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Joint ACAC/ICAO MID Workshop on GNSS

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ICAO Global Provisions and Regional Developments related to GNSS

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OUTLINE

- Back Ground
- Introduction
- GNSS developments in ICAO
- ICAO policy on GNSS
- GNSS performance requirements
- GNSS elements
- Future GNSS evolution
- MID Region Strategy
- Conclusion

Back Ground

- ***DRAFT CONCLUSION 1/5: GNSS SEMINAR***
-
- ***That, the ICAO MID Regional Office organizes, Seminar on GNSS covering the augmentation systems (ABAS, GBAS and SBAS) and Multi-constellations during 2015.***
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Introduction - ICAO

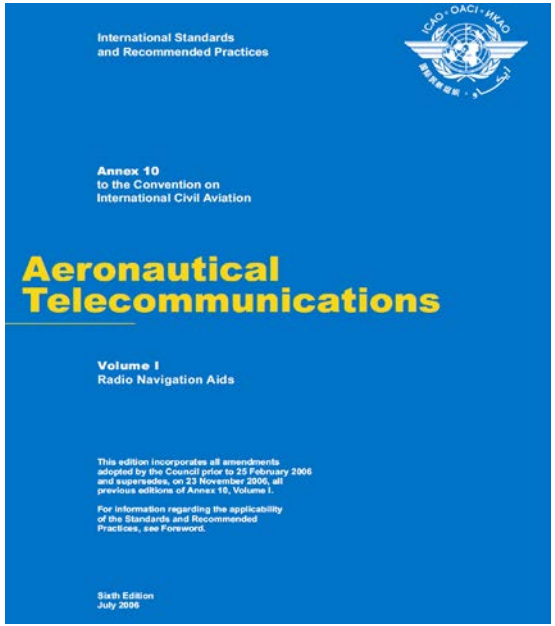
- Convention (Chicago, 1944) and Annexes
- UN Specialized Agency
- 191 member States
- Assembly (every 3 years)
- Council (36 States)
- Air Navigation Commission (19 members)
- Air Navigation Bureau
- Standards, Recommended Practices (SARPs)
- Headquarters: Montreal
- Regional offices: Bangkok, Cairo, Dakar, Lima, Mexico, Nairobi, Paris

Introduction - GNSS

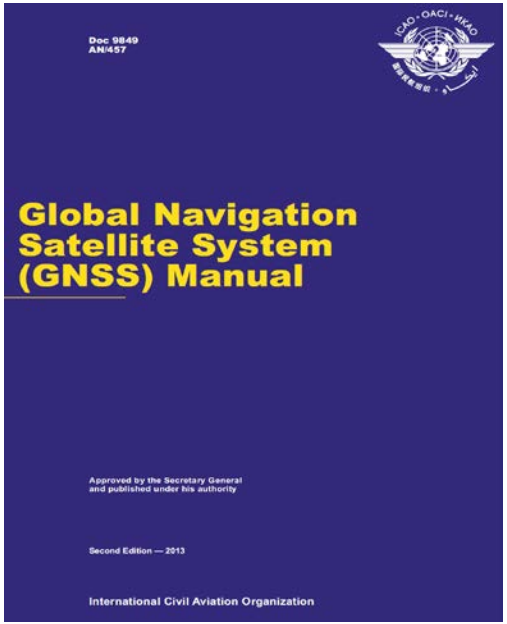
- The ICAO definition:
  - "**GNSS**. *A worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation."* [from ICAO 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

Global Provisions

Annex 10, Volume I



GNSS Manual



GNSS signal-in-space performance requirements (ICAO Annex 10, Volume I)

- 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 (ICAO Annex 10, vol.I)

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
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)	$1 - 2 \times 10^{-7}$ in any approach	10 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Category I precision approach (Note 7)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 6)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

NOTES.—
[…]

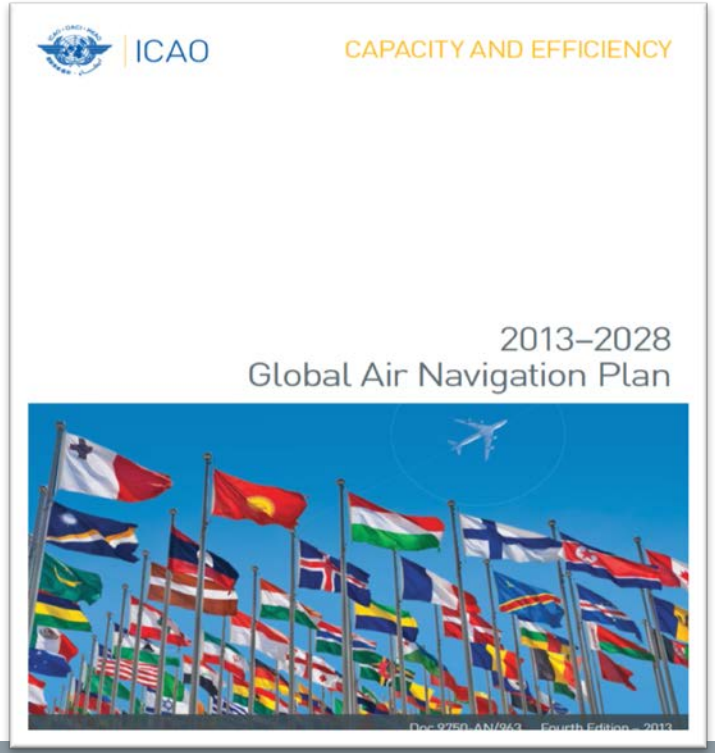
GNSS Manual

- The **ICAO *Charter on the Rights and Obligations of States Relating to GNSS Services*** highlights the principles that shall apply in the implementation and operation of GNSS, including: the primacy of safety; non-discriminatory access to GNSS services; State sovereignty; the obligation of provider States to ensure reliability of services; and cooperation and mutual assistance in global planning.

- The availability of multiple constellations broadcasting on multiple frequencies will make GNSS more robust and will allow service expansion with increased benefits after 2020 when systems and avionics are available.

- In the meantime, ANS providers can work with aircraft operators to expand GNSS-based services and benefits while planning next generation services.

GANP



When planning to implement GNSS-based operations, States are encouraged

- to refer to the **GANP** and relevant **ASBUs**,
- to comply with ICAO provisions; and
- to take advantage of the expertise and information available at the ICAO **planning and implementation regional groups (PIRGs).**

GNSS developments in ICAO

- **1991**: 10th Air Navigation Conference requests the initiation of an agreement between ICAO and GNSS-provider States concerning quality and duration of GNSS
- **1993**: ICAO GNSS Panel established 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 updates and enhancements
- **2003**: 11th Air Navigation Conference recommends a worldwide transition to GNSS-based air navigation and implementation of APV-I (SBAS)
- **2007**: 36th Assembly calls for implementation of PBN RNAV and RNP and for implementation of APV BaroVNAV and/or APV I (SBAS) for all instrument runways by 2016
- **2010**: 37th Assembly confirms and updates the commitment
- **2012**: 12th Air Navigation Conference addresses issues of use of multiple constellations and GNSS vulnerabilities

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*")

Current ICAO Directives on GNSS Implementation

12th Air Navigation Conference (2012) - Recommendations

- Recommendation 6/5 – ICAO work programme to support global navigation satellite system evolution
- Recommendation 6/6 – Use of multiple constellations
- Recommendation 6/7 – Assistance to States in mitigating global navigation satellite system vulnerabilities
- Recommendation 6/8 – Planning for mitigation of global navigation satellite system (GNSS) vulnerabilities
- Recommendation 6/9 – Ionosphere and space weather information for future global navigation satellite system implementation.

Current ICAO Directives on GNSS Implementation

ICAO Assembly Resolution A37/11

- Implementation of performance – based navigation (PBN) approaches with vertical guidance (APV) with
  - satellite-based augmentation system (SBAS) or
  - barometric vertical navigation (Baro-VNAV).

GNSS elements: ICAO GNSS Standards Menu

System	ICAO Standard?	Infrastructure in place today?	Aircraft provisions today?	In operational use by aviation today?
GPS L1	Yes	Yes	Yes	Yes, globally
GLONASS	Yes	Yes	Russia	Russia
SBAS L1	Yes	Regional support (WAAS, MSAS, EGNOS, GAGAN, SDCM…)	Yes	Yes, regionally
GBAS Cat I	Yes	Local support (individual airports)	Yes	Yes, locally
GBAS Cat II/III	2018	No	Advanced development	No
GPS L5	2018+	Partial (12 satellites)	Early development	No
Galileo	2018+	Partial (8 Full Operational Capability satellites +4)	Early development	No
Beidou	2018+	Partial (18 satellites)	Early development	No
SBAS L1/L5	2018+	No	Early development	No

GNSS elements today: GPS

- History
  - Programme approved in 1973 by the US DoD
  - First experimental satellite launched in 1978
  - Initial operational capability (IOC) and commitment to ICAO in 1994
  - Full operational capability (FOC) in 1995
  - Currently: satelllite replacement and modernization
  - Procurement history: Block I, II, IIA, IIR, IIR-M, IIF, IIIA..
  - Evolution (IF, IIIA): L5 signal in the DME band, L1C signal…
  - Currently managed by the US National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee

GNSS elements: GPS

- Nominal constellation: 24 satellites (currently 31 “healthy satellites” and 1 in on-orbit checkout as of 9 February 2016)
- Six orbital planes
- Near-circular, 20,200 km altitude (26,600 km radius) 12-hour orbits
- Managed by the US National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee
- Standard positioning service (SPS) frequency: 1 575.42 MHz

GNSS elements: GPS

- ICAO GPS Standards:
  - ICAO Annex 10, Volume I, section 3.7.3.1, applicable since 2001
- Purpose of ICAO standardization of GNSS systems:

  1) To enable global legal recognition of a system implemented by a single ICAO State
     - GPS example: it was implemented by the US and turned into an international civil aviation system by ICAO standardization

  2) To enable technical interoperability of systems implemented in different States (such as SBAS or GBAS):
     - GBAS example: we want all GBAS ground stations to behave in the same way to ensure that the aircraft receiver can deal with all of them regardless of the State it is flying to (same as ILS)

GNSS elements: GLONASS

- Nominal constellation: 24 satellites (current: 23 operational + 1 in commissioning + 3 undergoing checks, as of 9 February 2016)
- 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. Full operational capability subsequently restored.
- Operated by the Ministry of Defence of the Russian Federation
- Channel of standard accuracy (CSA) frequencies: 1602 MHz ± 0.5625*n* MHz (FDMA)
- Uses PZ-90 reference datum instead of WGS-84
- ICAO GLONASS Standards:
  - Annex 10, Volume I, section 3.7.3.2 (including conversion from PZ-90 to WGS-84)

GNSS elements: augmentation systems

- Three ICAO GNSS augmentation systems:
  - Aircraft-Based Augmentation System (ABAS)
  - Satellite-Based Augmentation System (SBAS)
  - Ground-Based Augmentation System (GBAS)
- Purpose: to overcome inherent limitations in the service provided by the core constellations and meet GNSS signal-in-space performance requirements

GNSS elements: ABAS

- **ABAS: aircraft-based augmentation system**
- The **foundation** of ICAO GNSS
- Purpose: to improve positioning quality by exploiting redundancy in satellite measurements and by augmenting GNSS information with on-board aircraft information
- Required to ensure that performance meets Annex 10 requirements (Volume I, Table 3.7.2.4-1, see above)
- Uses redundant satellite range measurements (and/or barometric and other position 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

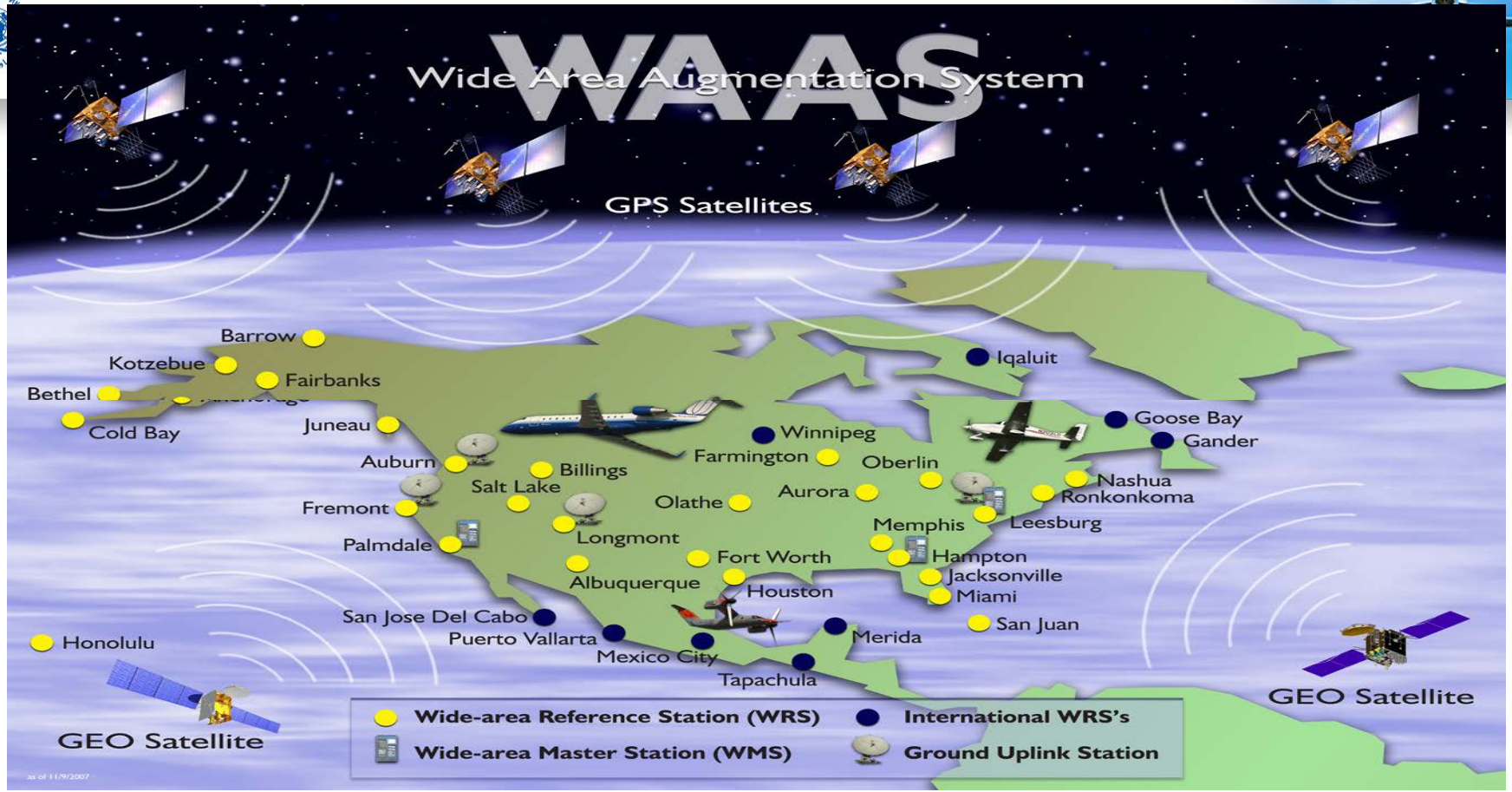
GNSS elements: SBAS

- **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 components:
  - 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)
- CAT I-like minima (“LPV200”) achieved with WAAS and EGNOS, developments underway for other SBAS
- ICAO Annex 10, Volume I, section 3.7.3.4

- Examples: WAAS, EGNOS, MSAS, GAGAN, SDCM

SBAS example: WAAS

- Wide Area Augmentation System (USA)
- Operational since 2003
- 38 reference stations
- 3 geostationary satellites
- International service agreements with Canada and Mexico
- Supports LPV200 approaches (CAT I - equivalent)
- Planned to transition to dual frequency operation (L1-L5)


WAAS
Wide Area Augmentation System
GPS Satellites
Barrow
Kotzebue
Fairbanks
Bethel
Cold Bay
Juneau
Auburn
Billings
Salt Lake
Fremont
Palmdale
Longmont
Albuquerque
San Jose Del Cabo
Puerto Vallarta
Honolulu
Mexico City
Tapachula
Winnipeg
Farmington
Olathe
Fort Worth
Houston
Merida
Iqaluit
Goose Bay
Gander
Oberlin
Aurora
Nashua
Ronkonkoma
Leesburg
Memphis
Hampton
Jacksonville
Miami
San Juan
GEO Satellite
GEO Satellite
Wide-area Reference Station (WRS)
International WRS's
Wide-area Master Station (WMS)
Ground Uplink Station

EGNOS expansion in MID region

- See EGNOS SAFETY OF LIFE SERVICE ROADMAP (January 2016)
- https://egnos-user-support.essp-sas.eu/new_egnos_ops/?q=content/service-implementation-roadmaps

SBAS aircraft provisions

- Certified avionics exist for a broad range of aircraft types (from GA to air transport)
- About 80,000 aircraft equipped in the US as of March 2015, the majority GA
  - (over 4000 SBAS approach procedures in US)
- Relatively few air transport category aircraft equipped but growing
- Certified avionics available for a wide range of aircraft types
- Airbus A350: most are equipped with SBAS/GBAS avionics

GNSS elements: GBAS

- GBAS: Ground Based Augmentation System (“LAAS: local area augmentation system” in the US)
- Operates in the VHF NAV band (108 [112] – 117.975 MHz)
- Supports precision approach service (currently up to CAT I, with CAT II/III SARPs due for adoption in 2018) and optionally positioning service
- Precision approach service provides “ILS-like” deviation guidance for final approach segments
- Can support multiple runways
- ICAO Annex 10, Volume I, section 3.7.3.5

GBAS current implementation status

- Cat I operations authorized or underway:
  - Australia: Sydney (current), Melbourne (planned)
  - Brazil: Rio de Janeiro (2016)
  - China: Shanghai trials
  - Germany: Bremen, Frankfurt (5 out of 6 runways)
  - Russia: procedures at 4 airports (installed at most major airports)
  - Spain: Malaga
  - US: Memphis, Newark, Houston
  - …
- Aircraft provisions:
  - Several Boeing and Airbus aircraft types equipped (optional/ standard)
  - Over 1500 air transport category aircraft equipped
- Cat II/III developments underway

GNSS evolution

- GPS evolution
  - GPS Block IIF satellites: add L5 safety-of-life signal in DME band
  - 12 satellites already transmitting “pre-operational” L5 signal (24 by 2024)
  - GPS III satellite acquisition program underway (L1C civil signal in addition to existing ones, backward compatible with current L1, with performance improvements)
- GLONASS
  - Achieved nominal configuration (24 satellites)
  - The new GLONASS-K satellites and the upgraded GLONASS-M satellites support the L3 CDMA safety-of-life signal in DME band (1202.025 MHz)
- Galileo
  - 8 Full Operational Capability satellites , 4 In-Orbit Verification satellites, Full 30 Satellites aimed 2020
- BeiDou
  - China’s GNSS system, 18 satellites in orbit, full deployment planned by 2020,

GNSS evolution: Multiconstellation/Dual frequency (MCDF)

- Technically promising
  - Performance improvements (increased availability, better protection against interference and ionosphere effects)
  - Potential operational benefits
- Open challenges
  - Regulatory issues: conflicting mandates/authorizations
  - Human factors issues: potential additional cockpit complexity due to different mandates/authorizations
  - Avionics development/certification/equipage

MID Region Strategy

- Based on ICAO GNSS implementation guidance
- Developed through the PIRG structure
- MID Region Air Navigation Strategy (MID Doc 002)
- MID Region PBN Implementation Plan (MID Doc 007)

MID ASBU Block 0 Modules Prioritization

Performance Improvement Areas (PIA)	Module	Priority	Module Name
PIA 1: Airport Operations	**APTA**	**1**	Optimization of Approach Procedures including vertical guidance
	WAKE	2	Increased Runway Throughput through Optimized Wake Turbulence Separation
	RSEQ	2	Improved Traffic Flow through Sequencing (AMAN/DMAN)
	SURF	**1**	Safety and Efficiency of Surface Operations (A-SMGCS Level 1-2)
	ACDM	**1**	Improved Airport Operations through Airport-CDM
PIA 2: Globally Interoperable Systems and Data - Through Globally Interoperable System Wide Information Management	**FICE**	**1**	Increased Interoperability, Efficiency and Capacity through Ground-Ground Integration
	DATM	**1**	Service Improvement through Digital Aeronautical Information Management
	AMET	**1**	Meteorological information supporting enhanced operational efficiency and safety
PIA 3: Optimum Capacity and Flexible Flights – Through Global Collaborative ATM	**FRTO**	**1**	Improved Operations through Enhanced En-Route Trajectories
	NOPS	**1**	Improved Flow Performance through Planning based on a Network-Wide view
	ASUR	2	Initial Capability for Ground Surveillance
	ASEP	2	Air Traffic Situational Awareness (ATSA)
	OPFL	2	Improved access to Optimum Flight Levels through Climb/Descent Procedures using ADS-B
	ACAS	**1**	ACAS Improvements
	SNET	2	Increased Effectiveness of Ground-based Safety Nets
PIA 4: Efficient Flight Path – Through Trajectory-based Operations	**CDO**	**1**	Improved Flexibility and Efficiency in Descent Profiles (CDO)
	TBO	2	Improved Safety and Efficiency through the initial application of Data Link En-Route
	CCO	**1**	Improved Flexibility and Efficiency Departure Profiles - Continuous Climb Operations (CCO)

Application of navigation specification by flight phase

Navigation Specification	FLIGHT PHASE								NAVAIDS/SENSORS				
	En-route oceanic/ remote	En-route continental	Arrival	Approach				DEP	GNSS	IRU	DME/ DME	DME/ DME/ IRU	VOR/ DME
				Initial	Intermediate	Final	Missed[1]						
RNAV 10	10	N/A		N/A				N/A	O	O	N/A		
RNAV 5[2]	N/A	5	5						O	O	O	N/A	O
RNAV 2		2	2					2	O	N/A	O	O	N/A
RNAV 1		1	1	1	1	N/A	1	1	O		O	O	
RNP 4	4	N/A		N/A				N/A	M				
RNP 2	2	2	N/A						M		SR	SR	
RNP 1[3]	N/A		1	1	1	N/A	1	1	M		SR	SR	
Advanced RNP (A-RNP)[4]	2	2 or 1	1	1	1	0.3	1	1	M		SR	SR	
RNP APCH[6]	N/A			1	1	0.3[7]	1	N/A	M		N/A		
RNP AR APCH				1-0.1	1-0.1	0.3-0.1	1-0.1		M				
RNP APCH APV				1	1	0.3	1		M				
RNP 0.3[8]	N/A		0.3	0.3	0.3	0.3	0.3	0.3	M				

Implementation targets of each PBN navigation specification in the MID Region

Airspace	Short term (2013-2018)		Medium term (2019-2025)	
	Navigation Specification Preferred	Targets	Navigation Specification Acceptable	Targets
En-route – Oceanic	RNAV 10	100 % by 2016	RNP 4*, RNP 2*, Defined airspace, (A-RNP)	TBD
En-route - Remote continental	RNAV 5 RNAV 10	W/A 100% by 2016	RNP 4*, RNP 2* Defined airspace (A-RNP)	TBD
En-route – Continental	RNAV 5 RNAV 1	100 % by 2017 W/A[1]	RNP 2* Defined airspace (A-RNP)	TBD
En-route - Local / Domestic	RNAV 5 RNAV 1	100 % by 2017 W/A	RNP 2* Defined airspace (A-RNP)	TBD
TMA – Arrival	RNAV 1 in surveillance environment RNP 1 in non-surveillance environment	50% by 2016 100% by 2018	RNP 1 and RNP 2 beyond 30 NM from ARP (A-RNP)	TBD
TMA – Departure	RNAV 1 in surveillance environment. RNP 1 in non- surveillance environment	50% by 2016 100% by 2018	RNP 1 and RNP 2 beyond 30 NM from ARP (A-RNP)	TBD
Approach	LNAV: for all RWY Ends at International Aerodromes LNAV/VNAV: for all RWY Ends at International Aerodromes	80 % by 2014. 100% by 2016 70% by 2016 and 100% by 2018	GLS (GBAS) For the defined RWY Ends	TBD
CCO and CDO	W/A	100% by 2018	W/A	TBD

– *W/A: where applicable/defined Airspace, in accordance with State PBN implementation Plans, the MID Region Air navigation Strategy and the MID ANP.*

– ** would be considered for implementation at the identified Airspace/TMAs, When no month is specified (e.g. by 2017) means by the end of the year (December 2017).*

Conclusion

- Implementation of GNSS and agreed target in the MID AN Strategy and the MID PBN plan
- States to share experience on GNSS implementation including sharing of training and implementation packages
- Identify operational requirements/Scope and improvements and plan for implementation
- Engage all Stake holders in all planning process
- Maximize the use of the available technologies before investing in any new technologies
- States and ICAO initiate GNSS Legal frame work project
- Assess the likelihood and effects of GNSS vulnerabilities in the MID Region airspace
- Augmentation systems issues
  - No easy solution
  - Early benefits through ABAS-supported (“Basic GNSS”) PBN RNP APCH procedures
  - SBAS/GBAS challenges

ICAO

THANK YOU