GNSS for an aviation

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ABSTRACT: In Polish aviation on-board GPS units are used for enroute procedures mainly. The use of GNSS for approach and landing procedures requires overcoming a lot of obstructions, including both organizational and technical ones. The paper presents information connecting with GNSS implementation in aviation.

1 OVERVIEW OF GNSS-BASED OPERATIONS

The Global Air Navigation Plan for CNS/ATM Systems (Doc 9750) recognizes the Global Navigation Satellite System (GNSS) as a key element of Communication, Navigation, Surveillance and Air Traffic Management (CNS/ATM) systems and a foundation upon which States can deliver improved aeronautical navigation services. Standards and Recommended Practices (SARPs) for the Global Navigation Satellite System (GNSS) were developed by the Global Navigation Satellite System Panel and introduced in ICAO Annex 10, Volume I in 2001 as a part of Amendment 76 to Annex 10. Guidance material in Attachment D to Volume I provides extensive guidance on technical aspects and application of GNSS SARPs that provided, at the publication date, for satellite-based en-route through Category I precision approach operations.

GNSS service can be introduced in stages as the technology and operational procedures develop. The staged implementation of GNSS service may be affected by various factors, including:

- the existing navigation services;
- availability of GNSS procedures design criteria;
- level of air traffic services supporting GNSS operations;
- aerodrome infrastructure;
- extent of aircraft equipage;
- completeness of relevant regulations.

Depending upon these factors, States may adopt different implementation strategies and derive different benefits from the various stages of implementation.

The introduction of augmentation systems enhances service and eliminates most limitations. Based on traffic volume and airspace structure, States can choose their level of involvement in the development and implementation of ABAS, SBAS and/or GBAS. These implementation efforts require a high level of cooperation among States to deliver maximum operational advantages to aircraft operators.

1.1 *Operations using Aircraft-Based Augmentation System* (ABAS)

In the early 1990s, many aircraft operators were quick to adopt GNSS because of the availability of relatively inexpensive GPS receivers. Operators used these early receivers as an aid to VFR and IFR navigation. They quickly saw the benefits of having a global area navigation (RNAV) capability, and demanded avionics that could be used for IFR navigation. The core satellite constellations were not developed to satisfy the strict requirements of IFR navigation. For that reason, GNSS avionics used in IFR operations should augment the GNSS signal to ensure, among other things, its integrity. The aircraft-based augmentation system (ABAS) augments and/or integrates GNSS information with information available onboard the aircraft to enhance the performance of the core satellite systems.

The most common ABAS technique is called receiver autonomous integrity monitoring (RAIM). RAIM requires redundant satellite range measurements to detect faulty signals and alert the pilot. The requirement for redundant signals means that navigation guidance with integrity provided by RAIM may not be available 100 per cent of the time. RAIM availability depends on the type of operation; it is lower for non-precision approach than for terminal, and lower for terminal than for en-route. It is for this reason that GPS/RAIM approvals usually have operational restrictions. Another ABAS technique involves integration of GNSS with other airborne sensors such as inertial navigation systems. Many States have taken advantage of GPS/ABAS to improve service without any expenditure on infrastructure. The exploitation of GPS/ABAS is a worthwhile first stage in a phased transition to GNSS guidance for all phases of flight. Initial approvals covered en-route, terminal and non-precision approach operations.

Many service providers have designed new GPS stand-alone approaches that offer significant benefits because they can be designed to provide the most effective flight path to the runway, do not require a course reversal and provide the pilot with precise position information throughout the procedure. Most GPS stand-alone approaches provide straight-in guidance, so they are considerably safer than circling approaches. In some States, pilots are authorized to fly suitable VOR, VOR/DME, NDB and NDB/DME non-precision approach procedures using GPS guidance. These are termed "GPS overlay" approaches and allow operators to benefit from better accuracy and situational awareness without the need for the service provider to design a new approach.

This is seen as an interim step to bring early benefits to users. Using GPS guidance, pilots follow the path defined by the traditional NAVAIDs, and comply with the visibility and minimum descent altitude associated with the traditional approach. Some VOR and NDB-based procedures are not suited to the overlay programme because certain approach legs cannot be adapted to the RNAV data coding system. GPS overlay approaches are not ideal from the pilot's perspective, because the original procedure was not intended to be flown using an RNAV system. An overlay approach should be removed from State Aeronautical Information Publication (AIP) when a GPS stand-alone approach is designed for the same runway to avoid the potential for confusion between two approaches to the same runway. Certain operational restrictions were deemed necessary for the implementation of GPS-based NPA procedures. The reasons for and nature of these restrictions varied by State including: the effects of GPS outages in large regions; the availability of traditional NAVAIDs as a backup; traffic density; and regulations for avionics redundancy.

A common operational restriction is that the pilot shall not take credit for GPS approaches at an alternate aerodrome when determining alternate weather minima requirements. Some States have also approved the use of GPS as the only navigation service in oceanic and remote areas. In this case avionics should not only have the ability to detect a faulty satellite (RAIM), but should also exclude that satellite and continue to provide guidance. This feature is called fault detection and exclusion (FDE). Under such approval, aircraft carry dual systems and operators perform pre-flight predictions to ensure that there will be enough satellites in view to support the planned flight. This provides operators with a cost-effective alternative to inertial navigation systems in oceanic and remote airspace. Some aircraft with existing inertial navigation systems have used another ABAS technique which involves integration of GNSS with the inertial data. The combination of GNSS FD, or FDE, along with the short term accuracy of modern inertial navigation systems provides enhanced availability of GNSS integrity for all phases of flight. As long as pilots rely on map reading and visual contact with the ground, this use of GPS can increase efficiency and safety.

1.2 *Operations using Satellite-based Augmentation System (SBAS)*

An SBAS augments core satellite systems by providing ranging, integrity and correction information via geostationary satellites. The system comprises:

– a network of ground reference stations that monitor satellite signals;
– master stations that collect and process reference station data and generate SBAS messages;
– uplink stations that send the messages to geostationary satellites; and transponders on these satellites that broadcast the SBAS messages.

By providing differential corrections, extra ranging signals via geostationary satellites and integrity information for each navigation satellite, SBAS delivers much higher availability of service than the core satellite constellations with ABAS alone. SBAS, in certain configurations can support approaches with vertical guidance (APV). There are two levels of APV: APV I and APV II. Both use the same lateral obstacle surfaces as localizer, however APV II may have lower minima due to better vertical performance. There will be only one APV approach to a runway end, based on the level of service that SBAS can support at an aerodrome. The two APV approach types are identical from the perspective of avionics and pilot procedures. In many cases, SBAS will support lower minima than that associated with non-precision approaches, resulting in higher airport usability. Almost all SBAS approaches will feature vertical guidance, resulting in a significant increase in safety. APV minima (down to 75 m (250 ft) DH approximately) will be higher than Category I minima, but APV approaches would not require the same ground infrastructure, so this increase in safety will be affordable at most airports. SBAS availability levels will allow operators to take advantage of SBAS instrument approach minima when designating an alternate airport. An SBAS approach does not require any SBAS infrastructure at an airport. SBAS can support all en-route and terminal RNAV operations. Significantly, SBAS offers the promise of affordable RNAV capability for a wide cross section of users. This will allow States to reorganize airspace for maximum efficiency and capacity, allowing aircraft to follow the most efficient flight path between airports. High availability of service will permit States to decommission traditional NAVAIDs, resulting in lower costs.

There are four SBASs being developed: the European Geostationary Navigation Overlay Service (EGNOS); the Indian GPS and GEO Augmented Navigation (GAGAN) System; the Japanese Multi-functional Transport Satellite (MTSAT) Satellite-Based Augmentation System (MSAS); and the United States Wide Area Augmentation System (WAAS). Geostationary satellite footprints define the coverage area of an SBAS. Within this coverage area, States may establish service areas where SBAS supports approved operations. Other States can take advantage of the signals available in the coverage area in two ways: by fielding SBAS components integrated with an existing SBAS or, by authorizing the use of SBAS signals. The first option offers some degree of control and improved performance. The second option lacks any degree of control, and the degree of improved performance depends on the proximity to the service area of the host SBAS.

In either case, the State, which established an SBAS service area, should assume responsibility for the SBAS signals within that service area. This requires the provision of NOTAM information, as described in Section. If ABAS-only operations are approved within the coverage area of SBAS, SBAS avionics will also support ABAS operations and in fact better meet availability-of-service requirements. Although the architectures of the various SBASs are different, they broadcast the standard message format on the same frequency (GPS L1) and so are interoperable from the user perspective. It is anticipated that these SBAS networks will expand beyond their initial service areas. Other SBAS networks may also be developed. When SBAS coverage areas overlap, it is possible for an SBAS operator to monitor and send integrity and correction messages for geostationary satellites of another SBAS, thus improving availability by adding ranging sources. This system enhancement should be accomplished by all SBAS operators.

1.3 *Operations using Ground-Based Augmentation System (GBAS)*

GBAS ground sub-systems are intended to provide a precision approach service and optionally may provide a GBAS positioning service. The precision approach service is intended to provide deviation guidance for final approach segments, while the GBAS positioning service provides horizontal position information to support 2D RNAV operations in terminal areas. A ground station at the airport broadcasts locally relevant corrections, integrity parameters and approach data to aircraft in the terminal area in the 108 MHz - 117 MHz band.

A GBAS installation will typically provide corrections that support approaches to multiple runways at a single airport. In some cases, the data may be used for nearby airports and heliports as well.

GBAS infrastructure includes electronic equipment, which can be installed in any suitable airport building, and antennas to broadcast data broadcast and to receive the satellite signals. Antenna location is independent of the runway configuration, but requires the careful evaluation of local sources of interference, signal blockage, and multipath. Sitting of the VHF data broadcast antenna should ensure that the coverage area is sufficient for the intended operations. The complexity and redundancy of GBAS ground station installation depends on the service provided. The cost and flexibility of GBAS will result in more runway-ends having qualified electronic precision approach guidance, resulting in significant safety and efficiency benefits. Such runways, however, should meet standards for physical characteristics and infrastructure.

2 GNSS IMPLEMENTATION FOR POLISH AVIATION

The implementation of GNSS operations requires that Polish aviation authority consider a number of elements including the following:

- planning and organization;
- procedure development;
- air traffic management (airspace and ATC considerations);
- aeronautical information services;
- system safety analysis;
- certification and operational approvals;
- anomaly/interference reporting;
- transition planning.

Considering the complexity and diversity of the global airspace system, planning can best be achieved if organized regionally and/or in wide areas of common requirements and interest, taking into account traffic density and level(s) of service required. Planning and implementation is a State's responsibility within FIRs where it provides air traffic services, unless States have agreed to jointly plan services in an area covering more than one State. Owing to the global nature of GNSS signals, it is important to coordinate the planning and implementation of GNSS services to the greatest extent possible.

While this objective is normally pursued through ICAO and its regional bodies, it should be supplemented by bilateral and multilateral coordination where necessary. The latter coordination should address detailed aspects not covered within the ICAO framework. Experience has shown that the decision to implement GNSS within States should be made at the highest level and coordinated regionally within the ICAO Regional Implementation Planning Groups. Successful implementation programmes usually involve cooperative efforts that include all departments and/or individuals who are affected by the possible outcomes, who will have the authority for committing resources to ensure completion of the programme.

There is a need for users, including air carriers, general aviation, and the military, to be included in the GNSS implementation team to allow them to communicate their specific requirements. Users will then be able to assist State authorities to develop an effective and efficient GNSS implementation strategy. A technical committee could be formed and given the responsibility for defining requirements and executing the implementation plan. Team composition may vary by State, but the core group responsible for the GNSS programme should include members with operational expertise in aviation, and could include:

- Operations (persons responsible for operational approvals, pilot training, and flight procedures);
- Airworthiness standards (persons responsible for approving avionics and installations);
- Aviation standards (persons responsible for developing instrument approach procedures and developing obstacle clearance criteria, etc);
- Aeronautical information service (persons who are involved in NOTAM, procedure
- design, databases etc);
- Air traffic services (persons responsible for developing ATC procedures and controller
- Training);
- Aerodrome operator (persons responsible for developing aerodrome infrastructure to
- support approach operations);
- Engineering (engineers responsible for the design of systems and equipment);
- Airline representatives (personnel from flight operations and flight crew training);
- Other user groups (representatives of general, business, commercial aviation, unions, as well as other modes of transport that may use GNSS; surveyors, GNSS receiver manufacturing representatives etc);
- Military representatives;
- Other foreign civil aviation or ICAO officials (for educational purposes).

The plan should identify capabilities that should be in place in order to meet various requirements for each approval stage and steps needed for implementation, and should consider regional and global planning for CNS/ATM systems. The GNSS plan should include the development of a business case. The adoption of CNS/ATM systems has major economic and financial implications for service providers and airspace users. Business case development at the State level is essential in determining the effect of GNSS and also to choose the most cost-effective implementation strategy.

It is important to note that there are not regulation and certification concerning the utility of GNSS in Polish aviation. The transition to GNSS represents a significant change for aviation, so it requires new approaches to regulations, providing service and operating aircraft. A successful transition to GNSS requires a comprehensive orientation and training programme aimed at all involved parties. This program should keep pace as GNSS evolves. It is most important that the decision-makers in aviation organizations receive a broad appreciation of the capabilities and potential of GNSS to deliver service.

The GNSS transition path and timetable depends on a variety of factors, so the information provided to decision-makers should evolve accordingly. Staffs in regulatory and service provider organizations require background training to be able to appreciate how GNSS could affect their area of responsibility. This should include: the basic theory of GNSS operations; GNSS capabilities and limitations; avionics performance and integration; current regulations; and concepts of operation. This should be followed by job-specific training to prepare staff to plan, manage, operate and maintain the system.

For many pilots, GNSS represents the first exposure to avionics that require programming instead of simply the selection of a frequency. The wide variety of pilot interfaces dictates a new approach to training and the certification of pilots. Aircraft operators should develop manuals and other documents aimed at assisting pilots to use GNSS properly and safely. ATC training should include the application of GNSS to RNAV to ensure maximum use of this technology.

3 THE GNSS FLIGHT TEST IN POLISH MILITARY AVIATION

Polish trainer jet called TS11 Iskra equipped with GPS hardware was used for the flight tests. The GPS observations were carried out with Ashtech GPS receivers (Ashtech Z-Surveyor, Ashtech Z-XII), for EGNOS corrections Javad Legacy receiver was used. Four GPS reference stations were taking part in the experiment, located along the aircraft route. The reliable - reference positions of the aircraft trajectory were determined as an average of four positions calculated independently on the basis of every reference station.

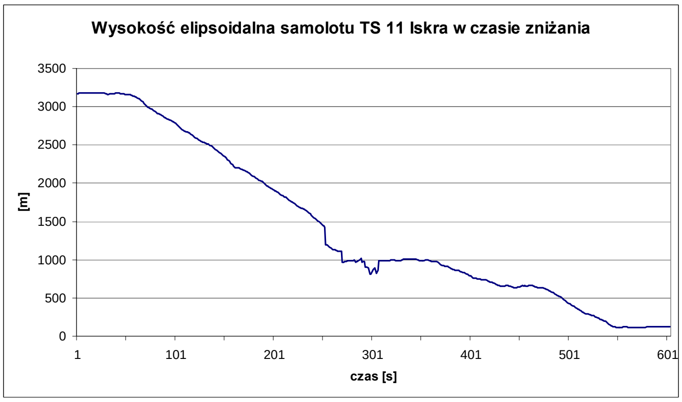

Fig. 1. Vertical plot of the TS-11 Iskra aircraft as a function of ellipsoidal height and GPS time

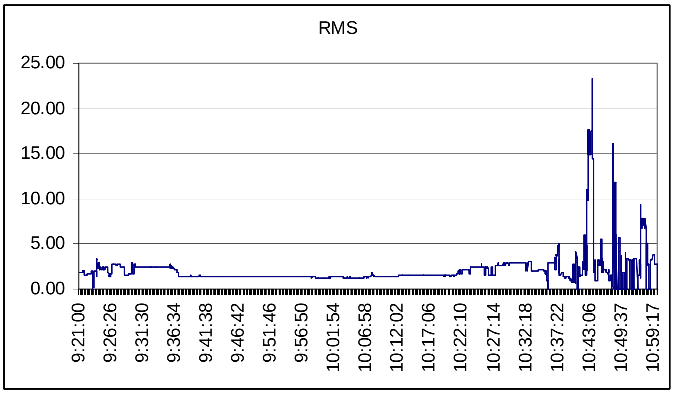

Fig. 2. Plot of mean geodesic co-ordinate errors during descent

The plot illustrates mean geodesic co-ordinate errors during descent as well, but it is important to note, that these errors rose, when the aircraft executed approach descent flight with changing flight parameters, such as G-force, the angle of pitch, banking and the value of angle acceleration.

4 CONCLUSIONS

The analyse of ICAO documents concerning GNSS implementation for aviation and experiences gained during the experiment allow to draw the following conclusions:

- differential real time positioning methods (SBAS, GBAS) are applicable during the approach and landing phase;
- mean geodesic co-ordinate errors obtained during the experiment, when corrections based on EGNOS were available, were only 0.5 m;
- ellipsoidal height parameter was stable and equalled 2 m, which is also favourable.
- non-precision landing procedures based on VOR/DME, NDB could be replaced with procedures based on GNSS, particularly with SBAS (EGNOS) and GBAS;
- implementation of GNSS will enhance flight safety and airspace capacity in area and terminal operations;
- the use of Polish part of the project EUPOS for Polish aviation is advisable.

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