ICAO policy on GNSS, GNSS SARPs and global GNSS developments

Jim Nagle

Chief, Communication, Navigation and Surveillance Section

ICAO

Presentation overview

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Introduction - ICAO

- Convention (Chicago, 1944) and Annexes
- UN Specialized Agency
- 190 Contracting States
- Assembly (ordinarily every 3 years)
- Council – 36 States
- Air Navigation Commission – 19 members
- Air Navigation Bureau
- Standards, Recommended Practices (SARPs)

Introduction - ICAO

Introduction – GNSS

- The theoretical **definition**:
  - “**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.”* [from ICAO Annex 10, Volume I]

- The practical **foundation**:
  - 1994/1996: US and Russia offer to ICAO to provide GPS (Global Positioning System)/GLONASS (GLObal NAvigation Satellite System) service for the foreseeable future on a continuous worldwide basis and free of direct user fees

GNSS developments in ICAO

- 1991: 10th Air Navigation Conference:
  - The Air Navigation Commission requests the initiation of an agreement between ICAO and GNSS-provider States concerning quality and duration of GNSS
- 1993: ICAO GNSS Panel established
  - Primary task: to develop SARPs in support of aeronautical applications of GNSS
- 1994/1996: GPS/GLONASS offers from US/Russia
- 1999: GNSSP completes the development of GNSS SARPS (applicable 2001)
- 2002 – today: GNSSP (subsequently renamed NSP) develops GNSS SARPs enhancements
- 2003: 11th Air Navigation Conference:
  - The Conference recommends a worldwide transition to GNSS-based air navigation

ICAO policy on GNSS

- 1994: Statement of ICAO policy on CNS/ATM systems implementation and operation approved by the ICAO Council:
  - "GNSS should be implemented as an evolutionary progression from existing global navigation satellite systems, including the United States' GPS and the Russian Federation's GLONASS, towards an integrated GNSS over which Contracting States exercise a sufficient level control on aspects related to its use by civil aviation. ICAO shall continue to explore, in consultation with Contracting States, airspace users and service providers, the feasibility of achieving a civil, internationally controlled GNSS"
- 1998: Assembly resolutions A32-19 ("Charter on the Rights and Obligations of States Relating to GNSS Services") and A32-20 ("Development and elaboration of an appropriate long-term legal framework to govern the implementation of GNSS")

The GPS/GLONASS offers

- GPS offer (1994):
  - GPS standard positioning service to be made available on a continuous worldwide basis and free of direct user fees for the foreseeable future. At least 6 years notice prior to termination.
- GLONASS offer (1996):
  - GLONASS standard accuracy channel to be provided to the worldwide aviation community for a period of at least 15 years with no direct charges collected from users.
- Both offers accepted by ICAO Council
- Offers reiterated at various occasions, most recently February 2007 (180th Session of the ICAO Council)

GNSS elements: GPS

- Nominal constellation: 24 satellites (30 active as of March 2007)
- Six orbital planes
- Near-circular, 20,200 km altitude (26,600 km radius) 12-hour orbits
- First experimental satellite launched in 1978, operational in 1995
- Managed by the US National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee
- Standard positioning service (SPS) frequency: 1 575.42 MHz
- Selective availability (SA) discontinued in 2000
- ICAO Annex 10, Volume I, section 3.7.3.1

GNSS elements: GLONASS

- Nominal constellation: 24 satellites (fewer active as of August 2007)
- Three orbital planes
- Near-circular, 19,100 km altitude (25,500 radius) 11:15-hour orbits
- First experimental satellite launched in 1982, operational in 1995, subsequent decline (plans to restore full operational capability by 2010)
- Operated by the Ministry of Defence of the Russian Federation
- Channel of standard accuracy (CSA) frequencies: 1602 MHz ± 0.5625*n* MHz
- ICAO Annex 10, Volume I, section 3.7.3.2

GNSS elements: augmentation systems

- Three ICAO GNSS augmentation systems:
  - aircraft-based augmentation system (ABAS)
  - satellite-based augmentation system (SBAS)
  - ground-based augmentation system (GBAS)
    - >ground-based regional augmentation system (GRAS)
- Purpose: to overcome inherent limitations in the service provided by the core constellations

GNSS elements: ABAS

- ABAS: aircraft-based augmentation system
- The basic element of ICAO GNSS
- Purpose: to augment/integrate GNSS information with on-board aircraft information
- Required to ensure that performance meets Annex 10 requirements (Volume I, Table 3.7.2.4-1)
- Uses redundant satellite range measurements (and/or barometric information) to detect faulty signals and alert the pilot
- Receiver-autonomous integrity monitoring (RAIM) – five satellites required (or four + baro)
- Fault detection and exclusion (FDE) – six satellites required (or five + baro)
- RAIM/FDE availability: are sufficient redundant measurements available?
- ICAO Annex 10, Volume I, section 3.7.3.3

GNSS elements: SBAS (1)

- SBAS: satellite-based augmentation system
- Augments core satellite constellations by providing ranging, integrity and correction information
- The information is broadcast via geostationary satellites, in the same band as the core constellations
- SBAS elements:
  - a network of ground reference stations that monitor satellite signals
  - master stations processing reference stations data and generating SBAS signals
  - uplink stations to send the messages to the geostationary satellites
  - transponders on the satellites to broadcast SBAS messages
- SBAS (where supported) provides higher availability of GNSS services and lower minima than ABAS
- Approach procedures with vertical guidance (APV-I and -II)
- Developments to achieve Cat-I-like minima are underway
- ICAO Annex 10, Volume I, section 3.7.3.4

GNSS elements: SBAS (2)

- Wide Area Augmentation System (**WAAS**) - commissioned for safety-of-life use in 2003
- European Geostationary Navigation Overlay Service (**EGNOS**) - initial operations started in 2005
- Multi-functional Transport Satellite (MTSAT) Satellite-based Augmentation System (**MSAS**) - satellites launched in 2005-2006
- GPS aided Geostationary Earth Orbit (GEO) Augmented Navigation (**GAGAN**) - to be completed in 2008
- SBAS coverage area *vs* service area:
  - SBAS coverage area: GEO satellite signal footprint
  - SBAS service area: service area established by a State within SBAS coverage area

GNSS elements: GBAS/GRAS

- GBAS: ground-based augmentation system
- Operates in the VHF NAV band (108 – 117.975 MHz)
- Supports precision approach service (currently up to CAT I) and optionally positioning service
- Precision approach service provides “ILS-like” deviation guidance for final approach segments
- Can support multiple runways
- GRAS: ground-based regional augmentation system
  - an extension of GBAS to provide regional coverage down to APV service
- ICAO Annex 10, Volume I, section 3.7.3.5

GNSS signal-in-space performance requirements

- **Accuracy** – The difference between the estimated and actual aircraft position
- **Integrity** – A measure of the trust which can be placed in the correctness of the information supplied by the total system. It includes the ability of the system to alert the user when the system should not be used for the intended operation (alert) within a prescribed time period (time-to-alert)
- **Continuity** – The capability of the system to perform its function without unscheduled interruptions during the intended operation
- **Availability** – The portion of time during which the system is simultaneously delivering the required accuracy, integrity and continuity

GNSS signal-in-space performance requirements (Annex 10, Vol.I)

Typical operation	Accuracy horizontal 95%	Accuracy vertical 95%	Integrity	Time-to-alert	Continuity	Availability
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}$/h	5 min	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}$/h	15 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{8}$/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}$/h	10 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1 - 2 \times 10^{-7}$ per approach	10 s	$1 - 8 \times 10^{-6}$ in any 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ per approach	6 s	$1 - 8 \times 10^{-6}$ in any 15 s	0.99 to 0.99999
Category I precision approach	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft)	$1 - 2 \times 10^{-7}$ per approach	6 s	$1 - 8 \times 10^{-6}$ in any 15 s	0.99 to 0.99999

Future evolution

- GPS and GLONASS evolution (GPS L5/ GLONASS L3 signals)
- Galileo
- GBAS support of Cat II/III landing operations

GNSS implementation in States

- Elements to be addressed for a State implementing GNSS operations:
  - planning and organization
  - procedure development
  - airspace considerations
  - aeronautical information services
  - system safety analysis
  - certification and operational approvals
  - anomaly/interference reporting
  - vulnerability

Implementation planning

- Planning to be coordinated on a regional / wide area basis (common requirements)
- Coordination through ICAO and its regional bodies (PIRGs)
- Bilateral/multilateral coordination as necessary
- Establish a GNSS implementation team, involving users and appropriate multidisciplinary expertise
- Sample team Terms of Reference: ICAO GNSS Manual (Doc 9849) Appendix C
- GNSS plan to include the development of a business case
- Training requirements

Procedures development

- ICAO PANS-OPS (Doc 8168) contains the design criteria for GNSS procedures
- Departure, arrival, approach procedures using “basic GNSS” receiver (ABAS) and/or SBAS/GBAS receiver
- Includes procedures for “APV” (approach procedure with vertical guidance):
  - APV/Baro-VNAV
  - APV with SBAS (LPV: localizer performance with vertical guidance)

Airspace considerations

- Accurate navigation in oceanic en-route airspace (no conventional navaids available)
- Lateral separation reductions enabled by ADS (GNSS-based) in non-radar airspace
- Continental en-route and terminal airspace: RNAV arrival and departure procedures reduce delays and less workload
- Terminal, approach/departure airspace: support to aerodromes not served adequately by conventional navaids

Aeronautical information services

- State's Aeronautical information publication (AIP) to cover these aspects:
  - Description of GNSS services
  - Information about the approval of GNSS-based operations
  - World Geodetic System – 1984 (WGS-84) coordinate system
  - Airborne navigation database
  - Status monitoring and NOTAM

WGS-84

- Coordinate system adopted by ICAO to be used in support of GNSS
- ICAO Annex 4, 11, 14 and 15
- Using different coordinate systems is a hazard
- Transition path to WGS-84:
  - mathematical transformation of existing coordinate
  - resurvey (preferred option)

Airborne navigation database

- Safety of GNSS navigation depends on the integrity of the data in the airborne navigation database
- Data originates with States
- Quality of the position data must be retained throughout the data chain
- Manual entry into the airborne database not permitted
- EUROCAE/RTCA standards (DO-200A/ED-76 and DO-201A/ED77)

Status monitoring

- With conventional navaids, ground equipment status maps directly to service availability:
  - ILS is down -> precision approach service is not available
- With GNSS, mapping of individual satellite status to service availability is not direct:
  - GPS satellite x is down -> impact on GPS service depends on user location, time, equipment characteristics and configuration
- Real-time ground-based monitoring of GNSS service is in general not a requirement:
  - Primary responsibility for basic GNSS status monitoring resides in the avionics (RAIM: Receiver Autonomous Integrity Monitoring)
- RAIM availability prediction obtained as part of flight planning (from GNSS avionics interface, external software, website…)

GNSS NOTAM

- GNSS NOTAM provide information on:
  - Individual satellite outages or temporary unavailability of service due to testing or anomalies
    - Example: GPS NOTAM (location indicator KNMH, U.S. Coast Guard Navigation System Centre) supplied by constellation operator as international NOTAM
  - Service outages at specific airports/airspaces
    - Example: SBAS NOTAM derived from service volume model software supplied by SBAS operator
- NOTAM requirements can vary depending on practical considerations (e.g. availability of conventional navaids as back-up)

System safety assessment

- Annex 11: safety assessment before making significant safety-related changes to ATC system
- Systematic analysis of hazards and mitigations during all phases of system’s life cycle
  - GNSS safety plan

Certification and operational approvals

- State responsibility to authorize GNSS operations in its airspace
- Approval document: for aircraft with certified equipment and approved flight manual
- Specifies any limitations on proposed operations
- VFR use or IFR use
- GNSS alone or with other systems
- Airworthiness certification based on RTCA/EUROCAE documents

Anomaly reporting

- Anomaly: GNSS service outage (may be due to interference)
- Pilot to report to ATC asap requesting special handling as required and file complete report in accordance with State procedures
- Controllers to record information of the occurrence, to identify other GNSS-equipped aircraft that may be affected, and to forward information to designated authority
- National focal point unit to collect anomaly-related information

Vulnerability

- Potential for interference is the main vulnerability
- Receiver interference mask specifies the level of interference that can be tolerated
- Several interference sources (eg. microwave links within L1 band in some States)
- Unintentional vs intentional interference
- States should:
  - assess sources of vulnerability and develop mitigations (technical, procedural back-up)
  - provide effective spectrum management and protection of GNSS frequencies to reduce the possibility of unintentional interference
  - use on-board mitigation techniques (eg inertial)
  - consider selective retention of conventional navaids as part of an evolutionary transition
  - take full advantage of new GNSS signals and constellations

GNSS and
Performance Based Navigation

ALL PBN Navigation specifications are based on GNSS either as the primary navigation infrastructure or as one element of the infrastructure

END

Thank you for your attention!

Background

Basic technical principles (1)

- The aircraft computes its position by "trilateration"
- A simplified geometrical explanation:
  - the aircraft computes distances d1, d2 and d3 from three satellites whose positions P1, P2 and P3 are known;
  - knowing distances from, and positions of, three satellites, it is a simple geometrical problem to derive the position of the aircraft:
    - the position of the aircraft is the intersection of the three spheres of radius d1, d2 and d3 and centres respectively P1, P2 and P3
    - (there are actually two intersection points, but typically only one of them is "reasonable")

Basic technical principles (2)

- How does the aircraft *know the position* of the satellites?
  - the satellite position information is broadcast by the satellites themselves as a part of the navigation message transmitted by each satellite
- How does the aircraft *compute its distance* from the satellites?
  - messages sent by the satellites are time-tagged with the time of transmission;
  - by comparing the time the message is received and the time the message was sent, the aircraft can measure the time taken by the message to travel from the satellite to the aircraft;
  - knowing the speed at which messages travel (the speed of light), and the time taken, the aircraft can compute the distance travelled by the message (or "*range*"), as follows:
    - **speed = distance/time, hence > distance= speed x time**

Basic technical principles (3)

- Some complications:
  - the simplified geometrical explanation assumes that time reference used by the satellites and by the aircraft are the same
  - however, this is not the case – the satellites carry “precise” clocks (atomic clocks), whereas the aircraft typically carries a relatively imprecise (and less expensive) quartz clock
  - hence, the “range” computed by the aircraft based on the equation shown above is not the “true” range – it is a “*pseudorange*”
    - Example: a 1 µs (microsecond) synchronization error between clocks corresponds to a 300 m error in range measurement
  - Solution: the clock error is resolved by using a fourth additional satellite to provide additional information to estimate aircraft clock error and thus derive “true range” information
  - Instead of three equations in three unknowns (the three position coordinates of the aircraft), the aircraft receiver solves four equations in four unknowns (the three position coordinates and the clock error)

GNSS signal-in-space performance requirements (Annex 10, Vol.I)

Typical operation	Horizontal alert limit	Vertical alert limit
En-route (oceanic/continental low density)	7.4 km (4 NM)	N/A
En-route (continental)	3.7 km (2 NM)	N/A
En-route, Terminal	1.85 km (1 NM)	N/A
NPA	556 m (0.3 NM)	N/A
APV-I	40 m (130 ft)	50 m (164 ft)
APV- II	40.0 m (130 ft)	20.0 m (66 ft)
Category I precision approach	40.0 m (130 ft)	15.0 m to 10.0 m (50 ft to 33 ft)