GNSS vulnerability in aviation domain

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International conference and exhibition

MELAHA 2014

Alexandria, Egypt, 1 – 3 Sept. 2014
1. Aviation uses of GNSS
2. Operational benefits
3. Four pillars of GNSS services
4. Chicago convention & GNSS
5. GNSS vulnerabilities
6. GNSS vulnerabilities mitigation
7. ICAO/ANC 12 and GNSS vulnerabilities mitigation
8. Finally
1. Aviation uses of GNSS:

Direct, obvious uses of GNSS:

- Aircraft Navigation:
  - Supports Area Navigation, User Preferred Route
  - Universal coverage worldwide - Terrestrial, Oceanic
  - Accuracy adequate for all ops except Precision Approach
  - Proven very high Availability, Continuity, Accuracy & Integrity
Aircraft Automatic Position Reporting:
- ADS-B – broadcast – used by other aircraft and ATC
- ADS-C – contract – used by ATC

Not so obvious uses of GNSS – Timing:
- Clocks – ATC & System monitoring of flight progress
- Multi-Radar/ADS-B Tracking
- Communication Bearers
- Multi-Lateration – Time difference of Arrival
Navigation with ground based
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2. Operational benefits:

- Safety
  - Under consideration of GNSS vulnerability

- Capacity
  - Traffic increase

- Efficiency
  - Better routes

- Environment
  - Noise complaints & emissions reeducation

- Access to Airspace
  - Increase airspace accessibility
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September 6, 2014
3. Four pillars of GNSS services:

- Accuracy
- Availability
- Continuity
- Integrity
Accuracy:

Aircraft navigation

..and where should we be going?

Where are we?

1. Reference state (from planning)
2. Current state
3. Guidance & control

Calculation:
Continuous, but with increasing error

“fixing”:
Periodic, with limited error
Availability:

Proportion of time the System is available to the time it had been planned for the system to be available
continuity:

The probability that a system will perform its required function without unscheduled interruption
integrity:

The level of trust that errors will be correctly detected
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Article 28 of Chicago convention

Air navigation facilities and standard systems:
Each contracting State undertakes, so far as it may find practicable, to:

a) Provide, in its territory, airports, radio services, meteorological services and other air navigation facilities to facilitate international air navigation, in accordance with the standards and practices recommended or established from time to time, pursuant to this Convention;
b) Adopt and put into operation the appropriate standard systems of communications procedure, codes, markings, signals, lighting and other operational practices and rules which may be recommended or established from time to time, pursuant to this Convention;
C) Collaborate in international measures to secure the publication of aeronautical maps and charts in accordance with standards which may be recommended or established from time to time, pursuant to this Convention.
Implications of Article 28 of the Chicago Convention: 
"A state may delegate the provision function to another entity, including a commercial or private operator..." The State "nevertheless remains responsible for setting and maintaining the standards of the services provided and for the quality of services provided..." "Under those circumstances [. . .] the relevant States continue to be responsible under Article 28 of the Chicago Convention, regardless of such delegation."

"The implementation of GNSS leaves unaffected the responsibility of States under Article 28, therefore a State using these signals for providing Air Navigation Services remained responsible under this Article despite the fact that it did not control such signals."

Different point of views:

**USA**

- No problem in legal framework or setting the law but the problems due to technical nature or a matter of the lack of resources and political will.

- Work on legal issues must not be permitted to delay technical implementation of CNS/ATM

AN-Conf/11-WP/160 presented by the United States
Different point of views:

**EUROCONTROL**

- most States will not be directly involved in the operation of GNSS systems... Air navigation within their sovereign airspace will consequently rely heavily on facilities beyond their direct control.

- States need to be satisfied.. that the GNSS signals and services offered within their airspace meet the appropriate performance requirements in terms of integrity, reliability, accuracy and continuity and that their liability is clearly defined.
Different point of views:

**African States**

- states who by themselves cannot provide the GNSS services but yet cannot be relieved of their responsibilities under the Chicago Convention.
- authorize the use of the system over which they have no control.
- committing both providers and users to accept certain international rights and responsibilities in a form of a binding and enforceable legal instrument which should clearly spell out the rights and responsibilities.
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5. GNSS vulnerabilities:

**History:**

**Late 2009:** Engineers noticed that satellite-positioning receivers for navigation aiding in airplane landings at Newark airport in US were suffering from brief daily breaks.

FAA after 2 months investigation track down the problem.

A cheap GPS jammer on truck passed by on nearby highway.

*The Economist, 2011*
5. GNSS vulnerabilities: 
Introduction:

GNSS is being introduced throughout the world:
– Potential to meet performance requirements for all phases of flight
– Improvement of safety and efficiency of air navigation

It is essential that the service providers
– identify the vulnerabilities of this system; and
– develop the necessary mitigations
5. GNSS vulnerabilities:
General:

- **Source of interference**: low signal power received from GNSS core satellite constellations and satellite-based augmentation system (SBAS).

- GBAS service depends on the core satellite signals while the very high frequency (VHF) data broadcast of a ground-based augmentation system (GBAS) is more difficult to interfere (its signal power is similar to that of terrestrial navigation aids).
• GNSS receiver must meet level of interference specified in ICAO annex 10 and within recommendation of ITU.
• such interference shall not result in hazardously misleading information (HMI).
• Current GNSS approvals use a single frequency band common to GPS, GLONASS, and SBAS (increase likelihood of unintentional & intentional interference).
• next generation GNSS will depend on multiple frequencies.
- GNSS provides precise time information to support the following applications but in non-critical manner:
  - ADS-B and ADS-C,
  - 4D navigation and trajectory synchronization,
  - required time of arrival,
  - multi-radar tracking systems,
  - air-ground data link,
  - flight data processing and ground communication network.
- Multilateration and wide area multilateration only applications are critical dependence on GNSS time.
Unintentional interference:

- GPS, GLONASS and SBAS GEOs filing with ITU to use a spectrum allocated for RNSS 1 559 – 1 610 MHz and 1 164 – 1 215 MHz bands, these bands are shared with ARNS (aeronautical radio navigation services).

- The GBAS VDB, as well as VDL-4, which are aeronautical mobile (R)1 services (AMRS), use the 108.025 – 117.975 MHz band, shared with ILS and VOR (ARNS).

- 1 164 – 1 215 MHz bands intended for future civil aviation applications.

- Galileo and BeiDou also have ITU filings in place.
Sources of potential interference to GNSS are:
- mobile and fixed VHF communications,
- harmonics of television stations,
- certain radars,
- mobile satellite communications and military systems.

The use of the 1 559 – 1 610 MHz band by point-to-point microwave links, which is allowed by a number of States. The use of these links is due to be phased out no later than 2015.
\textbf{1 164 – 1 215} MHz bands intended for future civil aviation applications are used also by DME/TACAN (distance measuring equipment/tactical air navigation system) which cause interference however the interference is tolerable but increase when DME/TACAN facilities are close to new GNSS band especially at higher altitude.
intentional interference and spoofing:

- GNSS used in many applications: financial, security and tracking, transportation, agriculture, communications, weather prediction, scientific research, etc........
- Threat analysis must consider jamming directed at non-aviation users could affect on aircraft operations.
- Likelihood of Interference will be highest near major population centres (with considering of type of airspace and traffic levels and availability of independent surveillance and communication services).
Spoofing: is the broadcast of GNSS-like signals that cause avionics to calculate erroneous positions and provide false guidance.
Spoofing of the GBAS data broadcast is at least as difficult as spoofing conventional landing aids. An authentication scheme has been developed that will make spoofing of GBAS virtually impossible.

States must evaluate and address the risk of intentional interference in their airspace. If States determine that the risk is unacceptable in specific areas, they can adopt an effective mitigation strategy.
States should prohibit all actions that lead to disruption of GNSS signals.

States should develop and enforce a strong regulatory framework governing the use of intentional in-band radiators including:
- GNSS repeaters,
- pseudolites,
- Spoofers & jammers

Also in-band radiators including certain television broadcast channels and other industrial applications.
ICAO Electronic Bulletin EB 2011/56 *Interference to Global Navigation Satellite System (GNSS) Signals* provides more information and a list of documents that States can use for guidance in developing regulations.
- states should establish regulations that forbid the use of jamming and spoofing devices and regulate their importation, exportation, manufacture, sale, purchase, ownership and use.
- Some States prohibit all actions that lead to disruption of GNSS signals and prescribe severe penalties for the purchase or use of jammers.
- States should develop the means to detect interference sources in support of enforcement programmes.
- States should take more preventive measures to reduce the likelihood of GNSS disruption to aviation by non-aviation users.
- ICAO DOC. 7300 & ITU Regulations protect GNSS frequencies for aviation use especially for electromagnetic spectrum of new application like mobile phones and broadband data service which emit signals stronger than GNSS signals.

- Future multi-constellation and multi-frequency GNSS equipment for aviation will be designed to maximize interference robustness as much as reasonably possible, it is important that new spectrum services do not neutralize these improvements.
Effect of ionosphere and solar activities:

- The ionosphere is a region of the upper atmosphere that is partially ionized. GNSS signals are delayed by varying amounts of time depending on the density of ionized particles (also depend on intensity of solar radiation and other solar energy bursts).

- Rapid and large ionospheric delay should addressed by system design.

- Solar storms can cause severe ionospheric scintillation that can cause temporary loss of one or more satellite signals.

- Ionospheric phenomena have negligible impact on en-route through NPA operations.
The type and severity of ionospheric effects vary with the level of solar activity.

Severe scintillation can disrupt satellite signals, but it occurs in patches not in wide area but multi-frequency receiver will not provide more protection but multi constellation GNSS will allow receiver to track another satellites, reducing the likelihood of service disruption.

Ionospheric scintillation is insignificant at mid-latitudes. In equatorial regions, and to a lesser extent at high latitudes, scintillation may result in the temporary loss of one or more satellite signals.
Scintillation can interrupt reception of broadcasts from a SBAS geostationary orbit (GEO) satellite.

Tropospheric effects are addressed by system design and do not represent a vulnerability issue.
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6. GNSS vulnerabilities mitigation:

- Installation and operation
  - On-aircraft interference: can be prevented by proper installation of GNSS equipment, its integration with other aircraft systems (e.g. antenna separation, out-of-band filtering) and restrictions on the use of portable electronic devices on board aircraft.
  - Spectrum management: creation of regulations/laws that control the use of spectrum; enforcement of those regulations/laws; and vigilance in evaluating new RF sources (new systems) to ensure that they do not interfere with GNSS.
- **New signals and constellations**
  - Stronger signals, diverse frequencies, additional satellites/constellations, future GEO satellites using satellites which lines of sight are separated by at least 45°

- **Inertial navigation systems (INS) and receiver technologies**:
  - Use of INS RNAV capability after the loss of GNSS or other position updating
  - Use of technologies that add robustness to GNSS receivers to mitigate interference: Anti-jam technologies include advanced antennas and receiver signal processing techniques
Procedural methods:
- Aircraft can revert visual navigation, ATC, air-to-air communications within non-ATC or non-radar airspace

Terrestrial radio navigation aids:
- RNAV DME supporting infrastructure (en route, TMA and approach within area coverage), or ILS/MLS infrastructure for precision approach.
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Recommendation 6/7—Assistance to States in mitigating GNSS vulnerabilities:

ICAO:

a) continue technical evaluation of known threats to the global navigation satellite system, including space weather issues, and make the information available to States;
b) compile and publish more detailed guidance for States to use in the assessment of GNSS vulnerabilities;
c) develop a formal mechanism with the ITU and other appropriate UN bodies to address specific cases of harmful interference to the GNSS reported by States to ICAO; and
d) assess the need for, and feasibility of, an alternative position, navigation and timing system.
Recommendation 6/8–Planning for mitigation of GNSS vulnerabilities:

- States:
  a) assess the likelihood and effects of global navigation satellite system vulnerabilities in their airspace and apply, as necessary, recognized and available mitigation methods;
  b) provide effective spectrum management and protection of GNSS frequencies to reduce the likelihood of unintentional interference or degradation of GNSS performance;
c) report to ICAO cases of harmful interference to GNSS that may have an impact on international civil aviation operations; 
d) develop and enforce a strong regulatory framework governing the use of GNSS repeaters, pseudolites, spoofers and jammers; 
e) allow for realization of the full advantages of on-board mitigation techniques, particularly inertial navigation systems; and
f) where it is determined that terrestrial aids are needed as part of a mitigation strategy, give priority to retention of distance measuring equipment (DME) in support of inertial navigation system (INS)/DME or DME/DME area navigation, and of instrument landing system (ILS) at selected runways.
Recommendation 6/9–Ionosphere and space weather information for future GNSS implementation:

- ICAO:
  a) coordinate regional and global activities on ionosphere characterization for global navigation satellite system implementation;
  b) continue its effort to address the GNSS vulnerability to space weather to assist States in GNSS implementation taking into account of long-term GNSS evolution as well as projected space weather phenomena.
Finally:

- International traffic extremely grow to reach a new lands over the world (tomorrow will be a very congested airspace & space).
- Conventional or terrestrial Nav. Aids became not enough to meet aviation requirements with reasonable cost (especially third countries).
- GNSS is must.
Know GNSS vulnerabilities mitigation no pain
No GNSS vulnerabilities mitigation know pain