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Critical infrastructure of the airport determined with PBN ICAO implementation

Abstract: The aviation transformation is entailing determined changes with resolution A-37 ICAO, ordering the global and domestic PBN introduction (Performance Based Navigation). Consolidating efforts economic financial European countries are carrying – out SESAR program (European Sky Singles Research ATM) constituting technical and technological backing up of the system the management with the air traffic (ATM) implemented in frames of the Uniform European airspace. In 2020 as a result of the completion of this program, should take place triple of increasing bandwidth ATM at the simultaneous improvement in indicators of the safety, 10% reduction in the negative influence of aviation on the natural environment, 50% reduction in costs Atm. the last phase carried out of the SESAR program is defined in provisions of the executive regulation of the Committee (EU) No. 409 / 2013. To underline he belongs, that the air transformation is determining action in the critical infrastructure of the airport, in order to reach the level required in the SESAR program. During the implementation of new techniques and the technology, of implementing organizational, structural changes identifying is required and of estimating the possibility of the appearance of the risk, in the destination of eliminating or cushioning effects of his threat. Hence to the purpose of the right assurance the level of the safety is being carried out „ Safety case ”.

Keywords: Safety case; PBN; SESAR; ATM

Introduction

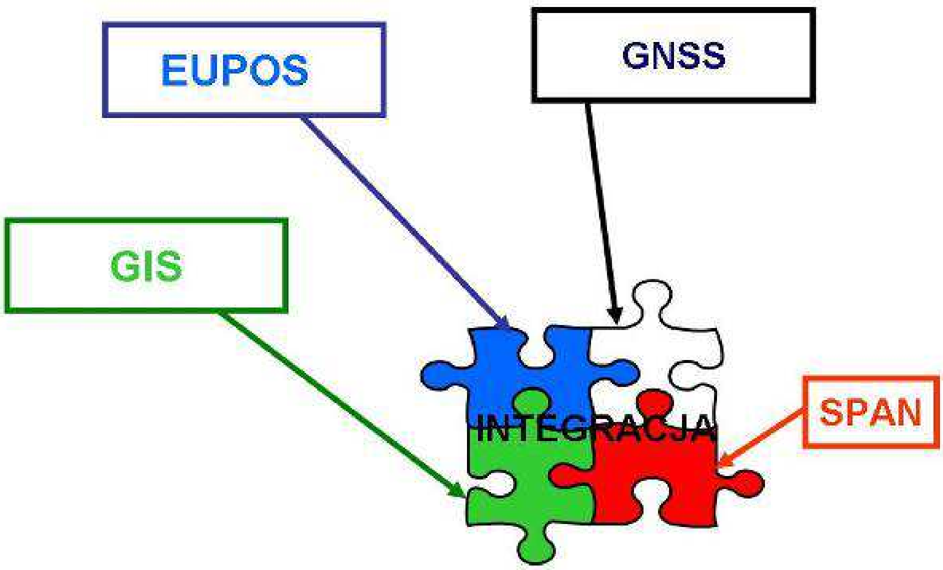
The aviation transformation, caused by scientific and technical development, determined ICAO to undertake activities related to the development of a prospective, global, operational air traffic management system - ATM (Air Traffic Management). Established in 1983. FANS (Future Air Navigation System) published in 1991. FANS final report, presenting the strategy of aviation information, communication, navigation, surveillance - CNS (communication, navigation, surveillance) and implementation of satellite techniques and technologies - GNSS (Global Navigation Satellite System). The report was the basis for developing the necessary operational assumptions for prospective ATM. Validation of the adopted solutions was performed as part of aviation tests, using Boeing and Aerobus aircraft in the less frequented area of the South Pacific airspace - PET (Pacific Engineering Trials) as part of the FANS-1 project. As a result of the tests performed: automatic dependent surveillance (ADS), digital controller / pilot telemetry (CPDLC), flight demand system (FMS), satellite communication (Inmarsat Data-2 service), onboard digital transmission system (ACARS), data link of the unit Control and display (DCDU) and for the remote control for sending and receiving messages (CPDLC, ARINC 622, EUROCAE ED-100 / RTCA DO-258). Despite the fact that the FANS project was not applied globally, the results obtained as a result of aviation tests enabled ICAO to develop assumptions for the global CNS / ATM system, which is currently being implemented. Also tested CPDLC became the current ICAO standard used in the global aeronautical communication network - ATN (Aeronautical Telecommunications Network) compatible with the European airspace is "LINK2000 + Program" [7][6]. The aviation tests carried out as part of the FANS project have proved that the introduction of certified IT-satellite techniques enables the increase of efficiency, flexibility and airspace capacity. This constituted the basis for the ICAO development and approval of the concept of the required navigational performance value - Required Navigation Performance Capability, which defines the parameters of horizontal deviation of the aircraft position from the planned route and the required accuracy of position determination during flight operations. The adopted RNPC assumptions defined navigational parameters for all users located in a given airspace, enabling its appropriate planning and use (including the width of airways, the shape of flight procedures, selection of acceptable separations (horizontal, vertical, side). The en-route flight requirements adopted in the RNPC proved to be imprecise for subsequent flight phases (approach, landing, departure). In subsequent years, the required navigational accuracy parameters - RNP (Required Navigation Performance) - were defined: accuracy, reliability (integrity), continuity, availability (availability). These parameters as general requirements were supplemented by ICAO in Standards and Recommended Practices and SARPs. The required navigational accuracy was defined as a total error - TSE (Total System Error) consisting of two errors: technical flight, pilot dependent - FTE (Flight Technical Error) and navigational system - NSE (Navigation System Error). On the other hand, reliability in the context of a containment region is defined as a measure of confidence in the navigation system, expressed by the probability that the navigation system will warn the user about the occurrence of certain conditions that may cause the aircraft to deviate outside the assumed area. The RNP parameters defined in this way enabled passage through area-based navigation (RNAV) to the currently implemented accuracy PBN (Performance Based Navigation), on the power ratified in 2007. ICAO A36 / A-37 Resolution. By ordering the implementation of precise GNSS approaches and other solutions, it contributes to environmental protection, significantly reducing fuel consumption and emissions.

The global aviation projects outlined above and adopted for implementation are included in the joint European SESAR program (Single European Sky ATM Research). It constitutes technical and technological support for the Single European Sky - SES II Plus and its effective implementation should lead to the implementation already in 2020 of a modern ATM system that allows three times the capacity of air traffic with an increasing number of aircraft operations while improving safety indicators. The use of modern technologies and procedures will also allow for a 10% reduction of the negative impact of aviation on the natural environment reducing the negative impact of aviation on the natural environment and a 50% reduction in the costs of air traffic management. This program is implemented on the basis of Regulation of the EU Council No. 219/2007, establishing public-private partnerships of EU members and Eurocontrol - SJU - (SESAR Joint Undertaking). This ensures the following: organizing, coordinating, updating the central air traffic management plan, providing the necessary funds (combining public and private sector funds) and managing them, organizing technical work in the field of research and development activities, validation and analysis, integration of institutions providing shipping services air, users, workers' associations, airports, manufacturing industries, and the scientific community. The SESAR Joint Undertaking is an EU body with legal personality and funded by contributions from its members, including private companies. The last, third phase of implementation of the SESAR program is being implemented and the Polish Air Navigation Services Agency (PANSA) representing our country joined the alliance in 2014.

Characteristics of the GNSS aviation system

The increase in air traffic in a uniform European space while ensuring security determines the modernization of terrestrial infrastructure and onboard equipment (Figure **1**) and the implementation of satellite techniques and technologies strictly with geographic information systems. This interdisciplinary approach is based on the assumption that airports should be a transport hub (rail, air, road) as part of the intermodal transport. Currently, systems cooperate closely (Fig. **2**): ASG EUPOS, Geographic Information (GIS, SIP), SPAN, GNSS (Global Navigation Satellite System)).

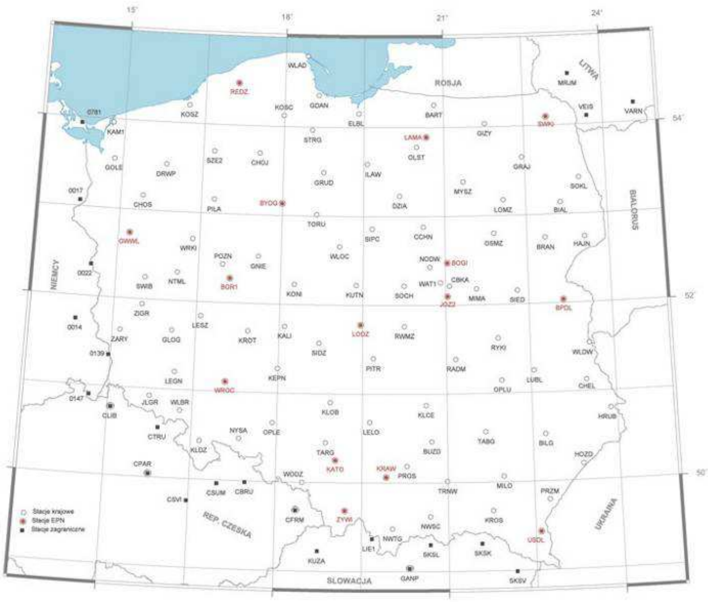
1. Modern contemporary aircraft equipment
Source: own elaboration



2. Systems integration in aviation applications: GNSS, SPAN, EUPOS, GIS
Source: own elaboration

Operating system ASG EUPOS is the European Network of Multifunctional GNSS Reference Stations developed since 2002 (Figure **3**). It is part of the international GNSS civil service - IGS (International GNSS Service), which monitors and corrects the accuracy of global satellite systems and sends relevant corrections to users. Five Polish RTK DGPS permanent stations located in: Borowa Góra, Józefosław, Lamkówek, Borówiec, Wrocław, equipped with GPS receivers with a precise P-code, belong to IGS. For the ASP EUPOS system, it was assumed that: terrestrial devices act as multi-functional, permanent DGNSS reference stations; the average distance between the stations is about 70 km; the coordinates of the station are determined with high precision; the basic standard is the GPS signal until the Galileo system is operational; high geodetic quality of the GNSS system will be provided by receivers in reference stations. In the Polish subsystem ASG EUPOS there are three basic segments: receiving, computing, a user. However, depending on your needs, you can use five websites:

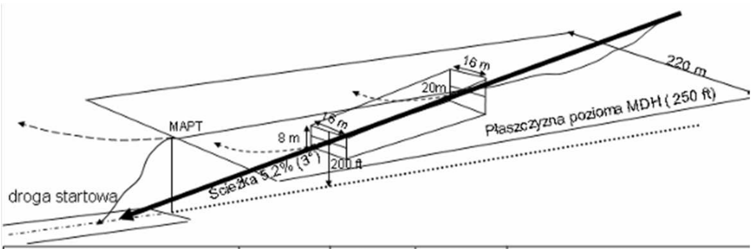
- KODGIS - RTCM corrective data in real time, from the selected reference station enable measurements and positioning with an accuracy of 0.25 m;
- NAWGEO - RTCM, RTK, VRS, FKP corrective data in real time from the selected or generated virtual reference station, enable measurements and positioning with accuracy: below 0.03 m horizontally and 0.05 m vertically;
- NAWGIS - RTCM real-time correction data from the selected reference station, allow measurements and positioning with an accuracy of 1.0 m;
- POZGEO - intended for calculations of GNSS observations performed with the static method in post-processing. The calculations use phase observations from single and dual frequency receivers, converted to a fixed format of observational data;
- POZGEO D - provides observation data for independent calculations in the postprocessing mode and makes it possible to obtain 0.1 m accuracy for L1 receivers and 0.01 m for L1 / L2 receivers. After completing the measurement at the reference stations, the user can download observation files via the website for selected or virtual reference stations for individual data processing.



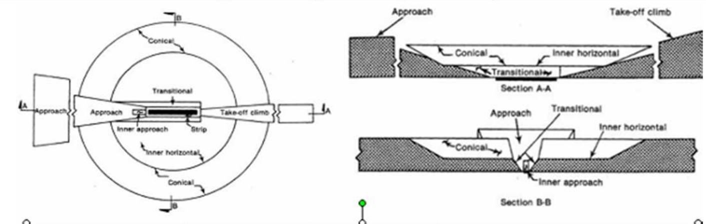
3. The deployment of the ASG EUPOS system station, where: GLO (GPS / GLONASS), MET (meteorological measuring sets), EPN (European), IGS (international)

Source: http://www.asgeupos.pl

Geographic Information Systems (GIS, SIP) - application thanks to digital photogrammetry (softcopy photogrammetry) for automatic generation of numerical terrain model (NMT) and creation of orthophoto maps (stored in computer information carriers). The user can easily collect this data, manage it and use it for different purposes. Computer science has integrated photogrammetry with remote sensing and GIS. The photogrammetric process includes three basic stages: image acquisition, photogrammetric processing, product development, which is why an algorithm is used to process geodata, interpretation and spatial analysis and photorealistic site visualization based on available geographic information about the area and a standard procedure for obtaining data. GIS / SIP systems are of particular importance in aviation when developing GNSS RNAV approach and landing procedures. However, there are measurement problems related to the fact that airports are located in urbanized areas, the need to perform a large number of point measurements at the airport (Figure **4**) and a well-defined radius around it (difficult to measure objects and obstacles), a large area of measurements (approach to landing, airport zones).



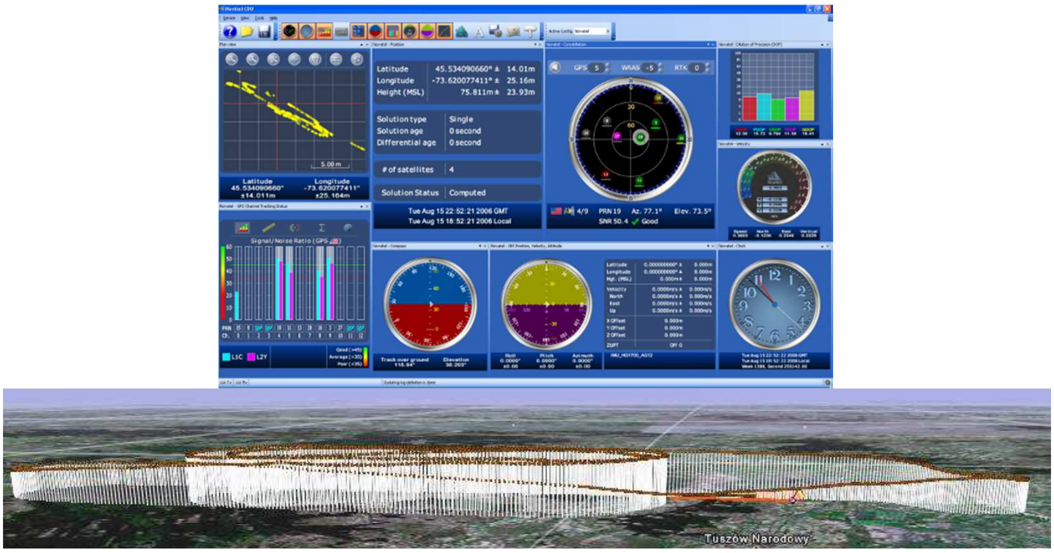
Kategorie podejść		CAT I	APV I	APV II	NPA
Dokładność	Pozioma	16 m		16 m	220 m
	Pionowa	4 do 6 m	8 m	20 m	---
Limit alarmu	Pozioma	40 m		40 m	
	Pionowa	10 do 15 m	20 m	50 m	---
DH/MDH (min.)	Pionowa	200 ft	200 ft	250 ft	250 ft
Wid. Poz. (mini.)	Z światłami ląd.	550 m	550 m	T.B.D	1200 m
	Bez świateł ląd.	1000 m	1000 m	T.B.D	1800 m
Strefy ochronne		zreduk. (ILS)	bliska ILS	bliska ILS	Minima zależą od przeszkód
Ścieżka		5.2% (3°)	5.2%(3°)	5.2% (3°)	zniżanie + stabilizacja
Wiarygodność / ciągłość SIS		tak	tak	tak	nie



Areas/Attributes	Area 1	Area 2	Area 3	Area 4
Horizontal Accuracy	50.0 m	5.0 m	0.5 m	2.5 m
Vertical Accuracy	30.0 m	3.0 m	0.5 m	1.0 m
Vertical Resolution	1.0 m	0.1 m	0.01 m	0. 1 m
Confidence Level	90%	90%	90%	90%
Terrain Database Post Spacing	3 arc second (approx. 90m)	1.0 arc second (approx. 30 m)	0.6 arc second (approx. 20 m)	0.3 arc second (approx. 9 m)

4. Diagram of metering of essential elements of the airport
Source: own elaboration

SPAN technique it is a combination of the inertial navigation system - INS (Inertial Navigation System) with a GPS satellite system. The measurement set and SPAN test results are shown in Fig. **5** and the comparative table **1.**



5. Results of the first SPAN flight tests (2007, Mewa plane): control panel system, obtained location - vertical section
Source: own elaboration

Tab. 1. A comparative combination of GPS and INS (the validity of combining these systems), *Source: own elaboration*

Feature	Characteristics of GPS work	Characteristics of INS work
independence	requires an external GPS signal	it does not require any external signals
vertical elevation accuracy	several times worse than horizontal	several times better than horizontal
dynamics accuracy	accuracy (depending on the satellites being tracked, geometry and positioning mode	accuracy stable from age to age, but is gradually degraded over time
characteristics of results	can provide absolute coordinates	it provides an accurate but relative coordinate
direction data	data on the direction of movement as a function of speed (azimuth and slope)	provides full direction data in 3 dimensions
frequency positioning	maximum 20 Hz positioning frequency	high frequency of work, to 200 Hz

The GNSS system (Global Navigation Satellite System) is a continuation of the developed (after the appearance of two systems: GPS and GLONASS) in 1995. European Satellite Navigation Program - ESNAP (European Satellite Navigation Action Program). In the first stage (GNSS-1), he set up the construction of a European, civilian, satellite EGNOS (European Geostationary Navigation Overlay Service) supporting GPS, GLONASS. Next years and obtained results, possibilities of economic development and benefits resulting from the implementation of the ESNAP program have verified the assumptions made. The efforts of the European Commission, the European Space Agency (ESA), the European Organization for the Safety of Air Navigation (Eurocontrol) were combined and, as a result, a test version of the ESTB system (EGNOS System Test Bed) was implemented, which in 2000 began transmitting navigation signals (Figure **6**). The EGNOS support system is compatible with military (GPS, GLONASS) and civilian (e.g. Galileo tested)). It is an "overlay augmentation" for military satellite systems, as it corrects the data received from them and emits appropriate corrections in real time to the user. Thus, it increases the accuracy, availability, continuity, and reliability of these systems, allowing wide application for civilian needs (Table **2**). EGNOS belongs to the group of satellite-assisted systems SBAS (Satellite Based Augmentation System) among which one can distinguish (Fig.**7**): WAAS (USA), MSAS (Japan), SNAS (China), EGNOS (Europe), GAGAN (India), GRAS (Australia), AFI (North African), SDCM (Russia), CWAAS (Canada), SACCSA (South America) and others. These regional systems meet international standards - MOPS (Minimum Operational Performance Standards), so they are available to every user.

It should be emphasized that GNSS is not a homogeneous system but composed of six components, contained in two basic groups of systems (Fig. **8**):

on the standard satellite constellation:

American military - GPS;

Russian military - GLONASS;

civil - GALILEO;

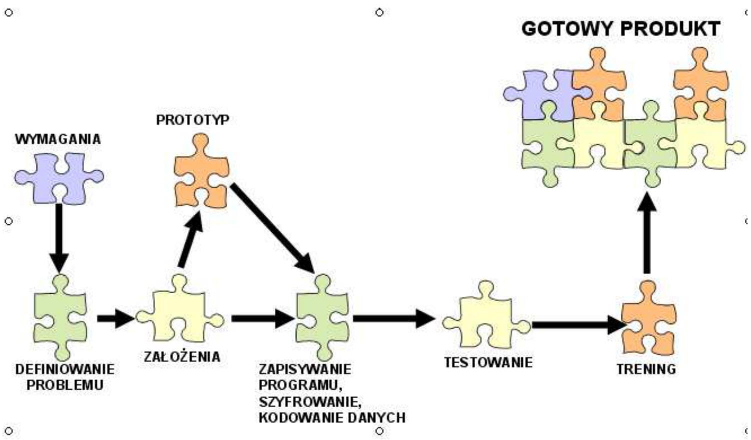
other (currently running).

supporting ("enhancement pads"), they correct data received from standard satellite systems, providing the required for the user depending on the needs: reliability, accuracy, availability, signal continuity. The first letter (A, S, G) indicates the position of the assistive system:

ABAS - verification and correction of data at the level of the user's receiver (e.g. aircraft, ship, means of transport);

SBAS - geostationary satellite provides corrective data to the user;

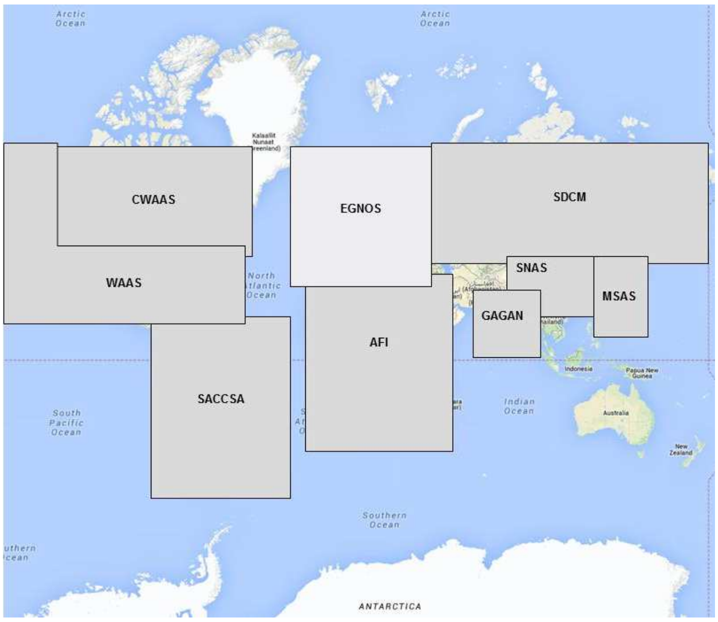
GBAS - terrestrial monitoring stations verifying satellite signals and correct data, which in the form of corrections provide in the VHF band - VDB to the user.



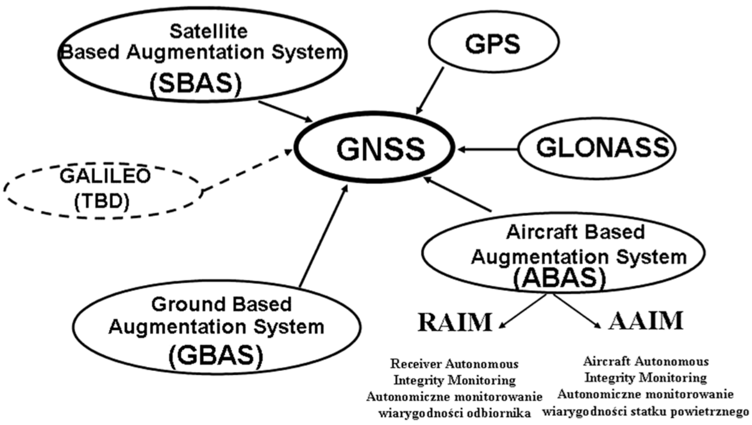
6. An algorithm for simulation laboratory tests of the integrated GPS / INS / GIS system

Tab. 2. Required parameter values depending on the flight phase according to ICAO

	Lateral Accuracy 95%	Vertical Accuracy 95% (1)(3)	Integrity (2)	Time to Alert (3)	Continuity (4)	Availability (5)
En-Route	2 NM (6)	N/A	$1\text{-}10^{-7}$/h	5 min	$1\text{-}10^{-4}$/h to $1\text{-}10^{-8}$/h	0.99 to 0.99999
ER, Terminal	0.4 NM	N/A	$1\text{-}10^{-7}$/h	15 s	$1\text{-}10^{-4}$/h to $1\text{-}10^{-8}$/h	0.99 to 0.99999
Initial and Intermediate Approach, NPA, SID	220 m	N/A	$1\text{-}10^{-7}$/h	10 s	$1\text{-}10^{-4}$/h to $1\text{-}10^{-8}$/h	0.99 to 0.99999
APV-I	16.0 m	20 m	$1\text{-}2\times10^{-7}$/h per approach	10 s	$1\text{-}8\times10^{-6}$ in any 15 s	0.99 to 0.99999
APV-II	16.0 m	8.0 m	$1\text{-}2\times10^{-7}$/h per approach	6 s	$1\text{-}8\times10^{-6}$ in any 15 s	0.99 to 0.99999
PA- CATI (8)	16.0 m	6.0 m to 4.0 m (7)	$1\text{-}2\times10^{-7}$/h per approach	6 s	$1\text{-}8\times10^{-6}$ in any 15 s	0.99 to 0.99999



7. Developing SBAS systems: WAAS (USA / FAA), MSAS (Japan), SNAS (China), EGNOS (Europe), GAGAN (India), GRAS (Australia)



8. The concept of GNSS concept
Source: own elaboration

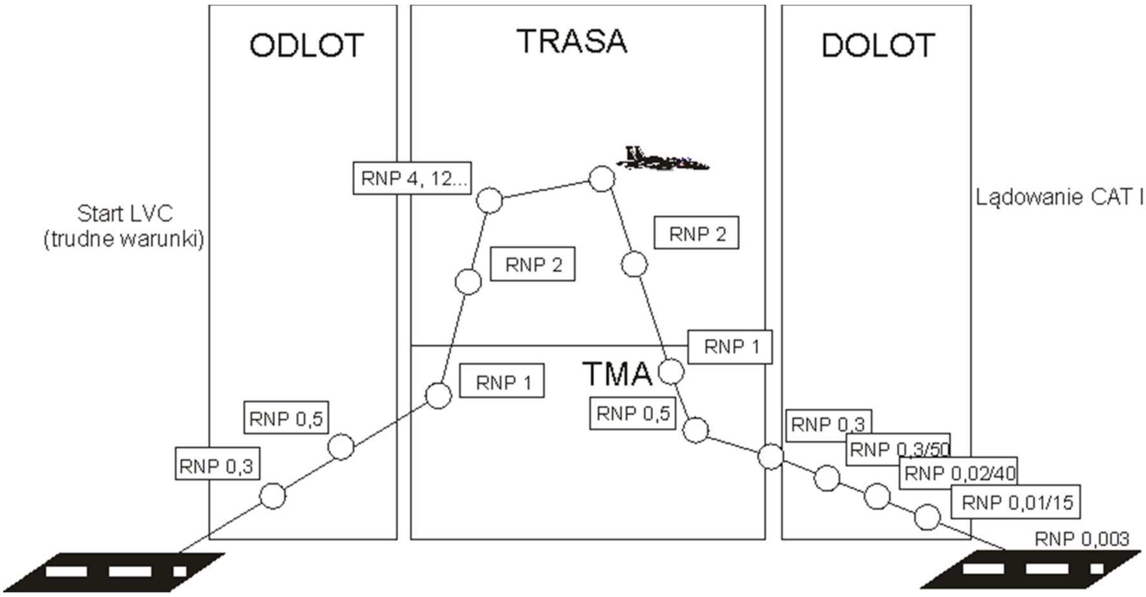
Characteristics of the PBN concept in the aspect of ICAO resolution

Scientific and technical solutions have also determined the evolution of air navigation, which plays a significant role in the global economic activity. There has been a shift from classic (sensor) navigation to precision navigation (PBN) in order to maintain aviation vitality and ensure safe, efficient and flexible use of airspace, reduce noise and exhaust emissions - activities related to environmental protection, sustainable operations at the global, regional, national level. Unfortunately, when examining technical efficiency, elements related to navigation systems and their parameters on which the category and number of aviation operations are possible (Table **3**) are not taken into account. When planning the airport infrastructure, the necessary implementation of the PBN concept is not taken into consideration, in which it is important to maintain a certain level: accuracy, reliability, availability, continuity depending on the activity performed, the flight stage (Figure **9**).

Tab. 3. Required accuracy, time to alarm, availability and coverage of the DGPS system for air transport

Zastosowanie w transporcie powietrznym	Dokładność (2 σ)	Czas do alarmu (s)	Dostępność (%)	Pokrycie wysokości (m)
Przeloty transoceaniczne	23km (12,6 Mn)	30	99,977	8400 – 12200m (27500 – 40000ft)
Przeloty krajowe	1000m	10	99,977	150 – 18300 (500 – 60000ft)
Terminale	500m	10	99,977	150 – 5500 (500 – 18000ft)
Podejście i lądowanie: nieprecyzyjne	100m	10	99,977	75 – 900 (250 – 3000ft)
Podejście i lądowanie: kategoria I	Poziom: 17,1m. Pion: 1,7m	6	99,999	30 – 900 (100 – 3000ft)
Podejście i lądowanie: kategoria II	Poziom: 5,2m. Pion: 1,7m	2	99,999	15 – 900 (50 – 3000ft)
Podejście i lądowanie: kategoria III	Poziom: 4,1m. Pion: 0,6m	2	99,999	0 – 900 (0 – 3000ft)

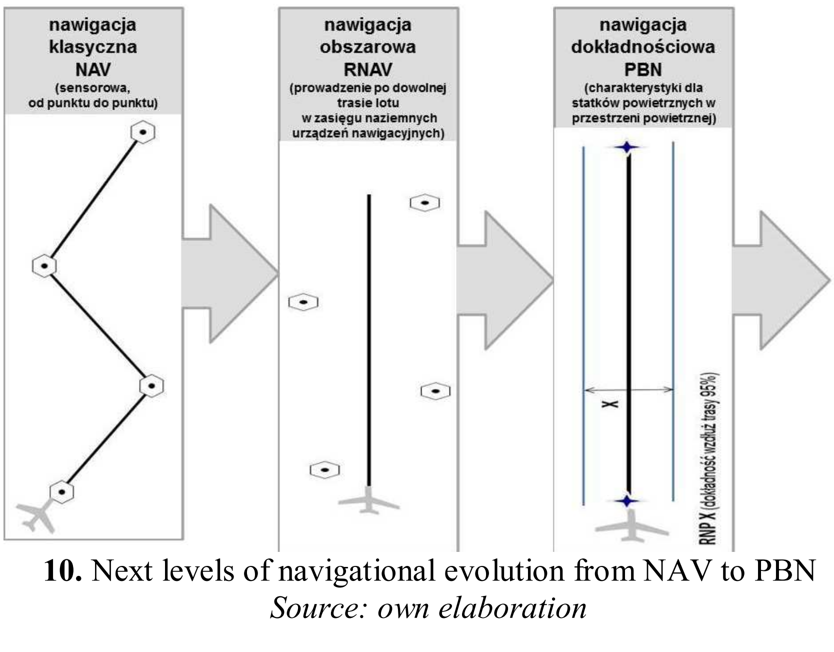
Source: own elaboration



9. Flight stages diagram and required RNP accuracy parameter
Source: own elaboration

PBN is the third level (Figure **10**) in the development of navigation, that is, the transition from sensor data to maintaining defined parameters for at least 95% of the activity. It requires appropriate equipment and is a development of the previous concept of RNP and at the same time provides global navigation of RNAV by defining the navigational specifications and applications used, and extends significantly the scope of requirements encompassing three main segments:

- system and aids to eventually eliminate or significantly compensate the impact of atmospheric conditions on aviation activities and increase the number of operations (category III C - cloud base 0 m, visibility 0 m), while reducing fuel consumption and noise - using offset approaches;
- adequate equipment for the terrestrial infrastructure and on-board aircraft,
- certification criteria for flight crew.



10. Next levels of navigational evolution from NAV to PBN
Source: own elaboration

The PBN concept is the main element of air traffic management implemented under the SES II Plus and SESAR programs. It introduces advanced techniques and technologies, improving efficiency and flexibility in the operational airspace, and at the same time reduces the negative impact of air transport on the environment and increases safety. However, it requires adequate infrastructure and the introduction of appropriate national rules that facilitate the use of GNSS. PBN was accepted for implementation in 2007. on the basis of ICAO resolution A36-23 "Performance-based navigation global goals" and ordered by the end of 2016. implement RNAV / RNP operations during en-route flights, in aerodrome areas, and implement procedures for basic or backup APV, Baro-VNAV or SBAS precision approaches. The assumed plan was difficult to implement and an updated ICAO Resolution A37-11 was prepared, which required the implementation of the PBN concept in national plans. It was also assumed to implement satellite basic instrumental approaches or as a backup for existing ILS. Poland is a signatory to this agreement and EASA deals with the implementation of PBN in Europe at the request of the European Commission, developing provisions regulating the harmonized implementation of the European PBN [8]. Undoubtedly, the evolution of navigation to PBN is a global priority, adopted by an association of 191 ICAO Member States, which sets the standards and recommended practices (SARPs) necessary for aviation safety, efficiency and environmental protection on a global scale. It also helps in the implementation of this concept, providing standards and guidelines in the ICAO manual [4], and also plans and verifies the implementation of recommendations in the Global Aviation Safety Plan GASP [2] and Global Air Navigation Plan reports [3].

Impact of PBN on critical infrastructure of the airport and possible benefits

The PBN under implementation defines service and performance levels in air traffic management (ATM), characterizing component parameters for aircraft and terrestrial infrastructure, supporting systems, integrated with a prospective European ATM system. Thus, the SESAR program has six main levels defined, which will be gradually, systematically implemented and applied in operational work. The necessity to take into account the different levels of services and efficiency currently existing in European air traffic management, forced the division of the implementation phase of the SESAR program into three segments - IP, closely related to the Initial Operational Capability - Initial Operational Capability (IOC). Therefore, three levels have been distinguished (Figure **11**) :

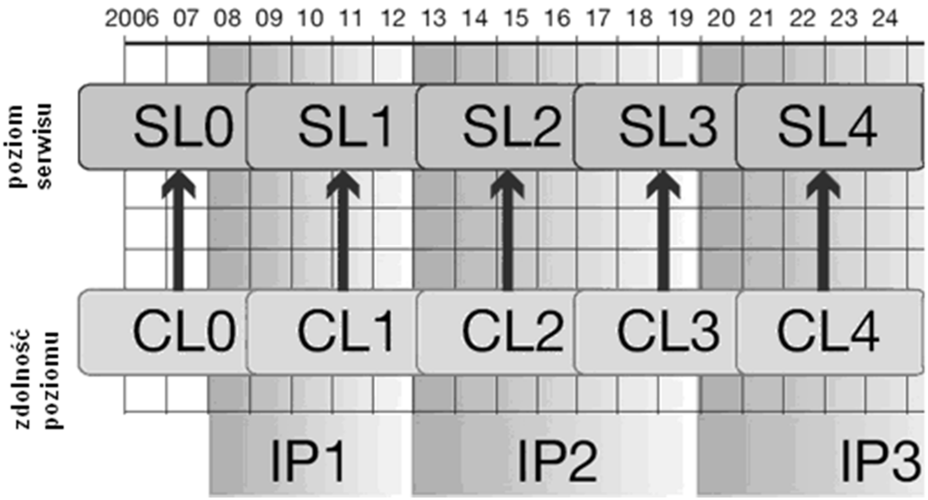
- ❖ short-term until 2012 - IP1 (Implementation Package 1), levels 0 and 1;
- ❖ medium-term (2013-2019) - IP2, levels 2 and 3;
- ❖ long-term (from 2020 onwards) - IP3, levels 4 and 5.

Performance levels are closely related to shareholder systems, operational procedures, human resources and others. Promoting to a higher level of efficiency means carrying out new projects and this requires investment (financial outlays, incurring costs). Service levels are closely related to the offered operational services and desired by the user. On the other hand, achieving a higher level means operational improvement and this implies specific benefits. However, the service provided at the appropriate site level, e.g. Y, requires both the service provider and the user to have the operational capability at the same level - Y, as compatibility is required. At the same time, a system with an adequate level of capacity should also provide lower-level services. This ensures interoperability between systems that have different levels of capability, for example:

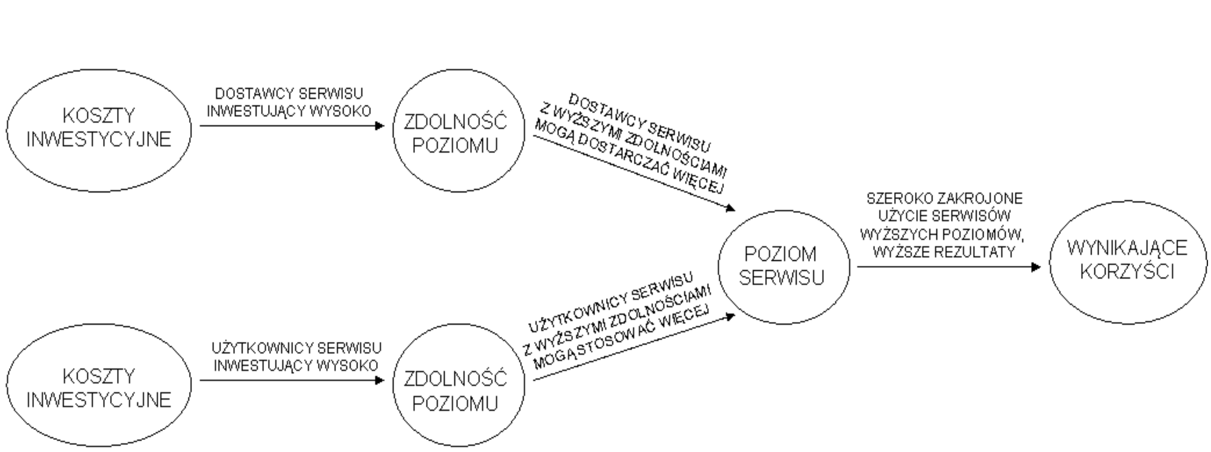
- ❖ aircraft with level 3 moves to the airport with level 2 - service is provided at a lower level - airports 2 and such will benefit;
- ❖ aircraft with level 1 moves to the airport with level 2 - service is provided at a lower level - aircraft 1 and these will be benefits;

Service operation requires that the supplier and user have the required capability, but not necessarily all the features of the required level. It is a known fact that in a diverse ATM environment, such discrepancies in capabilities will occur in a certain, but limited, scope. It was assumed that the implementation of the ATM service level assumes geographical synchronization as far as possible on-board equipment and airport infrastructure to avoid wasting potential capacity (Figure **12**).

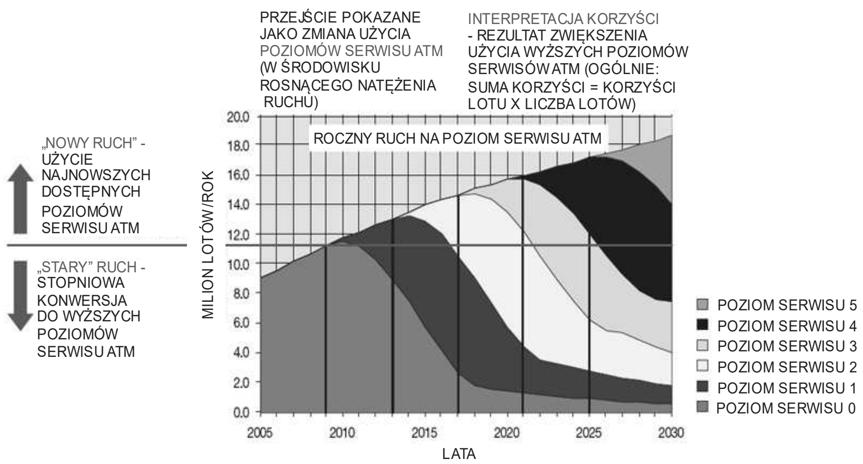
A transitional strategy of individual shareholders was adopted, which assumes the simultaneous, gradual evolution of existing systems towards higher, service levels (Figure **13**). However, it is assumed that there will be several delays due to objective reasons. They will occur as a result of the implementation of equipment, upgrades to correspondingly higher levels: aircraft, air operations centers, airports, ATM facilities. This does not mean that it is required that each unit implements, upgrades in succession level by level. Probably economic considerations, in many cases the airport manager (e.g. user, Air Navigation Services Agency - service provider/operator) will cause shareholders with the least required equipment to want to leave the lower level and decide to reach (as far as they can) the highest level (e.g. from level 1, go straight to level 3).



11. Distribution of service levels and performance in relation to segments of the SESAR Implementation Phase
Source: own elaboration



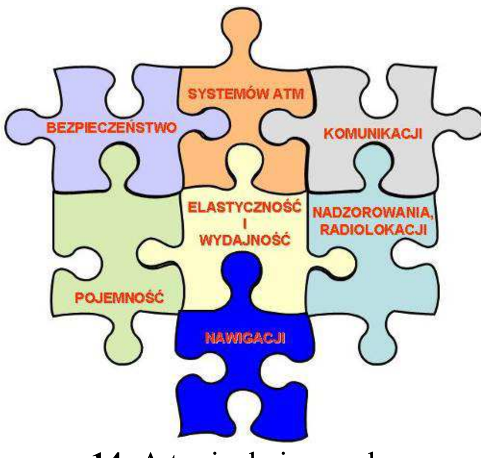
12. Relations between ATM services and level sites
Source: own elaboration



13. The relationship between ATM service and performance levels
Source: https://www.atmmasterplan.eu

Summary

Implementation of the ICAO global PBN program has tangible benefits in: .... The determinant is forecasted by a significant increase in air traffic. The reason for this state of affairs, according to experts, is the increase in the number of air operations also in the Polish airspace and passengers at Polish airports, progressive decentralization of air traffic, allocation of adequate funds for the development of aviation infrastructure for regional airports and local airports, as part of operational and regional programs . This implies the need to modernize the aviation infrastructure, as it is required to maintain safety, implement appropriate ATM management systems, communication - connection, flexibility, and efficiency as well as airspace capacity, supervising - radiolocation, navigation (Figure **14**). International arrangements [9] show that airport services, airspace management require licensed specialists in the field of work organization in the aviation industry at various levels, managers familiar with aviation specifics and other specialists in air navigation. The words of the President of ULC [10] are remarkable, saying that there are about one thousand people per million passengers employed directly at the airport, three thousand around it (services, trade, etc.) and 15,000 in the whole region serviced by the airport. This means that the growth of air traffic generates employment growth in this sector. Similar data can be found in the documents of the European Commission [1].



14. A typical air puzzle
Source: own elaboration

Source materials

[1] Communication from the Commission to the Council, The European Parliament, The European Economic and Social Committee and The Committee of the Regions. An action plan for airport capacity, efficiency and safety in Europe. Brussels, 2007.
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