IMPLEMENTATION OF GNSS BASED SERVICES

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1. Performance Requirements
   a) Accuracy
   b) Integrity and Time-to-Alert
   c) Continuity
   d) Availability

2. Operational Applications of GNSS
   a) Performance Based navigation (PBN)
   b) ADS-B
   c) ADS-C

3. Implementation of Services based on GNSS
4. GNSS Limitations
5. GNSS Vulnerability
6. GNSS Evolution
Performance Requirements

- **Accuracy**: difference between computed and true position. Can change over a period of hours due to satellite movements and the effects of the ionosphere -> Augmentation systems.

- **Integrity**: the correctness of the information supplied by the total system. Integriti is based on avionics performing complex calculations to ensure that the error in computed position will not exceed the maximum allowed for the current operation. Level of integrity for each operation -> specific horizontal/lateral, and for approaches with vertical guidance, vertical alert limits (HAL/LAL and VAL). Avionics continuously calculate corresponding protection levels (HPL/LPL and VPL). The terms HAL/HPL are used with ABAS and SBAS, whereas the terms LAL/LPL are used with GBAS. Time to alert: maximum amount of time allowed for failure detection.
## Performance Requirements

### SIGNAL-IN-SPACE PERFORMANCE REQUIREMENTS

<table>
<thead>
<tr>
<th>Typical Operation</th>
<th>horizontal Alert Limit</th>
<th>Vertical Alert Limit</th>
<th>Time-to-Alert</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Enroute (oceanic/continental low density).</td>
<td>7.4 Km (4 NM)</td>
<td>N/A</td>
<td>5 min</td>
</tr>
<tr>
<td>2. Enroute (continental).</td>
<td>3.7 km (2 NM)</td>
<td>N/A</td>
<td>5 min</td>
</tr>
<tr>
<td>3. Terminal.</td>
<td>1.85 km (1 NM)</td>
<td>N/A</td>
<td>15 s</td>
</tr>
<tr>
<td>4. Initial approach, intermediate approach, non precision approach (NPA), departure.</td>
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</tr>
<tr>
<td></td>
<td>556 m (0.3 NM)</td>
<td>N/A</td>
<td>10s</td>
</tr>
<tr>
<td>5. Approach with vertical guidance (APV-I).</td>
<td>40 m (130 ft)</td>
<td>50 m (164 ft)</td>
<td>10s</td>
</tr>
<tr>
<td>6. Approach with vertical guidance (APV-II).</td>
<td>40 m (130 ft)</td>
<td>20 m (66 ft)</td>
<td>6s</td>
</tr>
<tr>
<td>7. CAT 1 precision approach.</td>
<td>40 m (130 ft)</td>
<td>35 ± 10 m (115 ± 33 ft)</td>
<td>6s</td>
</tr>
</tbody>
</table>
Continuity: system capability function without unscheduled interruptions

- ABAS: continuity depends on the number of satellites in view
- SBAS and GBAS, continuity depends on redundancy of augmentation system components.

Availability: is the portion of time during which the system is simultaneously delivering the required accuracy and integrity.

- The level of availability in a certain airspace at a certain time should be determined through design, analysis and modelling, rather than through measurement.
- When setting availability specifications for specific airspace, States should take into account traffic density, available conventional aids, radar surveillance coverage, potential duration and geographical size of outages, as well as flight and ATC procedures.
## Performance Requirements

### SIGNAL-IN-SPACE PERFORMANCE REQUIREMENTS

<table>
<thead>
<tr>
<th>Typical operation</th>
<th>HORIZONTAL Accuracy</th>
<th>VERTICAL Accuracy</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>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>
</tr>
<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>Approach operations</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>with vertical guidance APV-I</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Approach operations</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>with vertical guidance APV-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAT 1 precision Approach</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>
</tbody>
</table>
Operational Applications of GNSS

GNSS enables:

- Navigation guidance for all phases of flight, from en route through to precision approach.
- Moving map displays, terrain awareness and warning systems (TAWS) and synthetic vision systems.
- Emergency Locator Transmitters (ELTs).
- Variety of precision timing applications.

GNSS provides accurate guidance in remote, oceanic and mountainous areas where it is too costly or impossible to provide reliable and accurate conventional navigation aid guidance.

GNSS can also provide service where it is not possible to install conventional aids.

GNSS allows a phased decommission of ground-based navaids.
Operational Applications of GNSS

supports positioning, navigation and timing (PNT) applications:

• Performance-Based Navigation (PBN),
• Automatic Dependent Surveillance – Broadcast (ADS-B)
  • Improved surveillance performance -> key to reduced separation standards, increased airspace capacity and the ability to support user-preferred trajectories.
• Automatic Dependent Surveillance – Contract (ADS-C)
  • In oceanic and remote areas, ADS-C position reports are relayed via communications satellites to air traffic control (ATC) -> reduced separation standards.

provides a common time reference used to synchronize systems, avionics, supports a wide range of non-aviation applications, 4D Navigation and trajectory synchronization, required time of arrival, multilateration and wide area multilateration, multi-radar tracking systems, air ground data link, flight data processing and ground communication networks
Operational Applications of GNSS

GPS/ABAS provides improve to service without incurring any expenditure on infrastructure.

ABAS supports the RNP APCH navigation specification to LNAV minima and when combined with barometric vertical guidance (Baro VNAV), supports approaches with vertical guidance to LNAV/VNAV minima.

Integrity monitoring: receiver autonomous integrity monitoring (RAIM), which uses GNSS information exclusively, and aircraft autonomous integrity monitoring (AAIM), which also uses information from additional on-board sensors such as inertial reference systems (IRS) -> fault detection (FD) or fault detection and exclusion (FDE).

Basic GNSS receiver is an essential element of ABAS that supports en-route, terminal and NPA operations and provides, as a minimum, RAIM fault detection.
Operational Applications of GNSS

SBAS support the application of GNSS signals-in-space within all the PBN specifications, ranging from oceanic en route to approach with vertical guidance.

three levels of SBAS capability that provide:

- to support PBN en route through NPA: core satellite status and GEO ranging; and clock and ephemeris corrections; and
- To support APV: clock, ephemeris and ionospheric corrections

four classes of SBAS avionics that support different performance capabilities. Class I equipment supports en-route, terminal and LNAV approach operations. Class II supports en route through LNAV/VNAV approach operations. Class III and IV support en route, terminal and four approach minima levels: LPV, LP, LNAV/VNAV and LNAV.

SBAS supports RNP APCH with vertical guidance to LPV minima, and localizer-like guidance to LP minima where vertical guidance is not feasible due to obstacles or terrain.

In States without SBAS service and where few aircraft are equipped with Baro VNAV, GNSS can provide lateral guidance for straight-in approaches to the majority of runways now served by circling procedures.
Operational Applications of GNSS
Annex 10: GBAS will support CAT I precision approach and the provision of GBAS positioning service in the terminal area.

draft SARPs amendment for GBAS to support CAT II/III approaches is completed and currently undergoing validation by States and industry.

multiple approaches: A single GBAS ground installation may provide guidance for up to 49 approaches within its VDB coverage.

GBAS avionics standards have been developed to mimic ILS to simplify the integration of GBAS with existing avionics.
### LEVEL OF SERVICE FROM GNSS AUGMENTATION ELEMENTS

<table>
<thead>
<tr>
<th>GNSS augmentation /Operation</th>
<th>Oceanic and remote en-route</th>
<th>Continental en-route</th>
<th>Terminal</th>
<th>Approach and landing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nav specific:</strong></td>
<td>RNAV 10, RNP 2, RNP 4</td>
<td>RNAV 1, RNAV 2, RNAV 5, RNP 2, Advanced RNP</td>
<td>RNAV 1, Basic RNP1, RNP 0.3, Advanced RNP</td>
<td>RNP APCH, RNP AR APCH</td>
</tr>
<tr>
<td>Core satellite constellation with ABAS</td>
<td>Suitable for navigation when fault detection and exclusion (FDE) is available. Preflight FDE prediction might be required</td>
<td>Suitable for navigation when receiver Autonomous integrity monitoring (RAIM) or another navigation source is usable</td>
<td>Suitable for navigation</td>
<td>Suitable for NPA when RAIM is available (and another navigation source is usable at the alternate aerodrome)</td>
</tr>
<tr>
<td>Core satellite constellation with SBAS</td>
<td>Suitable for navigation</td>
<td>Suitable for navigation</td>
<td>Suitable for navigation</td>
<td>Suitable for NPA and LPV, depending on SBAS performance</td>
</tr>
<tr>
<td>Core satellite constellation with GBAS</td>
<td>N/A</td>
<td>GBAS positioning service output may be used as an input source for approved navigation system</td>
<td>GBAS positioning service output may be used as an input source for approved navigation system</td>
<td>Suitable for NPA and precision approach (PA) Cat 1 (potentially II/III in future)</td>
</tr>
</tbody>
</table>
GNSS enables compliance with ICAO Assembly Resolution A37/11, which requires States to “… complete a PBN implementation plan as a matter of urgency to achieve:

1) implementation of RNAV and RNP operations (where required) for en route and terminal areas according to established timelines and intermediate milestones;

2) implementation of approach procedures with vertical guidance (APV) (Baro VNAV and/or augmented GNSS), including LNAV only minima, for all instrument runway ends, either as the primary approach or as a backup for precision approaches by 2016 with intermediate milestones as follows: 30 per cent by 2010 and 70 per cent by 2014; and

3) implementation of straight-in LNAV only procedures, as an exception to 2) above, for instrument runways at aerodromes where there is no local altimeter setting available and where there are no aircraft suitably equipped for APV operations with a maximum certificated take-off mass of 5,700 kg or more.”
Implementation of Services based on GNSS

The transition to GNSS-based services will be based on cost beneficial solution supported by safety and security analyses.

The transition to GNSS-based services requires new approaches to regulation, provision of services, airspace and procedures and operation of aircraft.

A successful transition requires a comprehensive orientation and training programme aimed at all involved parties, including decision makers in aviation organizations.

- Training should include: the basic theory of GNSS operations; GNSS capabilities and limitations; avionics performance and integration; applicable regulations; and concepts of operation.
Implementation of Services based on GNSS

Operational specification: PBN Airspace concept

To decide on the implementation of GNSS -
> International Implementation Planning:
  Take advantage of the expertise and information
  from ICAO

Development of a Concept of Operations (CONOPS)
Development of a Concept of Operations (CONOPS)

- involve all stakeholders at the national and regional level,
- development of the safety case,
- business case and regulations.
- current and projected regional and State traffic flows and volumes as described in regional plans;
- stated requirements of aircraft operators and their current and planned fleet composition and avionics equipage;
- plans of States in the region;
- certification and operational approvals;
- training of ANS provider staff and aircrews;
- airspace planning and procedure development;
- air traffic management, including airspace and ATC considerations, including ATC standards and procedures and automation systems;
- aeronautical information services, including the notification of system failures;
- GNSS signal vulnerability and anomaly/interference reporting;
- effects on the environment, including emissions and noise; and
- transition planning.
Implementation of Services based on GNSS

comprehensive implementation plan.

System Testing and Procedure Validation

Monitoring and recording of GNSS Information

• Annex 10 recommends that a State that approves GNSS-based operations should monitor and record relevant GNSS data to support accident and incident investigations.

• These data can also be used periodically to confirm GNSS performance.

• The objective is not to support a real-time notification process.
Implementation of Services based on GNSS

GNSS Service Status Notification: State ANS providers have the responsibility to report the status of air navigation services. If the status of a service changes or is predicted to change, users should be notified via direct communications from air traffic services (ATS) and/or via a NOTAM or aeronautical information system (examples).

• EXAMPLES:

• Core Satellite System Status NOTAMs: Operators of GNSS core constellations should provide information on actual and projected outages of their satellites.

• Interference NOTAMs: ANS providers must be prepared to act when anomaly reports from aircraft or ground-based units suggest signal interference. If an analysis concludes that interference is present, ANS providers must identify the area affected and issue an appropriate NOTAM.
## Implementation of Services based on GNSS

### AVIONICS STANDARDS DOCUMENTS

<table>
<thead>
<tr>
<th>Augmentation systems</th>
<th>United States FAA Technical Standard Order (TSO)</th>
<th>RTCA (EUROCAE) Minimum Operational Performance Standards/Minimum Aviation System Performance Standards (MOPS/MASPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABAS</td>
<td>TSO-C129A Level 2 (en-route/terminal)</td>
<td>TSO-C129A Levels 1 or 3 (NPA)</td>
</tr>
<tr>
<td></td>
<td>TSO-C196</td>
<td>EASA ETSO-C129c</td>
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<td>RTCA/DO-208</td>
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<td>EUEOCAE ED-72A</td>
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<td>RTCA/DO-316</td>
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<tr>
<td>SBAS*</td>
<td>TSO-C145</td>
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<tr>
<td></td>
<td>TSO-C146A</td>
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<tr>
<td></td>
<td>EASA ETSO-C145c, -C146c</td>
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<td>RTCA/DO-229D</td>
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<td>EASA ETSO-C145c, -C146c</td>
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<tr>
<td>GBAS</td>
<td>TSO-C161A</td>
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<tr>
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<td>TSO-C162A</td>
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<td>RTCA/DO-245A</td>
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<td>RTCA/DO-246D</td>
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<td>RTCA/DO-253C</td>
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<td></td>
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<td>EUROCAE ED-95</td>
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</tbody>
</table>

* SBAS avionics meet all ABAS requirements
GNSS signals from satellites are very weak at the receiver antenna, so are vulnerable to interference.

Current GNSS approvals use a single frequency band common to GPS, GLONASS and SBAS.

There are a number of sources of potential interference to GNSS from both in-band and out-of-band emitters, including mobile and fixed VHF communications, harmonics of television stations, certain radars, mobile satellite communications and military systems. -> Effective spectrum management is the primary way to reduce the likelihood of unintentional and intentional interference with GNSS signals.
Many reported instances of GNSS interference have been traced to on-board systems, including VHF and satellite communications equipment and portable electronic devices. Such interference can be prevented by proper installation of GNSS avionics (e.g. shielding, antenna separation and out-of-band filtering), integration with other aircraft systems and restrictions on the use of portable electronic devices.

Primary concern is the proliferation of personal privacy jammers.

Retaining DME is recommended as part of a mitigation strategy in the case of a GNSS outage.

Spoofing is the broadcast of GNSS-like signals to cause avionics to calculate erroneous positions and provide false guidance -> technically much complex.

Pilots could note deviations through normal monitoring of instruments and displays; and in a radar environment, ATC could observe deviations.
Ionospheric Effect/ Scintillation:

- GNSS signals are delayed by a varying amount depending on the density of ionized particles, which itself depends on the intensity of solar radiation and other solar energy bursts.
- The likelihood of disruption due to scintillation will depend on the geographic area and will require scientific assessment.
- Ionospheric phenomena have negligible impact on en route through NPA operations.
Scintillation affects all GNSS frequencies

Multi-constellation GNSS would allow the receiver to track more satellites, reducing the likelihood of service disruption.

Vulnerability of receivers is highly dependent on their design.
GNSS Evolution

GNSS will evolve by improving existing elements and creating new elements

The key to acceptance by aircraft operators is the business case – the value of incremental operational benefits must exceed the cost of new avionics and their share of the cost of GNSS infrastructure. GPS, GLONASS, ABAS, SBAS and GBAS, as well as ADS-B and ADS-C, already provide very significant benefits to aircraft operators.

Availability of a second frequency will allow avionics to calculate ionospheric delay in real time, effectively eliminating a major error source.
Multi-Constellation/Multi-Frequency GNSS

- Today’s GNSS-based services rely for the most part on GPS,
- New constellations/ GNSS augmentation systems are available and to be deployed
- improves GNSS technical performance.
- will enhance performance and service coverage.
- mitigate the risk of service loss due to a major system failure
- improves robustness and will allow GNSS to meet performance requirements when there is interference or an individual system failure.
- availability of more than thirty interoperable ranging sources could allow ABAS to provide worldwide vertically guided approaches with minimal, or potentially no need for external augmentation signals in the long term.

the possibility to develop advanced RAIM (ARAIM) that could support high availability for en route through NPA and also support APV globally
Questions?
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