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The Navigation Infrastructure of Airports and New Trends in ATM

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ABSTRACT: Aim of publication is to introduce reader with general need and current situation of development of air traffic management systems and evaluation of actual operating network of aviation electronic support systems. The theme of the contribution is actual because there is currently an increase in the volume of the air traffic, which places increased demands on the safety level of air transport. Attempting to find new answers related to insufficient navigation systems has led aviation authorities to develop progressive systems based on cooperation with satellite navigation systems. Solution for capacity limited airports is development of system GBAS – Ground Based Augmentation System. The main purpose of publication is to present drafts of possible rationalization of navigation infrastructure of M.R. Stefanik airport. The effort to use the maximum potential of airspace consisted in the search for new concepts and trends in air traffic management based on the development of the technical pillar and new ways of managing the entire ATM system.

1 INTRODUCTION

With ongoing increasing of air traffic volume, aviation authorities faces the facts, that conventional navigation systems, which have been for many years sufficient for standard traffic, will not any more fulfill needs of cost – effective, fast and efficient air traffic management. The solution was design of new progressive concepts of navigation based on satellite navigation – GNSS (Global Navigation Satellite Systems) or combination with conventional systems. Need of rationalisation has its origin in increased inefficient flights, number of delays, flight cancellations, costly systems and ineffective traffic management in general as major priority for aviation sector will be always ensuring safety. International Air Transport Association recognizes partnership among industry and government as the key part for ensuring safety in aviation sector [1,2].

Lack of capacity with increasing volume of air traffic caused significant delays in the number of flights, in combination with fragmentation of air space is considered to be one of the biggest challenges in air traffic management nowadays. In 2018 was recorded disproportionate increase in delays compared to the increase in the volume of air traffic transport. While the number of flights increased by only 14 %, delays increased up to 273 % [3].

Attempting to find solution has led organizations and providers to design new concepts of technical area and to consider development of entire air traffic management system. European Union is trying to maintain leaders position in the international aviation field by increasing efficiency of airspace usage which leads to, except another benefits, decreasing of carbon dioxide emissions, which more than doubled in comparison with last two decades. The assumption is, that without proper measures can CO2 emissions increase up to 300% till 2050. Development of technical pillar represents gradual elimination of operational and non cost - effective navigation aids. The main purpose of development is to reach full potential of airspace, which is related to establishment of European and American collaborative programs SESAR (Single European Sky ATM Research) and NEXTGEN (Next Generation program), which were preceded by the concept CNS/ATM (Communication, Navigation and Surveillance / Air Traffic Management) and establishment of the FANS committee (Future Air Navigation Systems committee) at the initiative of the International Civil Aviation Organization (ICAO) in 1983 [1,2,4].

Both programs are based on principals of global cooperation and harmonization and represents key milestone in the field of air traffic management developing. Thanks to its extensive research expertises in Air Traffic Management field, Eurocontrol through SESAR participates in 50 projects of total number 63, falling under program SESAR 1, as ATM (Air Traffic Management) master plan, future Air Traffic Control systems development, building the future ATM architecture and network [5].

In order to optimise the performance of European navigation network, the European commission set up in 2011 ATM network manager to optimise the airspace use in Single European sky. In addition to binding legal acts, the Network Manager develops tools for their implementation and shall meet the strategic objectives defined in the Network Strategic Plan. The main technical and operational developments are the strategic network projects covering the following areas: Air Traffic Flow Management, information systems, safety, airspace capacity, airspace, airports and CNS optimalisation [5].

Cooperation with a wide range of partners such as ATM providers, producers, authorities, is centralised by the Network manager Directorate. The Directorate provides specific resources to ensure that systems and sub-systems cooperate in a harmonised manner. Using independent expertise, the directorate seeks to capture European ATM requirements and transform them into the development of Communication, Navigation and Surveillance technologies [5]

2 CONCEPT CSN / ATM

As we have already stated, the situation overall but mainly in the post-war period in the management of air traffic flow required searching for the optimal solutions. With the intention of revitalizing the aging infrastructure, which was not able to effectively handle increasing overload of air traffic management, the FANS committee was created to identify new systems and technologies for future direction of communication and surveillance. The main purpose of committee was studying of economics, technical, operational and institutional questions, including costs effects, advantages related to potential future systems and concepts including satellite technologies [1,2].

Four years after initiation of the committee was draft of future systems submitted to the ICAO Council – ICAO Doc 9524, known as FANS/4 REPORT. The committee considered the application of satellite technologies to be the only prospective solution that would help international civil aviation overcome weaknesses of actual systems. Concept CNS represented technological pillar of the draft which described gradual transition from actual infrastructure to advanced systems in mutual interaction with the development of the ATM concept [1,2].

Navigation applications generally aim to the use of GNSS systems and the availability of RNAV (Area Navigation) systems on all aircraft types in accordance with the PBN (Performance Based Navigation) manual. For the precision approach and landing phase, which has been associated with conventional Instrumental Landing System ILS and Microwave Landing System MLS so far, the aim is to use SBAS (Satellite-based Augmentation Systems) satellite technologies and the systems GBAS (Ground based Augmentation Systems) and GLS (GBAS Landing System) [5].

First real approach to future navigation systems using GBAS technology took place at Frankfurt Airport in Germany using an Airbus A319 and Boeing 747 – 8 in September 2014 as part of noise protection programme. DFS - Deutsche Flugsicherung GmbH, Air Navigation Service Provider in Germany, in cooperation with Frankfurt Airport, Lufthansa, BARIG (Board of Airline Representatives in Germany) and other representatives, applied numbers of noise abatement measures of which one represents increasing of ILS glide slope operations of 3.2 degrees at Frankfurt´s Runway Northwest (25R/07L), inaugurated for bi-directional landings in 2011° [6,7].

Increased glide slope allowed aircrafts to fly in higher altitudes before reaching landing threshold. This measure has resulted in noise reduction between 0.5 to 1.5 db (A), depending on aircraft type. Technical prerequisites were met by installing two additional independent ILS systems for each direction making the runway one equipped with four ILS systems. Trying to find cheaper solutions was DFS contracted by Frankfurt Airport to purchase and operate GBAS CAT 1 station, Honeywell SLS 4000 product, which transmits five approach procedures GLS CAT I, with glide slope of 3,0° [7,8].

On 3 September 2014, was made first GBAS landing, operated by Lufthansa Boeing 747-8, which made Frankfurt Airport world´s first hub airport, enabling ground based augmentation system (GBAS) landings under good visibility, means by CAT I. CEO of the air navigation service provider DFS, Klaus – Dieter Scheurle, sees system GBAS as future replacement for ILS into Frankfurt and other airports in Germany, as he stated for Avionics International. In the period of September 2014 to February 2015 Frankfurt airport handled more than 200 GBAS approaches operated by previously mentioned Lufthansa Boeing 747-8, but also A380 superjumbos by Emirates as well as e Boeing 737-700/- 800 from Sun Express, Air Berlin and TUIfly [6,8].

In 2022 was reached next step of GBAS development at Frankfurt airport under collaboration with Lufthansa and Airbus as part of SESAR project named Demonstration of Runway Enhanced Approaches Made with Satellite Navigation – DREAMS. DFS upgraded GBAS station for category II landings, making airport the first one in the world to support GBAS CAT II operations. Deployed system supports up to 48 approach combinations for various runways. Upgrade allowed to publish GLS CAT II operations with 3° and 3.2° glideslope [7,9].

Regarding Olaf Weber (GBAS product manager for DFS), was the major challenge to reduce GBAS sensitivity to decorrelation due to ionosphere delay variations between ground stations and aircraft. Therefore, DFS integrated SBAS receiver to ground station which allows usage of navigational service EGNOS for assuring continuity requirements Frankfurt Airport's GBAS system development is being managed in several steps: approaches with a glide slope of 3.0 degrees, increased 3.2° approach procedures for airport´s centre and southern parallel runways, implementing the ICAO regulations for independent GLS/ GLS and ILS/ GLS approaches [7,8].

While many civil aviation regulatory authorities and organizations as ICAO, FAA (Federal Aviation Administration) noted benefits of GBAS usage, system is still rarely used and involved in navigation infrastructure at airports globally [7].

In order to fly GBAS procedures, an aircraft has to be equipped with Multi-Mode Receiver (MMR) which most of new in production aircrafts feature – but number of properly equipped aircrafts at Frankfurt Airport is relatively low, about rate of 10 percent. Multi-Mode Receiver comprises several receivers in the one device (ILS,VOR,GNSS), what is significant for weight and space saving in the aircraft. The biggest aircraft manufacturers have implemented GBAS landing device in several aircrafts as A380, A350 and A320 by manufacturer Airbus and B737-NG, B747-8 and B787 by manufacturer Boeing [10].

3 NAVIGATION INFRASTRUCTURE OF M.R. STEFANIK AIRPORT

As stated, GNSS systems are predetermined to become primary positioning systems by 2030 with optimizing and reducing conventional infrastructure.

Conventional landing system ILS has been generally proven to be functional and reliable but its financial inefficiency and operational limitations predetermine its replacement by GBAS (Ground Based Augmentation System) system based on satellite navigation. Functionality of ILS system can be in some cases affected by topography, operation of another vehicles and aircrafts or appearance of barriers on the surrounding area. For this reason was defined sensitive area – rectangular space located 150 m along parallel lines on both sides of runway centerline. Area is situated between localizer and runway threshold from runway direction [11,12].

For GBAS system, which operates using data packet transmission, sensitive area is not defined. GBAS system´s increased accuracy has its origin in applying differential corrections.

System GBAS consists of 4 to 6 reference GNSS signal receivers, ground unit which is able to cover more runways by one single ground facility at once, what allows possible operation of precision category CAT II/III on both runways. This fact allows increasing of runways capacities in form of extended approach directions, touchdown points, different angles, but it also means distribution of the weight among two runways which lead to reducing of maintenance cost [11].

M.R. Stefanik Airport navigation infrastructure contains two perpendicular runways. Main runway – runway 13 – 31 (with dimensions 3190 m x 45 m) with precision approach CAT IIIA (with decision altitude less than 30m and visibility for minimum 200 m)and runway 04 – 22 of precision category of the approach CAT I (with decision altitude for min 200 ft and visibility for minimum 500 m) with dimensions 2900 m x 60 m [12].

Current precision approaches of M.R. Stefanik Airport:
RWY 22: NDB – DME, ILS CAT I, LOC, RNAV (GNSS).
RWY 31: NDB – DME, ILS CAT I, ILS CAT II / IIIA, LOC, RNAV GNSS [12].

Current navigation infrastructure of M.R. Stefanik Airport:
ILS CAT I – LOC 22 (OKR), ILS – GP 22; ILS CAT III A – LOC 31 (OB), ILS – GP 31,
NDB (OB), NDB (OKR), ¬ DME (OB), DME (OKR), ¬ VOR/DME (JAN),
L (B), ¬ OM, MM [12].

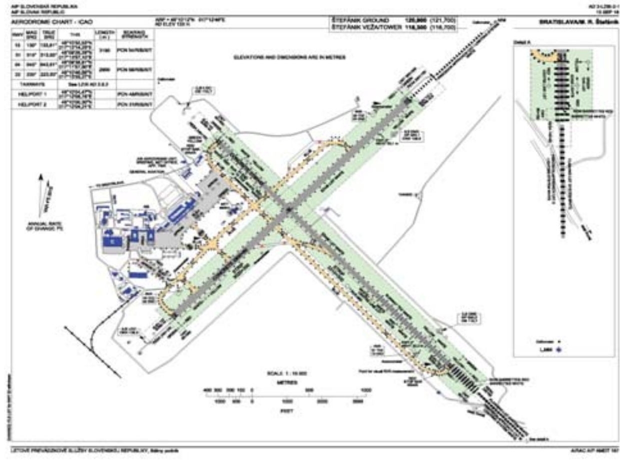

Figure 1 Navigation infrastructure of airport M.R. Stefanik Airport [12]

Application of the system GBAS means advantages in form of elimination of delays, elimination of flight cancellations caused by weather conditions, steeper and shorter approaches, more efficient approaches, reduced operational costs, reduced maintenance volume and related costs and last but not least reduced environmental impact due to noise reduction and lower CO_2 production. In addition, GBAS system does not require recurring flight validation like the ILS system what is reducing maintenance costs; only one GBAS ground station is needed to service all runways ends with reducing acquisition costs [13].

In summary, ground based augmentation systems brings benefits for each sector in the form of:

Airlines benefits: noise abatement up to 3.2 degree glide slope which can reduce noise by 3-5 dB, flexible flight path, fuel savings, reduced emissions, improved safety by greater precision guidance [13].

Airport benefits: improved capacity, flexibility in ground station location, reduced maintenance and acquisition costs [13].

Air navigation service providers benefits: reduced traffic delays, more accurate approaches, reduced capital investments, easier flight inspection, operation during routine inspections [13].

3.1 *Navigation infrastructure rationalization*

In the idea of rationalization we used financial data from cost benefit analysis from Implementation of GBAS system at Prague´s Vaclav Havel airport. As analysis comes from the year 2013, we took into the account rate of inflation in Slovakia since this period, which represents approximately 25% [14]. We can see in the following graph inflation development since the 2010. All financial data has approximate character and are expected to be similar for European market.

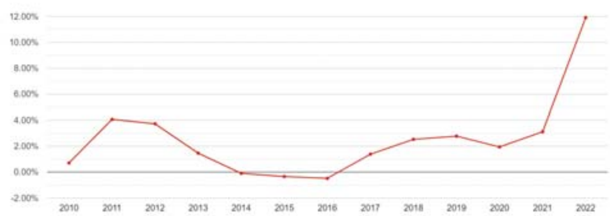

Figure 2. Inflation development in Slovak Republic [14]

DME / ILS CAT I system´s estimated costs including construction, calibration and installation represents amount of 920 000 €. Assumed costs of construction DME / ILS CATII/III system represents amount of 1 000 000€ as shown in the table 3. We assume that navigation infrastructure similar to infrastructure of M.R. Stefanik Airport represents amount of 1 920 000€. Estimated overall operational costs in which are included equipment test, maintenance costs and spare parts, as we can see in the tab. 1, represents 230 000€ early [15].

Table 1. Summary of operational costs [15]

Operational costs	Price (€)
GBAS CAT I	53 750
GBAS CAT II	53 750
ILS CAT I	98 750
ILS CAT II/III	131 250

Assuming future navigation infrastructure is necessary consider vulnerability of GNSS systems in terms of ionospheric interference, intentional or unintentional interferences, constellations and design operational network with respects to reverse mode in case of satellite outage. We considered two concepts of rationalization, considering replacement of both system separately with reverse mode in form of conventional ILS system.

3.1.1 *Replacement of conventional ILS CAT I system by GBAS CAT I*

In the first scenario, we considered replacement of the system ILS CAT I by the GBAS CAT I system on the runway 04 – 22 and remaining of the conventional ILS CAT II/IIIA system on the runway 13-31. Set up costs needed for GBAS CAT I, means 867 500€, as shown in the table 2, are in the comparison with conventional ILS CAT I represented by 920 000€ [15] lower, represents difference of 52 500€.

Likewise, as shown in the table 1, operational costs of GBAS system are comparatively lower, represented by difference of 45 000€. In case of satellite outage would be available ILS CAT II/III system on the runway 13 – 31 [15].

3.1.2 *Replacement of conventional ILS CAT II/IIIA system by GBAS CAT II/III*

In the second scenario, we worked with application of system GBAS CAT II/III on the runway 13 – 31 and leaving reverse system ILS CAT I on the runway 04 – 22. In the comparison, as shown in the table 3, set up costs of GBAS infrastructure are significantly higher than conventional ones, represents difference 492 500€. On the contrary, operational costs of conventional ILS CAT II/IIIA are higher, by amount 77 500€ [15]. In supposed GBAS CAT II/III installation would be price difference overcome in approximately 6 years, as we can see on the timeline in the picture 2.

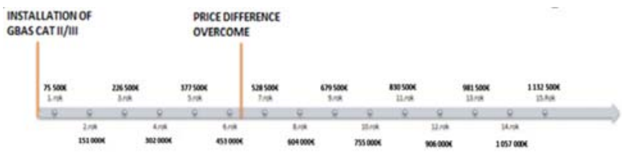

Figure 3. Overcome of price difference

Extended landing options could solve problems of many airports which are affected by capacity limitations, environmental constraints or limited options of extending their operational infrastructure caused by geographical constraints. Negative impacts can be partially reduced.

Table 2. Set up costs of GBAS infrastructure [15]

GBAS INFRASTRUCTURE	PRICE (€)
GBAS CAT I	625 000
INSTALLATION	150 000
CIVIL WORKS	55 000
CERTIFICATION	37 500
TOTAL	867 500
GBAS CAT II & III	1 250 000
INSTALLATION	150 000
CIVIL WORKS	55 000
CERTIFICATION	37 500
TOTAL	1 492 500

Table 3 Set up costs of ILS infrastructure [15]

ILS INFRASTRUCTURE	PRICE (€)
DME, ILS CAT I	420 000
INSTALLATION	218 750
CIVIL WORKS	243 750
CALIBRATION	37 500
TOTAL	920 000
DME ILS CAT II / III	500 000
INSTALLATION	218 750
CICIL WORKS	243 750
CALIBRATION	37 500
TOTAL	1 000 000

It is necessary just to point up to satellite navigation back up while possible satellite outage. One of the possible alternatives can be relative navigation system which determines position of the object by data received from other users [16].

4 NEW TRENDS IN ATM

In 2011, a Memorandum of cooperation in the field of research and development in civil aviation area was signed between the USA and the European Union. The memorandum defined the need to harmonize the NexGen and SESAR programs with the aim of global cooperation and interoperability, smooth operations and safe procedures. The cooperation gained significant importance in 2014, when it was summarized in five cross-cutting activities that intersect all areas of harmonization. Programs aim to increase the safety, capacity, efficiency, predictability, and resiliency of aviation [17,18].

Main elements of the Nextgen and SESAR concepts are described below.

4.1 *PBN navigation*

PBN navigation is an advanced form of satellite navigation creating shorter and more efficient GPS routes compared to standard ones created with conventional radars. The base of Performance Based Navigation is area navigation or RNAV. RNAV is a method of navigation which permits aircraft operation on required flight path within coverage of station referenced navigation aids or within the limits of the capability of selfcontained aids, or a combination of them. PBN offers significant advantages in form of reduced infrastructure, improved operational efficiency, increased airspace capacity, reduces environmental impact [17].

4.2 *Automatic Dependent Surveillance Broadcast – ADS – B*

ADS – B is the next generation surveillance technology developed as a replacement for conventional systems and transition to satellite tracking. ADS-B technology is providing real-time precision, shared situational awareness and advanced applications for air traffic controllers and pilots. Initial information is broadcast by satellites system to the aircraft, subsequently are distributed by ADS – B system to ground stations and to other aircrafts together with additional information about the flight. ADS – B provides benefits in terms of improved safety, reduced cost of surveillance infrastructure, increased capacity due to lower separations, surveillance on the spaces where conventional radar has no range, time reserves and information in cases of emergency [17,18].

4.3 *CPDLC DCL – Departure Clearance*

CPDLC DCL is an element of the data comm systems and represents the transition from voice to digital communication between air traffic controllers and pilots. New access to information in the form of digital text confirmations, instructions and procedures can shorten the departure time, ensure accuracy and eliminate any misunderstandings and language barriers between ATC and pilots. Unlike classic procedures that require multiple voice communication and can take several minutes depending on the quality of the connection and communication, CPDLC instructions are displayed on the FMS screen and the entire process is shortened to a few seconds [18].

4.4 *LPV-200 (Localizer Performance with Vertical guidance)*

Is instrument approach based on a navigation system that is not required to meet the precision approach standards defined by ICAO Annex 10 but which provides both course and glidepath deviation information. Approaches for LPV minima have characteristics very similar to an Instrument Landing System (ILS) characteristics. The main difference is the source of the guidance signals. Whilst an ILS is ground-based approach, necessitating associated transmitters and antennas for each runway, source for RNAV LPV guidance is Global Navigation Satellite System (GNSS) which can be used to simultaneously providing guidance to number of aircraft realising concurrent approaches at multiple locations. LPV minima may have decision altitude as low as 200 feet height above touchdown zone elevation with related visibility minimums as low as 1/2 mile, when the terrain or airport infrastructure supports the lowest minima. Advantage of the LPV is accuracy guidance and increased integrity due to GNSS signal [19].

4.5 *GBAS system*

As stated previously, GBAS system – Global Navigation Satellite System dependent system is considered as alternative to ILS – Instrumental landing system, uses single ground station for transmission corrected GNSS system data to appropriately equipped aircraft to allowing precision approach with greater flexibility.

From pilot point of the view, GBAS avionics is involved in the MMR – Multi-Mode Receiver, the same as for ILS, so there is no needed additional training. The only difference is five digit Channel Number in case of GLS approach, rather than ILS radio frequency. Number of approaches simultaneously carried out by current generation GBAS stations and VHF frequency broadcast – VDB takes from 26 to 48 approaches. Each approach is related to unique channel identifier. In case of two close airports there is possibility of usage of the one GBAS ground station [20,21].

GBAS system received operational public approval at US airports like Houston ´s George Bush airport, Newark Liberty International airport. Many international airports have also the GBAS system in public operational use as for example already stated Frankfurt, Bremen, Sydney, Malaga, Russian locations and others more than 100 airports. Operational approval for flying GLS procedures have airliners as British Airways, Delta Airlines, Emirates, Cathay Pacific, Lufthansa, Quantas, Swiss Air, Air Berlin and others. GBAS is available for the most new commercial aircrafts including Airbus A330/340, A350, A380, A320 and Boeing 787, B747/8 and B737/NG [20,21].

Federal Aviation Administration, other states and GBAS R&D currently focuses on Specification development and incorporating requirements for CAT II/III precision approach to SARPS – ICAO Standards and recommended practices [20,21].

5 CONCLUSIONS

The most appropriate solution for rationalization of M.R. Stefanik airport is from our point of view remaining of conventional system ILS CAT I on the runway 04 – 22 and replacement of ILS CAT II/IIIA system by GBAS CAT II / III. Set up cost difference can be overcome in almost 7 years. Although set up cost of GBAS system is more demanding, advantages of the system can bring saving in lower operational expenses, maintenance costs and lower impact on environment.

Implementation of GBAS system is slowly – moving process and long term project in global manner, but represents future airport navigation technology. Faster implementation of system does not depend only on airport applications, it is necessary industry and political support.

Infrastructure rationalization does not include just airports, concept of future navigation focuses on gradual reduction of systems VOR (VHF Omni-directional Range system) and NDB (Non-Directional Beacon). Performance based navigation known as PBN with definition of minimum operational network are rooted in ICAO Annex 10 [22].

MON – Minimum operational network of VOR system would be designed and constructed with respect to reverse systems and awareness to terminal areas capabilities, as part of infrastructure VOR – DME (Distance Measuring Equipment), for non precision approaches and SID / STAR routes to aircraft navigation which are not equipped by PBN supporting systems [23,24].

Guidance documents advices to remain VOR/DME systems over separate VOR. Overall MON infrastructure would take into the consideration life cycles of devices and PBN system implementation process to gain maximum cost effectiveness GBAS system benefits predicts its position in future navigation. Planned massive use of GNSS system comes with questions with not solved character so far, in form of clearing charges for satellite systems operational costs. Not solved character results from massive usage of satellite systems, which are, in contrast of conventional devices, not managed by standard air traffic providers. Basic satellite navigation services are provided free of charge, organization ICAO opened discussion for finding way of allocation expenses among users of extended services [22,23,24].

First cost allocation discussion was opened during CNS/ATM Conference in 1998[22]. ICAO invited participants to find possible ways of cost allocation along all users including civil navigation and another users. Relevant information and applications related to legal and economic allocation aspects were collected by ICAO.

Definition of first basic principles were issued in the year 2007 in guidance policy form, with emphasis to fairness and non discrimination of aviation sector which represents major user. Allocations amongst service users should be the subject of transparent consultations between full users spectrum and GNSS service providers[11]. Satellite system providers in Slovakia are ESSP SAS (European Satellite Services Provider) consortium in case of satellite system EGNOS and US Department of Defense for system GPS [25].

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