 2001.
WHAT IS GNSS?

GNSS Concept development in ICAO

Since 2002 and up to date, the GNSSP (renamed to Navigation System Panel) has developed and is in charge of the updates to GNSS/Navigation SARPS and Guidance material.

During the 11th Air Navigation Conference (2003), the Conference recommended a global transition to Air Navigation based on GNSS.

In 2006 the SARPS for GRAS were developed.

Since 2008, Annex 10 and its guidance material were updated to include the PBN concept.

Since 2009, annual amendments have been included in ICAO Annex 10 and its guidance material to update the Standards based on the GNSS implementation experiences and the maturity of systems.
WHAT IS GNSS?

Satellite Navigation ... Basically Multilateration

Multilateration:
By knowing your distance from at least 3 points of known-position, you can determine your own position.

For Satellite Navigation: a, b & c are satellites, and a fourth is needed to solve for clock variations.
WHAT IS GNSS?

**GNSS Elements**

- **Actual Path**
- **Assumed Path**
- **Earth’s Ionosphere**

**GNSS Ranging and Timing**

- Approach: $t_{\text{arrival}} - t_{\text{transmitted}} \sim$ distance from satellite
- Assumes straight path of radio frequency signals
  - Earth’s ionosphere actually disrupts/bends that path
- Augmentations correct for that bend using dual-frequency measurements
  - Currently not possible directly in aircraft; some signals not protected.
WHAT IS GNSS?

GNSS Elements

- GPS/ GLONASS/
  GALILEO/
- SBAS
- ABAS
- GNSS Receivers
- GBAS/ GRAS

GNSS Navigation Services
WHAT IS GNSS?

GNSS Elements

Core Constellations
- GPS
- GLONASS
- Galileo (under development)

Augmentation Systems
- Aircraft-Based Augmentation System (ABAS)
- Space-Based Augmentation System (SBAS)
  - Uses geostationary satellites
  - India (GAGAN), Japan (MSAS), Europe (EGNOS), US (WAAS)
- Ground-Based Augmentation System (GBAS)
- Ground-Based Regional System (GRAS)
WHAT IS GNSS?

GNSS Elements

WAAS

SBAS/GRAS

Enroute Oceanic

Enroute Domestic

Terminal

Approach

Surface

GBAS

LAAS
WHAT IS GNSS?

• ABAS is an avionics implementation that processes GPS and/or GLONASS signals to deliver the accuracy and integrity required to support en route, terminal and non-precision approach (NPA) operations.

• SBAS uses a network of ground reference stations and provides signals from Geostationary Earth Orbit (GEO) satellites to support operations from en route through to approaches with vertical guidance over a large geographic area. SBAS approach operations do not require augmentation stations at the airports served.

• 2012: almost 3,000 SBAS vertically guided approach procedures were implemented (North America), some of which support Category I (CAT I) minima. Over 1,100 of these serve airports without ILS.
WHAT IS GNSS?

Wide Area Augmentation System

- Communication Satellite
- GPS Satellites
- Ground Earth Station
- Wide Area Master Station
- Wide Area Reference Station
GBAS uses monitoring stations at airports to process signals from core constellations and broadcast corrections and approach path data to support precision approach operations.

GBAS has the potential to support CAT II/III and some surface movement operations, as well as terminal area navigation.

2012: approximately 40 GBAS stations around the world were supporting testing and CAT I operations with special approvals.
WHAT IS GNSS?

GNSS Elements

Ground Based Augmentation System (GBAS) Architecture
**WHAT IS GNSS?**

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>108-117.975</td>
<td>GBAS/GRAS broadcast link</td>
</tr>
<tr>
<td>1164-1215</td>
<td>GPS L5, Galileo E5, future SBAS, GLONASS L3</td>
</tr>
<tr>
<td>1215-1240</td>
<td>GPS L2 (site-by-site ground use only)</td>
</tr>
<tr>
<td>1559-1610</td>
<td>SBAS, GPS L1, GLONASS, Galileo E1</td>
</tr>
</tbody>
</table>
GNSS SARPS and General considerations

Reference documentation and GNSS related Standards

- Doc. 7300  International Civil Aviation Convention
- Doc. 8733  CAR/SAM Air Navigation Plan
- Doc. 9750  Global Air Navigation Plan
- Annex 2    Rules of the Air
- Annex 4    Aeronautical Charts
- Annex 6    Aircraft Operations
- Annex 10   Aeronautical Telecommunications
             Vol 1: Radio Navigation Aids
- Annex 11   Air Traffic Services
- Annex 14   Aerodromes
- Annex 15   Aeronautical Information Services
- ICAO Strategic Objectives
GNSS SARPS and General considerations

Reference documentation and GNSS related Standards

Doc. 9849
GNSS MANUAL

Doc. 4444
PROCEDURES FOR AIR NAVIGATION SERVICES ATM

Doc. 7030
REGIONAL SUPPLEMENTARY PROCEDURES

Doc. 8071
MANUAL ON TESTING OF RADIO NAVIGATION AIDS VOLII

Doc. 8126
AERONAUTICAL INFORMATION SERVICES MANUAL

Doc. 8168
AIRCRAFT OPERATIONS
## GNSS SARPS and General considerations

### Reference documentation and GNSS related Standards

<table>
<thead>
<tr>
<th>Document</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doc. 9161</td>
<td>Manual on Air Navigation Services Economics</td>
</tr>
<tr>
<td>Doc. 9426</td>
<td>Air Traffic Services Planning Manual</td>
</tr>
<tr>
<td>Doc. 9613</td>
<td>PBN MANUAL</td>
</tr>
<tr>
<td>Doc. 9689</td>
<td>Manual on Airspace Planning Methodology for the Determination of Separation Minima</td>
</tr>
<tr>
<td>CIR 321</td>
<td>Guidelines for the implementation of GNSS longitudinal separation minima</td>
</tr>
<tr>
<td>CIR 267</td>
<td>Guidelines for the Introduction and Operational Use of the Global Navigation Satellite System (GNSS)</td>
</tr>
<tr>
<td>CIR. 278</td>
<td>National Plan for CNS/ATM SystemsRef. EC</td>
</tr>
<tr>
<td>2/84-07/41</td>
<td>Provisional Policies about GNSS costs assignments</td>
</tr>
<tr>
<td>EB 2011/56</td>
<td>Interference to Global Navigation Satellite System (GNSS) Signals</td>
</tr>
<tr>
<td>EB 2011/33</td>
<td>Status of the Implementation of the Satellite-Based Augmentation System (SBAS)</td>
</tr>
</tbody>
</table>
GNSS SARPS and General considerations

Reference documentation and GNSS related Standards

- GNSS Manual (Doc 9849)
- Circular 326 – Assessment of ADS-B Multilateration Surveillance to Support Air Traffic Services and Guidelines for Implementation
### Reference documentation and GNSS related Standards

<table>
<thead>
<tr>
<th>Annex 10, Vol I</th>
<th>Global Positioning System (GPS) that provides the Standard Positioning Service (SPS) as defined in 3.7.3.1;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global Navigation Satellite System (GLONASS) that provides the Channel of standard Accuracy (CSA) navigation signal in 3.7.3.2;</td>
</tr>
<tr>
<td></td>
<td>aircraft-based augmentation system (ABAS) as defined in 3.7.3.3;</td>
</tr>
<tr>
<td></td>
<td>satellite-based augmentation system (SBAS) as defined in 3.7.3.4;</td>
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<tr>
<td></td>
<td>ground-based augmentation system (GBAS) as defined in 3.7.3.5;</td>
</tr>
<tr>
<td></td>
<td>ground-based regional augmentation system (GRAS) as defined in 3.7.3.5; and</td>
</tr>
<tr>
<td></td>
<td>aircraft GNSS receiver as defined in 3.7.3.6.</td>
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</table>
GLOBAL AIR NAVIGATION PLAN Doc 9750

GPI-21 – Navigation Systems, establishes:
Strategy to allow PBN introduction and evolution supported by a robust navigation infrastructure providing an accurate, reliable and seamless global positioning capability

Doc 8168: PANS-OPS, Volume I y II

• Criteria for GNSS operations in terminal, non precision approach and departure with a basic GNSS receiver
• Provides information on the GNSS implementation aspects to help the States in the introduction of GNSS operations
Reference documentation and GNSS related Standards


*primary purpose of this manual is to provide information on the operational implementation of GNSS to assist States to introduce GNSS-based services.*

*explains the services provided with GNSS, including the performance characteristics and the operational possibilities of GNSS Augmentation Systems.*

*Provides General issues for GNSS Implementation.*

*The manual is aimed at air navigation service providers responsible for fielding and operating GNSS elements, and at regulatory agencies responsible for approving the use of GNSS for flight operations. Additionally, it provides GNSS information to aircraft operators and manufacturers.*

*A new unedited version is available: June 2012*
GNSS SARPS and General considerations

Reference documentation and GNSS related Standards


guidance on testing of satellite-based radio navigation systems: testing of non-precision approach (NPA) procedures using an aircraft-based augmentation system (ABAS), guidance on testing of a satellite-based augmentation system (SBAS) and a ground-based augmentation system (GBAS), as well as on the flight validation of instrument flight procedures.
ICAO Policy in the Implementation and Operation of CNS/ATM Systems approved by the Council (1994):

“The GNSS shall be implemented gradually considering the existing global satellite-based navigation systems, including the GPS System of United States and the GLONASS of the Russian Federation, towards an integrated GNSS in which the contracting States have sufficient control regarding aspects related to its use by Civil Aviation. ICAO shall continue exploring, in consultation with its contracting States, airspace users and service providers, the feasibility of having a internationally controlled Civil GNSS.”

Similarly: (1998) Assembly resolutions:
- A32-19: Rights and Obligations of the States related with the GNSS Services
- A32-20: Development and elaboration of a legal long term framework for managing the implementation of GNSS.
For the introduction of new GNSS navigation elements, the State shall evaluate the navigation systems with respect to 4 essential criteria:

1. Accuracy,
2. integrity (including time to alert),
3. Service continuity, and
4. Service availability.
Guidelines on Provisional Policy on GNSS cost assignment

a) **Basic GNSS** Services: free for being a common resource for various user categories

**More advanced** GNSS Services (including the augmentations) shall be paid, in the majority of the cases by all users

b) The incremental costs for more advanced GNSS Services shall be assigned among the users that effectively could have benefits. This assignment shall be carried out at a regional level and have in account the needs of the different users categories, in the places where the service level can be adjusted to satisfy the different needs.

c) **Cost Distribution** among all the users before proceeding to recover civil aviation costs, all compatible with ICAO policy on air navigation services fees.
**GNSS SARPS and General considerations**

**Performance requirements**

### Signal-in-space performance requirements

<table>
<thead>
<tr>
<th>Typical operation</th>
<th>HORIZONTAL Accuracy 95%</th>
<th>VERTICAL Accuracy 95%</th>
<th>INTEGRITY</th>
<th>TIME TO ALERT.</th>
<th>CONTINUITY</th>
<th>AVAILABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enroute</td>
<td>3.7 Km (2.0 NM)</td>
<td>N/A</td>
<td>1-1 x 10⁻⁷/h</td>
<td>5 min</td>
<td>1-1 x 10⁻⁴/h a 1-1 x 10⁻⁸/h</td>
<td>0.99 a 0.99999</td>
</tr>
<tr>
<td>Enroute, Terminal</td>
<td>0.74 Km (0.4 NM)</td>
<td>N/A</td>
<td>1-1 x 10⁻⁷/h</td>
<td>15 s</td>
<td>1-1 x 10⁻⁴/h a 1-1 x 10⁻⁸/h</td>
<td>0.99 a 0.99999</td>
</tr>
<tr>
<td>Initial Approach</td>
<td></td>
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<tr>
<td>Intermediate Approach</td>
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<tr>
<td>Non precision Approach (NPA)</td>
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<tr>
<td>Departure</td>
<td></td>
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</tr>
<tr>
<td>Initial Approach</td>
<td>220 m 720 ft</td>
<td>N/A</td>
<td>1-1 x 10⁻⁷/h</td>
<td>10 s</td>
<td>1-1 x 10⁻⁴/h a 1-1 x 10⁻⁸/h</td>
<td>0.99 a 0.99999</td>
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<tr>
<td>Intermediate Approach</td>
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<tr>
<td>Non precision Approach (NPA)</td>
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<tr>
<td>Departure</td>
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<tr>
<td>Approach operations with vertical</td>
<td>16 m 52 ft</td>
<td>20 m 66 ft</td>
<td>1-2 x 10⁻⁷ in any approach</td>
<td>10 s</td>
<td>1-8x10⁻⁶ en 15 s</td>
<td>0.99 a 0.99999</td>
</tr>
<tr>
<td>guidance APV-1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Approach operations with vertical</td>
<td>16 m 52 ft</td>
<td>8 m 26 ft</td>
<td>1-2 x 10⁻⁷ in any approach</td>
<td>6 s</td>
<td>1-8x10⁻⁶ en 15 s</td>
<td>0.99 a 0.99999</td>
</tr>
<tr>
<td>guidance APV-2</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CAT 1 precision</td>
<td>16 m 52 ft</td>
<td>6 m a 4 m 20 ft a 13 ft</td>
<td>1-2 x 10⁻⁷ pin any approach</td>
<td>6 s</td>
<td>1-8x10⁻⁶ en 15 s</td>
<td>0.99 a 0.99999</td>
</tr>
<tr>
<td>Approach</td>
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</tbody>
</table>
The combination of GNSS elements and a fault-free GNSS user receiver shall meet the signal-in-space requirements defined in Annex 10, Volume I, Table 3.7.2.4-1:

<table>
<thead>
<tr>
<th>Typical Operation</th>
<th>horizontal Alert Limit</th>
<th>Vertical Alert Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Enroute (oceanic/continental low density).</td>
<td>7.4 Km (4 NM)</td>
<td>N/A</td>
</tr>
<tr>
<td>2. Enroute (continental).</td>
<td>3.7 km (2 NM)</td>
<td>N/A</td>
</tr>
<tr>
<td>3. Enroute, terminal.</td>
<td>1.85 km (1 NM)</td>
<td>N/A</td>
</tr>
<tr>
<td>4. Initial approach, intermediate approach, non precision approach (NPA), departure.</td>
<td>556 m (0.3 NM)</td>
<td>N/A</td>
</tr>
<tr>
<td>5. Approach with vertical guidance (APV-I).</td>
<td>40 m (130 ft)</td>
<td>50 m (164 ft)</td>
</tr>
<tr>
<td>6. Approach with vertical guidance (APV-II).</td>
<td>40 m (130 ft)</td>
<td>20 m (66 ft)</td>
</tr>
<tr>
<td>7. CAT 1 precision approach.</td>
<td>40 m (130 ft)</td>
<td>35 a 10 m (115 a 33 ft)</td>
</tr>
</tbody>
</table>
Questions?