Perspectives of Basic GNSS in Aircraft Operation in Slovak Republic

Ing. Ivan Ferencz, Letecký úrad Slovenskej republiky, ferencz@caa.sk
Ing. František Jún, CSc., Žilinska univerzita, jun@fpedas.utc.sk

Abstract: Aircraft Navigation in the beginning of 21st Century is in the process of transition from conventional navigation to area navigation. While conventional navigation is characterised with relatively stabilised air routes network with ground-based navigation facilities at intersections, area navigation facilitate much more effective air routes design and even flights outside of defined routes. One of the most significant enablers of area navigation are Global Navigation Satellite Systems, especially NAVSTAR GPS. Contradictory to earlier expectations, experiences show, that transition process is (and will be) not so smooth and easy. GNSS systems enable much precise navigation compare to ground based radio navigation systems VOR and NDB. It is shown than the navigation accuracy is not the only factor. A degree of guarantee, that information presented to the pilot is correct determinates application of GNSS systems in aviation.

Key words: GNSS, GPS, B-RNAV, P-RNAV, Navigation Accuracy, Navigation Integrity, Receiver Autonomous Integrity Monitor, GALILEO, Aircraft Instrument Procedure, Required Navigation Performance.

1. Conventional and Area navigation

The term “Conventional navigation” is used to underline basic difference between two styles of aircraft navigation.

1.1. Conventional navigation

Basic principle of conventional navigation is provision of track guidance to or from the navigation facility. For example, VHF Omnidirectional Range (VOR) is constructed and adjusted so that similar instrumental indications in aircraft represent equal clockwise angular deviations (bearings), from magnetic North as measured from the location of the VOR. Aircraft can fly only “to” the VOR or “from” the VOR along specified track, called a Radial.

1.2. Area navigation

Contradictory to conventional navigation, area navigation means provision of track guidance regardless of location of air navigation ground station. This type of navigation can be supported by the same systems as are used for conventional navigation. But the most valuable
navigation sources are UHF Distance measurement Equipments (DME) a Global Navigation Satellite Systems (GNSS).

2. Navigation Accuracy

Instrument procedure is series of prescribed manoeuvres and it is expected, that aircraft deviations from the nominal procedure track will be kept within defined boundaries, called protection areas. Amplitude of deviation from nominal track depends on availability of navigation infrastructure, performance of onboard equipment and capability of aircraft keep calculated flight path. Related error budget comprise position fixing error and flight technical error.

2.1. Position fixing error (PFE) and tolerance (PFT)

Position fixing error is horizontal distance between calculated position on board of the aircraft and its actual position. Quantity of this error depends of inherent space system accuracy, airborne receiver accuracy and system computational tolerance. A value corresponding to $2\sigma$ of PFE distribution is a Position Fixing Tolerance (PFT).

2.2. Flight technical error (FTE) and tolerance (FTT)

Flight technical error is lateral distance between calculated flight path on board of the aircraft and its actual position and it is a product of ability of the pilot or the avionics to fly the aeroplane along a selected path. A value corresponding to $2\sigma$ of FTE distribution is a Flight Technical Tolerance (FTT).

3. Integrity

Integrity is a measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts).

Ground based air navigation systems as VOR, DME, NDB or ILS have implemented means to put system out of its operational use in case if there is not guaranteed, that signal is of required quality. System functions are permanently monitored and unhealthy system is automatically switched off in specified time. Consequently, onboard system identifies loss of signal from ground component and indicates appropriate alarm to pilot. These automatic actions are complemented by standardised aeronautical information procedures and all pilots concerned receive information that the system is not in operational use.

This mechanism is not enforced for basic GNSS. Current NAVSTAR GPS or GLONASS don’t have implemented any barricade to protect user from using signal of unacceptable quality. This feature is integrated into WAAS or EGNOS systems and it will be available in GALILEO Safety of Life service - but it is not a case of basic GNSS.

To overcome this disadvantage, entire integrity machinery has to be carried on board. To make integrity available, Aircraft-based Augmentation Systems as an Aircraft-based Autonomous Integrity Monitor (AAIM) and Receiver Autonomous Integrity Monitor (RAIM) have been developed. Monitoring of integrity is required function of airborne GNSS receivers. Integrity Monitor Alarm Limit (IMAL) is not of fixed value, but it depends on operation mode of GNSS receiver.
<table>
<thead>
<tr>
<th>Operation</th>
<th>95% Accuracy</th>
<th>95% Accuracy</th>
<th>95% Accuracy</th>
<th>RAIM alarm limit</th>
<th>Time to Alert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enroute</td>
<td>33m</td>
<td>230m</td>
<td>230m</td>
<td>3.7 km (2.0 NM)</td>
<td>30s</td>
</tr>
<tr>
<td>Terminal</td>
<td>33m</td>
<td>230m</td>
<td>230m</td>
<td>1.9 km (1.0 NM)</td>
<td>10s</td>
</tr>
<tr>
<td>Approach</td>
<td>33m</td>
<td>104m</td>
<td>230m</td>
<td>0.6 km (0.3 NM)</td>
<td>10s</td>
</tr>
</tbody>
</table>

Table 1 GPS horizontal accuracy as defined in different aviation standards

4. Basic GNSS Containment

Because pilot of the aircraft will not receive any warning before reaching IMAL, it is assumed, that aircraft position may not be assessed with better accuracy as actual IMAL. Additionally, FTT and Time to Alarm (TTA) have to be accommodated into GNSS containment calculation. As a consequence, real (or anticipated) performance of GNSS system depicted in term of PFE is not so critical for instrument procedure design as IMAL and TTA. This philosophy as transposed into ICAO PANS-OPS [3] is illustrated at Table 2. (ATT means Along Track Tolerance and XTT Cross Track Tolerance). An example of application Terminal and Approach criteria of Basic GNSS procedure design is at picture 1.

<table>
<thead>
<tr>
<th>ENROUTE TERMINAL FINAL</th>
<th>FAF</th>
<th>MAPt</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMA L</td>
<td>3.70/2.00</td>
<td>1.85/1.00</td>
</tr>
<tr>
<td>TTA</td>
<td>30 sec</td>
<td>10 sec</td>
</tr>
<tr>
<td>FTT</td>
<td>3.70/2.00</td>
<td>0.93/0.50</td>
</tr>
<tr>
<td>ATT</td>
<td>3.70/2.00</td>
<td>1.85/1.00</td>
</tr>
<tr>
<td>XTT</td>
<td>7.41/4.00</td>
<td>2.78/1.50</td>
</tr>
<tr>
<td>Area</td>
<td>14.82/8.00</td>
<td>9.26/5.00</td>
</tr>
</tbody>
</table>

Table 2 Different tolerances used in instrument procedure design
A size of basic GNSS Containment is comparable with protection area of conventional radio-navigation aids, as is illustrated at Picture 2, where as an example is VOR placed at extended Runway centreline.

5. Aircraft operation aspects

Carrying of Basic GNSS receiver on board of the aircraft is not required. On the other hand, overall Europe is mandatory carriage of Basic Area Navigation Equipment (B-RNAV) since 1998 above certain Flight Level. Because this requirement is often fulfilled with TSO-C129a certified GNSS receiver, significant number of aircraft are Basic GNSS capable even assuming, that some portion of onboard installations are certified for the enroute navigation only.
Implementation of precision area navigation (P-RNAV), as an interim step into full area navigation concept done between 2004-2006 accept use of B-RNAV equipment to fly RNAV standard instrument arrival and departure routes above minimum safe altitude. In process of P-RNAV implementation using modern Safety Case methodology have been highlighted more weak points of present GNSS avionics – for example insufficient requirements for onboard database and inconsistent flight path data processing.

6. Regulatory aspects
While a basis for P-RNAV operation is JAA TGL 10 [4], no common procedure to obtain operational approval for RNAV approaches is available. That leads to situation, in which some States develop and publish into national Aeronautical Information Publication particular requirements for aircraft aspiring to conduct RNAV Approach operation. As a consequence, the same aircraft may perform Basic GNSS approach in one State, but can’t do the same in the other.

Communication, Navigation and Surveillance (CNS) is a service, which is subject of certification in accordance with Single European Sky legislation. As it is envisaged in Regulation (EC) No 550/2004 of the European Parliament and of the Council of 10 March 2004 on the provision of air navigation services in the single European Sky [5], NAVSTAR GPS as well as GLONASS services are not provided by certified CNS provider. In case of aircraft accident or incident caused by GNSS failure, nobody but aircrew will hold final responsibility for such unhappy event. Potentially, this situation might be changed in the future after GALILEO will be fully deployed. A GALILEO Concession Holder will operate the System and any aviation application will be enabled only after complete certification process performed by appropriate National Supervisory Authority.

7. Basic GNSS today
The most essential requirement for use Basic GNSS receiver in aircraft operation under Instrument Flight Rules (IFR) is TSO-C129a certification of receiver [2] and its proper integration into aircraft.

Such installation has good chance to obtain B-RNAV approval [6] and can be used in European B-RNAV operation, i.e. above specified flight level (by State) and for some RNAV standard instrument arrivals or departutures – above Minimum Sector/Radar Altitude.

When more stringent P-RNAV approval [4] is obtained, Basic GNSS make all RNAV Standard Instrument Arrivals and Departures overall Europe available.

Both B-RNAV as well as P-RNAV requires “reversionary capability” i.e. conventional avionics such VOR, ADF and DME have to be present on board.

While for B-RNAV application is degree of harmonisation between States high, P-RNAV initiative was not fully adopted. And practically zero level of harmonisation exists for Basic GNSS Approach operation. In some States is such operation fully widely accepted (USA), other States have in force special requirements for avionics, installation, aircrew training, database quality etc. (Germany) or in addition conventional Missed Approach has to be designed (France). Many States did not authorise any GNSS operation.

Very common and well-accepted applications of Basic GNSS are “Overlays” of conventional procedures, where conventional approach procedure is complemented with WGS-84 Waypoints Data. This enable to fly instrument procedure with GNSS avionics, but crosscheck with conventional instrument indication is mandatory.
For completeness, there are other – more sophisticated - GNSS applications, as are APV I, APV-II, LNAV/VNAV, Baro-VNAV…. These are not subject of this article.

8. Conclusion

B-RNAV above flight level 125 is mandated in Slovakia since 1998 and this was the first and last GNSS application. That time, a rapid GNSS implementation was expected and short-term plans of conventional navigation infrastructure decommission have been developed. Lesson learned from B-RNAV and experiences with not very successful P-RNAV project indicate, that conventional navigation based on VOR and NDB ground stations will probably not be substituted with Basic GNSS. Prospective of Basic GNSS avionics in Slovakia is in P-RNAV implementation and in overlays of existing conventional procedures. Relevant standard for operational approval of Basic GNSS approach operation (working draft JAA TGL xx) is waiting for approval, as current JAA TGL 3 [7] is considered as insufficient.

Because SBAS service EGNOS is available Europe-wide and it will be soon approved for civil aviation, it looks more realistic, that approach procedures based on conventional VOR’s and NDB’s will be replaced directly with RNP procedures (with GALILEO plus GPS or GLONASS receivers on board) in horizon of next 10 years. And potential of current GPS Standard Position Service will never be fully exploited in aviation.

Literature

[4] JAA TGL 10, Airworthiness and Operational Approval for Precision RNAV Operation in Designated European Airspace