MODERN AVIONICS-ATM ERGONOMICS AND INNOVATION TECHNOLOGIES IMPLEMENTATION GAP ANALYSES. LATVIAN AND GEORGIAN CASE STUDIES

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Abstract - According to EUROCONTROL's latest research, by year 2035 airports across Eu-rope are expected to handle 14.4 million flights and 1.4 billion passengers. However, current Air Traffic Management (ATM) system is not adequately prepared for such volume of air traffic, and as a result it might lead to a congested airspace, causing even more delays on the ground and in the air. This situation is economically inefficient and has a significant adverse impact on environment due to carbon emission and noise pollution. For this reason, continuous development and modernization of the ATM system is necessary. The Global Air Navigation Plan (GANP) is a flexible engineering-technical methodological document, that allows all International Civil Aviation Organization (ICAO) member states to advance their air navigation capacities based on their specific operational requirements. One of the most problematic parts for successful implementation of the GANP is an innovative ATM, modern avionics technologies and effective interrelation between systems and users, considering ergonomic factors. A system "operator-machine-environment" depends on human performance, as well as on level of automation of systems involved.

Paper focuses on Latvian and Georgian case studies, as in both counties ATM technologies and level of automation continuously grows and becomes more advanced. The development of modern aircraft avionics systems re-quires new skills of aviation professionals, that is why training becomes even more challenging and important. As a result of the research a methodological approach and general model for effective interconnection of modern avionics and innovative ATM technologies is proposed, taking into consideration human factors.

Keywords - Air Traffic Management, Avionics, Ergonomics.

I. INTRODUCTION

ATM significantly contributes to safety and reliability of air traffic. Regulation of air traffic flow further enhances quality of air navigation service and improves operational effectiveness of ATM system. It also has a positive impact on environment, reducing operational and fuel costs.

Ultimately, air traffic flow regulation enables effective airspace organization by maximizing its utilization and providing dynamic and flexible flight paths. Airspace organization involves optimization of a structure of airspace, its classification, placement of air traffic services routes, as well as applicable visual and instrument flight procedures. These optimizations are conducted in accordance with standards and recommendations set by ICAO GANP [1]. It becomes clear that current navigation aids gradually become outdated and, as a result, they are not able to meet requirements of modern aircraft systems. The next stage of the development of air navigation is closely tied to use of GPS, GLONASS and GNSS for civil aviation purposes. These systems allow to receive signals from satellites, enabling determination of object coordinates from any place around the globe, these systems pro-vides greater reliability and accuracy. They are also more stable against atmospheric conditions, which increases airspace capacity, provides economic bene-fits, and reduces impact of human factors. Additionally, an innovative concept Performance-Based Navigation (PBN), is utilized to enhance aviation safety, improve aircraft flight performance, increase airspace capacity and enhance air navigation services [2]. Under these circumstances the development and implementation of innovative on-board technologies become critical, and it requires more proactive approach and further enhancement, which might also include new functionalities and technologies, such as: on-board Automatic Dependent Surveillance–Broadcast/Contract (ADS-B/C), MLAT-Multilateration, Controller and Pilot Data Link Communication (CPDLC), Airborne Collision Avoidance System (ACAS) and others. Fig. 1 shows schematic diagram of a logical architecture of ATM system. It is seen and understood that infrastructure capabilities and avionics avail-able on board define operational capabilities of ATM [3].

Ground based satellite navigation and innovative technologies are in active phase of implementation on a global, regional and national levels proposed by the GANP activities, in order to increase capacity, efficiency, and accuracy of ATM system. Every ICAO member state is requested to fulfil GANP requirements and implement the best international practices and standards in their Air Navigation Service Providers (ANSP's) operations.

Human performance related considerations is one of the key elements which focus areas should be taken into account in effective modernization of ATM

system on any level- global, regional or national. Here are some of examples which should be considered:

- Quality of initial training of new personnel;
- Familiarization and hands-on training procedures for new staff;
- Requalification process for currently active professionals;
- Introduction of new knowledge, skills and attitudes;
- New roles and responsibilities;
- Social factors and management of changes in daily routine caused by increased level of automation [2].

Main issue in more active implementation of the GANP is that currently there are no common requirements for all categories of ATM personnel, moreover, the development of ATM technologies is faster than training of personnel with ap-propriate qualifications. This problem is critical in countries, which have started an active modernization of ATM infrastructure in last few years. In particular, Latvia and Georgia are among these countries. The table 1 shows the progress made so far in Single European Sky ATM Research (SESAR) essential operational changes. In the implementation of the SESAR phases based on the official statistics of the EUROCONTROL (LSSIP 2022 – Local Single Sky Implementation, Latvia, Georgia) [4,5].

An additional issue in that circumstance is that, as official investigation reports and statistical data of aviation accidents and incidents proves, there are still several factors, that have a direct connection with the incomplete human competencies and procedural errors in the ATC maintenance process [6,7].

II. RESEARCH METHODOLOGY

As a key instrument to solve above mentioned problem and fulfill the objectives, the following methods have been used to obtain necessary information: literature analysis, widely analysed current theoretical and practical works of scientists in the aviation field common research area. Also the synthesis of information from reports, strategies, working plans, broadcasts, analytical documents, and useful data proposed from international aviation organizations (ICAO, FAA, EUROCONTROL, SESAR), the processing of official investigation reports on aviation accidents and incidents. In order to achieve the aims of the research basically used analysis, synthesis, statistical, and comparison methods.

In particular, for statistical data processing SPS retail analytics software used, for getting feedback from the aviation professionals organized data collection methods and different types of survey tools: telephonic surveys, face-to-face surveys, online surveys, and focus groups. Collected data based on the information gained from specific data sources from airlines, ANSPs, and aviation educational institutions representatives analysed by using the following methods: gap analysis, SWOT analysis, and text analysis. Investigation content was oriented and linked to the gap between innovative technologies implementation specific technical characteristics and aviation professionals' real knowledge/skills requirements.

The main aim of the research (Fig.3) is to develop a methodological approach based on gap analyses and modelling, that determines logical relationship between air traffic management system and on-board innovative technologies and also connects learning outcomes of the proper training or studies programmes with human performance development [8].

The main objectives of the research are as follows:

1. To create a taxonomy of ATM innovative technologies, onboard modern systems, and human performance;
2. To propose a methodology for assessment of the gap between the implementation of ATM and avionics innovative technologies, taking into account human factors;
3. To design, implement, and evaluate an approach for educational courses, syllabi and modules development in ATM and avionics technicians/engineers preparation educational programs.

The main three open questions of the research are as follows:

1. Which main function parameters are enhanced by the implementation of innovative technologies in avionics and ATM systems operation?
2. What theoretical and practical parts should utilized in educational courses and syllabi in parallel with technological environment changes?
3. Which new tasks should be integrated into training program content, and how should maintenance tools and job aids be accordingly organized?

The main contribution of this work is, that by putting developed models into practice together with enhanced ergonomic factors in the new technological environment of ATM and on-board systems, it is possible to harmonize them effectively, which represents the scientific value of the research and validated as a part of key result at increased level of flights safety with enhanced competencies of involved aviation professionals. Fig. 4 shows a taxonomy of human factors and training in system design. From it is seen that human factors- related topics involve all parts of theoretical and practical training, for this reason it is necessary to take into account that human factors is present from a very beginning of training until the end.

In order to obtain information about ATM systems currently developed or introduced, a surveys and interviews of professionals in ATM technical support,

airlines and aviation training and education institutions had been done in several companies. For the purpose of data and privacy protection names of these companies are not published. Later information obtained was categorized and organized in a way to ask Latvian and Georgian representatives to express their opinion regarding the mentioned systems or tools in their ANSPs. Taxonomy and classification of these systems or tools was done in respect to influence on aviation professionals' everyday work routine. Table 3. and Table 4. show a summary of obtained information from surveys and interviews.

III. EARLY RESULTS

In order to assess the impact of changes in radio navigation and surveillance equipment used in ATM on users- pilots, air traffic controllers, technicians - it is necessary to analyse how equipment has changed and is the data provided by such equipment more appropriate or not. Accuracy and reliability of beacons have been taken as key factors, because this is what defines such operational criteria of ATM as availability of airspace, airspace sector capacity, separation minima applicable between two or more aircraft, air traffic controller's (ATCO's) workload, and consequently - ATCO's level of stress and afterward level of fatigue [9]. AT THE FIRST STAGE OF RESEARCH PRESENTED METHODOLOGY FOR ASSESSING THE ACCURACY AND RELIABILITY OF THE RADIO NAVIGATION AND RADAR SYSTEMS WIDELY USED FOR TODAY, IN PARTICULAR, VERY HIGH FREQUENCY OMNI DIRECTIONAL RADIO RANGE (VOR), DISTANCE MEASURING EQUIPMENT (DME), THE INSTRUMENT/MICROWAVE LANDING SYSTEMS (ILS/MLS) AND THEIR PROPER ON-BOARD SYSTEMS. MATHEMATICAL CALCULATIONS, AS WELL AS METHODS OF ANALYSIS AND SYNTHESIS WERE USED TO DETERMINE THEIR OPERATION COMPLIANCE WITH MODERN TECHNICAL REQUIREMENTS AND NORMS SET BY INTERNATIONAL AVIATION ORGANIZATIONS, AND A TAXONOMY OF THE MAIN PROBLEMATIC ISSUES WERE CLASSIFIED [10].

A methodology for partially solving the above-mentioned problematic issues is proposed, including ways to increase the accuracy of the VOR radio beacon.

The formula for the dependence of phase on azimuth is given:

$$U = U_m[1 + m\cos(\Omega t - \alpha)]\cos\omega t \quad (1)$$

Where m is the modulation coefficient; Ω - rotation frequency of the moving antenna; α - azimuth of the aircraft; ω - angular frequency of high frequency oscillations.

Several modifications to improve the accuracy of a VOR radio beacon using the formula are given in Table 2.

Mathematical calculations has established practical approaches to extend also the DME and bring it into line with ICAO requirements [11]:

$$D^2{}_d = R^2 + (R+H)^2 - 2R(R+H)$$
$$\cos\eta = 2(1-\cos\eta)(R^2+RH) + H^2 \quad (2)$$

Arc of spherical length at distances of no more than 600-700 km

$$D^2{}_d = 4\sin^2\frac{\eta}{2}(R^2+RH) + H^2 \rightarrow \sin^2\frac{\eta}{2} = \frac{D^2{}_d - H^2}{4(R^2+RH)} \quad (3)$$

So

$$\sin^2\frac{\eta}{2} = \sin^2\frac{D_s}{2R} = \frac{D^2{}_d}{4R^2}$$

Than

$$\frac{D^2{}_s}{4R^2} = \frac{D^2{}_d - H^2}{4(R^2+RH)}; \rightarrow D_s = \frac{\sqrt{D^2}{}_d - H^2}{\sqrt{1+\frac{H}{R}}} \quad (4)$$

Based on the research compared to the metric range ILS and MLS systems with following main advantages: increased accuracy and protection from obstacles; great reliability; providing wider airspace coverage, take-off management; runway and ground traffic management. The MLS device operates in the 5 GHz band. Compared to the ILS system, the MLS system provides an azimuth overlap in the forward sector up to ±60°, with an elevation angle of 10-20°.

Different methods of increasing the effectiveness of ground radar and on-board systems have been investigated, however, the implementation of the mentioned techniques in practice, based on the data of international aviation organizations, is insufficient to meet the airspace safety requirements expected by ICAO Annex 19 and GANP 2016-2030 [1,2]. Based on it research work focused on analysis of the implementation of alternative innovative technologies necessary to meet the increased requirements caused by the growth intensity of flights, in order to successfully solve the given problems: lower material costs, provide easy technical service, increase accuracy, reliability and meet the safety requirements imposed on the system. In particular, the ways of automatic solution of navigation tasks are classified below, which should ensure the quality of adjustment of flight modes, especially the quality of transition processes [11].

- Frequency (aperiodicity);
- Shortness (short time constant);
- Astatism (absence of systematic error after the end of transient processes);
- Sustainability.

In order to fulfill these tasks, it is necessary to implement innovative technologies in the ATM system, on the ground, and in the cockpit. For example, alternative radio broadcasting technology of aircraft navigation service ADS-B, ADS-C, and Multilateration (MLAT) system, in the work

mathematically developed, an algorithm of operation of each system and classified their advantages in relation to existing analogues [12].

The closed form of the lateralization algorithm allows to establishment of linear relationships between the parameters as a result of mathematical transformations and doesn't require prior knowledge of any information about any aircraft. For these reasons, the closed form of the lateralization algorithm is adopted in practice. Determine how aircraft coordinates are obtained using the hybrid Time Difference of Arrival (TDOA) lateralization algorithm. Let's assume that the first stage has already been completed and time readings have been received from the antennas [13].

If τ_I is TDOA measurement performed by the principle, which is defined by the i number of antennas whose coordinates are: (x_i , y_I , z_I). Then, the equation that defines X = (x, y, z) from the transmitter to the antennas TDOA measurement of received signals will have the following form:

$$\tau_i = \sqrt{\frac{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2}{c}} \quad (5)$$

Where c = 3 x 10^5 km.

Eq. (5) describes the non-linear relationship between aircraft location (x) and TDOA measurement (τ). If we square both sides of the equation, then equation will take the form:

$$(\tau_i \times c)^2 = (x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 \quad (6)$$

By further simplifying formula (6), will have:

$$(\tau_i \times c)^2 = (x^2 + y^2 + z^2) - (2_{xxi} + 2_{yyi} + 2_{zzi}) + (x_i^2 + y_i^2 + z_i^2) \quad (7)$$

Designation:

$$\tau_i \times c = R_i, \quad R = (x^2 + y^2 + z^2), \quad K_i(x_i^2 + y_i^2 + z_i^2) \quad (8)$$

If enter the formula (8) into (7), then will get:

$$R_i^2 = R - (2xx_i + 2yy_i + 2zz_i) + K_i \quad (9)$$

In the case of 4 receiving antennas, will have:

$$R_1^2 = R - (2xx_1 + 2yy_1 + 2zz_1) + K_1 \quad (10a)$$

$$R_2^2 = R - (2xx_2 + 2yy_2 + 2zz_2) + K_2 \quad (10b)$$

$$R_3^2 = R - (2xx_3 + 2yy_3 + 2zz_3) + K_3 \quad (10c)$$

$$R_4^2 = R - (2xx_4 + 2yy_4 + 2zz_4) + K_4 \quad (10d)$$

Based on the mathematical calculations it is clear, that the optimization of the functional parameters in different systems and antennas provides the possibility of large-scale and more effective use of different satellite navigation-based innovative alternative systems, 4D trajectory operations, SBAS/GBAS, MLAT, ADS-B, ADS-C, and other innovative ATM technologies compared to primary and secondary radars significantly reduce material costs, facilitate maintenance work required for system operation, and increase the level of reliability (fewer errors, better security, more exploitation period), efficiency, and accuracy of the air traffic control system. In-depth technical analyses of the mentioned systems' characteristics, provided multiple benefits to both pilots and air traffic controllers, increasing flight safety and efficiency [14].

In particular:

1. Traffic - When using the ADS-B system, the pilot has access to information about the surrounding aircraft. This information includes altitude, direction, speed, and distance to the aircraft;
2. Flight Information - Flight Information Service-Broadcast (FIS-B) transmits flight information such as Temporary Flight Restrictions (TFRs) or notices issued by aviation authorities to aircrafts. Which notify pilots of potential hazards on routes or specific locations (NOTAMs);
3. Cost - ADS-B ground-based radars are significantly less expensive to install and operate than primary and secondary radar systems. Unlike alternative flight weather services that are offered commercially, subscription fees are waived when using ADS-B service and its other benefits;
4. Reduced negative impact on the environment - ADS-B technology provides accurate calculation of aircraft position. This allows air traffic controllers to direct air traffic in or out of congested airspace in less time than previously possible, it reduces aircraft delay time, allowing the aircraft to continue smoothly in the appropriate direction, and using ADS-B it is possible to track landing trajectories improvement and time reduction as well, which is expressed as a positive effect on the harmful impact on the environment and fuel consumption as well as reducing the noise level.

The advantages of the mentioned systems are expressed by meeting the requirements of EUROCONTROL and ICAO, technical testing showed that the mentioned systems significantly exceeded the previous systems in detecting defects, this number reached a percentage of 98%, and the accuracy and quality of work were also improved. Based on the innovative technologies developed many concepts for ATM technical parameters optimization, a fully operational ADS-B system (ADS-B Out and ADS-B In) requires all aircraft to be equipped with certified ADS-B avionics, certified ADS-B ground stations with complete airspace coverage and globally agreed operational procedures [15]. Fig. 5 provides the developed concept of ADS-B systemic use for

ground and on-board technologies effective interconnection example.

In parallel with technical parameters optimization and new technologies implementation in ATM system, aviation professionals have an essential role in the transition to and successful realization of the process. It is therefore critical that the concepts being developed consider the strengths and weaknesses of existing and future skilled personnel at every juncture [1,15]. All actors with a stake in a safe air transportation system will need to intensify efforts to manage risks associated with human performance and the sector will need to proactively anticipate interface and workstation design, training needs, and operational procedures while promulgating best practices [16].

The research identified competencies of personnel that require development in order to meet the requirements of modern ATM technologies, analysed the gap between the training curricula learning outcomes and the industry requirements, proposed the modelling and methodology for harmonized and best scenario of integration new technologies and human factors based on the taxonomy and validated classification of technologies and ergonomics [17].

IV. CONCLUSIONS AND FUTURE STUDY

Case studies have been handled in order to identify possible gaps in the training of aviation personnel involved air traffic controllers, pilots, and ATM engineers/technicians. Based on the research identified and considered examples of recently developed and introduced new technologies that either are already used or might be used in the near future in Latvia and Georgia.

The technologies considered are summarized in a table 4.

In the research different technologies have been analysed and the conclusions have been made:

- New software technologies or tools are designed to make operational processes more flexible and to make air traffic controllers more reliable by introducing more automation, where automation analyse parameters and gives solutions. Risk: Air traffic controller step by step gets used to automation and loses skills in manual operation, consequently
- Unable to complete tasks without automation, and not having enough skills for manual operations;
- New radio navigation tools were introduced to increase the accuracy of systems and reliability of service. Risk: GLS is based on GPS, PBN is based on GPS. Might experience some difficulties if GPS is lost;
- New specific functionalities for air traffic controllers and pilots require a more detailed understanding of operational procedures of air traffic control or pilotage of aircraft to keep systems operational. Risk - technicians unable to fix problems due to lack of knowledge in pilotage of aircraft or air traffic control procedures [18].

The effectiveness of human performance should be taken into account both at the stages of planning and designing new systems and technologies, as well as during their implementation and operation. In order to prevent the risks caused by human errors, their extensive and reliable management cannot be achieved without the coordinated efforts of regulatory authorities, service providers, operating personnel with the following measures:

a) Stress management during critical incidents in order to provide rational assistance to relevant personnel;
b) Detection of problems related to the human factor and appropriate processing;
c) Fatigue and sleep management for shift workers, providing them with knowledge and strategies useful for better sleep management, as well as managing fatigue risks;
d) Predicting and managing the new potential forms of errors caused by the human factor, which arise as a result of the use of new technologies;
e) Development of training courses and guidelines (Table 3), which allows for better reduction of problems caused by the human factor [19].

As a result, this research shows that on the one hand every new system, tool, or function introduces more reliable parameters of characteristics, but on the other hand - more attention should be focused on personal training and maintenance procedures [20]. More harmonized interconnection of the main three research tasks provides increased safety, capacity, and efficient level of ATM operation for the future growth requirements of air transportation in Latvia, Georgia, and globally. With the fast-growing and high-density global air traffic, ensuring efficiency and air transportation safety becomes a critical challenge. Innovative technologies and automatization are already revolutionizing the way air traffic management systems are manufactured and hence is believed to play a key role in optimizing air traffic flow [21].

At this stage of the research continue the investigation to fully answer the open questions and effectively translate the gained results to training programs, tools, and job aids. The recommendations of the research obtained international experience and are possible to be provided, for both, aviation training institutions as well, for air navigation service providers, and have a positive impact on the further development of the aviation industry.

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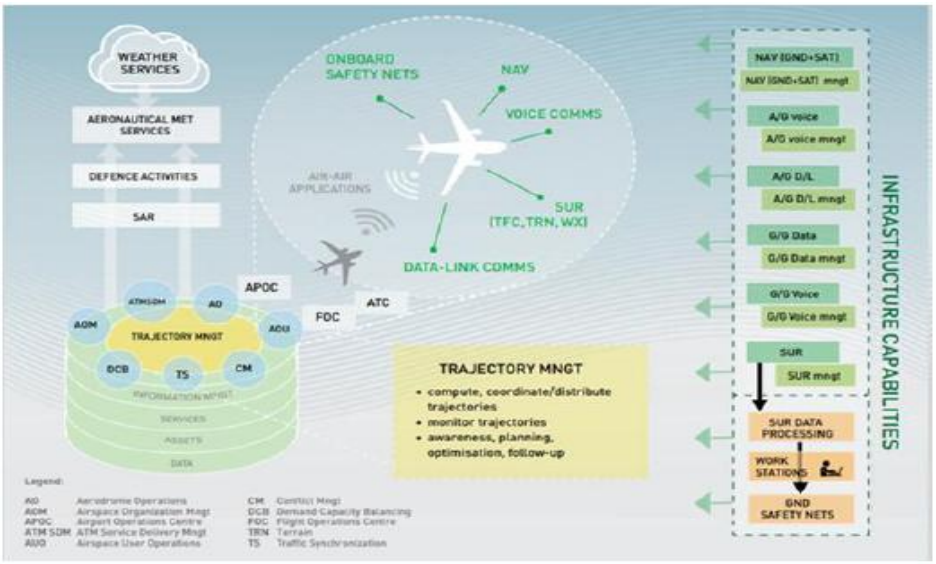


Fig. 1. ATM logical architecture (ICAO)



Fig. 2. GANP implementation structure on national level (ICAO)

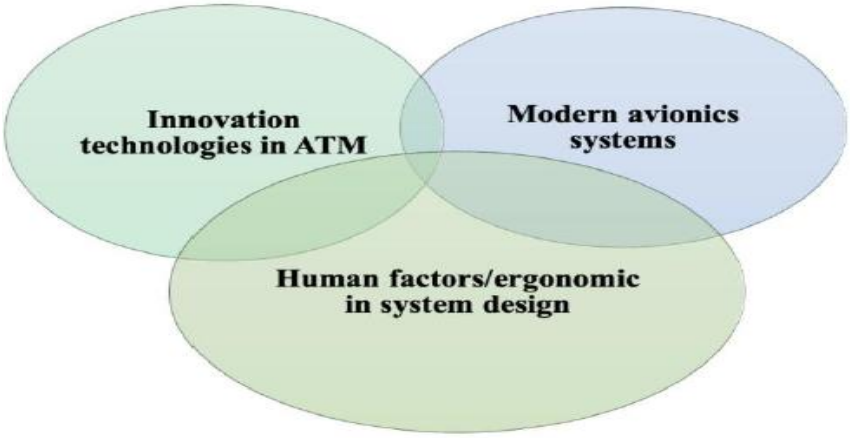


Fig. 3. Vienne diagram for graphic representation main aim of the research

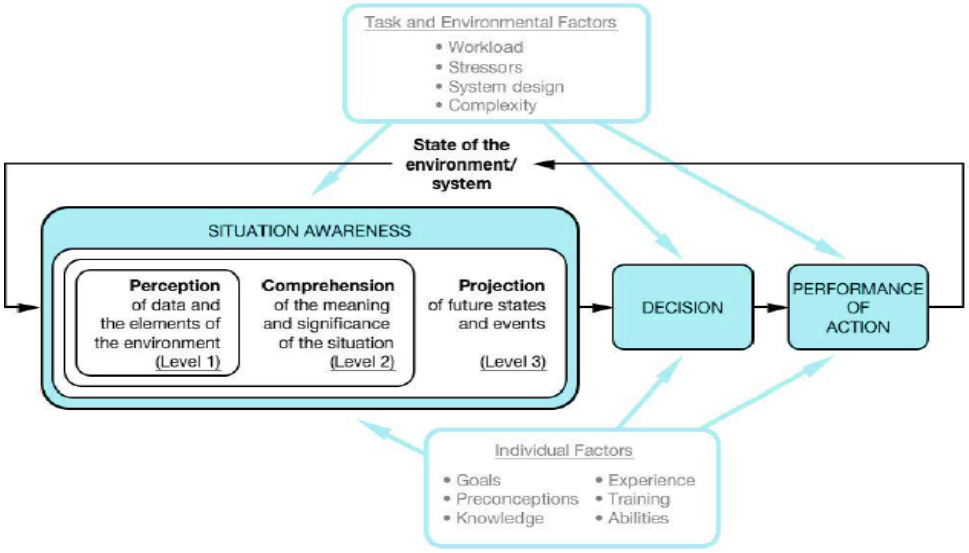


Fig. 4. Taxonomy of human factors/training as categories in the system design

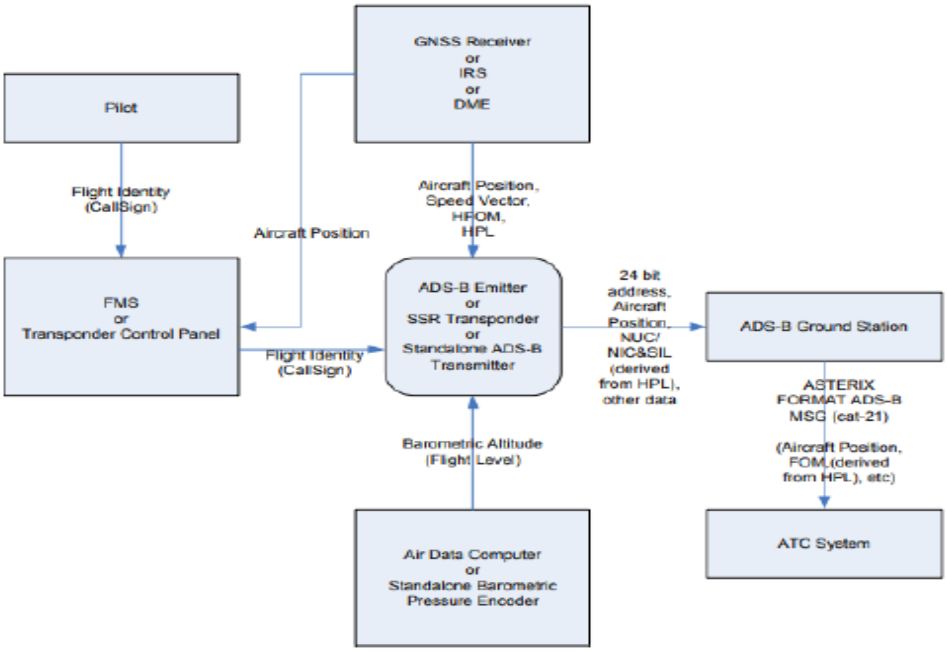


Fig.5. ADS-B diagram as an enhanced concept of ATC system

Latvia	Georgia	Essential Operational Changes in ATM system
100%	100%	Interconnected ATM Networks
91%	84%	Traffic Management System (TMA) and Airport Performance
87%	82%	Infrastructure and Services of Communication and Navigation Systems (CNS)
100%	100%	Digital Aeronautical Information Management (AIM) and Meteorological (MET) Services
100%	90%	Fully Dynamic and Optimised Airspace
100%	100%	Trajectory Based Operations

Table 1. SESAR essential operational changes (Latvia and Georgia)

Radio Beacon	Azimuth measurement error (deg)	Note
VOR	2.5	
DVOR	1.5	D- Doppler
PDVOR	0.8	P- Precision
PDVOR(H)	0.5	H- High
PDVOR(M)	*0.3*	M- Medium

Table 2. VOR radio beacon validated modifications

Taxonomy of avionics modern technologies for better integration in system design	Taxonomy ATM innovation technologies implementation in system design	Principles for a better integration of human factors/ergonomic (HF/E) in system design	Recommended tasks for synthesis in curricula and syllabi
On-board Automatic Dependent Surveillance – Broadcast (ADS-B)	Optimization of approach procedures including vertical guidance, by using of performance-based navigation (PBN) and ground-based augmentation system (GBAS)	Build joint design teams and don't treat HF/E as a mandatory add-on	Implementation of the ICAO Manual on Air Traffic Safety Electronic Personnel (ATSEP) requirements in the educational programs of ATC systems engineers and technicians
Control and Pilot Data Link Communication (CPLC)	Increased runway throughput through optimized wake turbulence separation Improve traffic flow through sequencing (AMAN/DMAN)	Make a coherent user centered design logical HF/E product	Development of new syllabi and educational courses in the following area: Safety management of navigation aids, technical maintenance principles, GNSS modern systems, automatic flight control systems and etc.

Electronic Attitude Direction Indicator (EADI)	Safety and efficiency of surface operations and enhanced vision systems (EVS)	Trying for a short, iterative user-centered design process	Strengthening the teaching of the ATM and on-board innovative technologies interconnections and functionalities
Electronic Flight Instrument System (EFIS)	Improved airport operations through. Increased interoperability, efficiency and capacity through ground-ground integration	Develop objective HF/E criteria instead of following user opinions	Add the following new tasks in content of syllabus: modern pilotage-navigation complexes and new trends in air navigation, electrostatic sensitive devices, and software management control.
Electronic Horizontal Situation Indicator (EHSI)	Service improvement through digital aeronautical information management	Assess as early as possible with the help of different prototypes	Development of content for the following educational courses: Performance Based Navigation, Ultra High Frequency use in new radar and communication systems.
On-board Automatic Dependent Surveillance – Contract (ADS-C)	Meteorological information supporting enhanced operational efficiency and safety	Select convenient conditions for assessment: Evaluate daily operations as well as critical decisions and solutions	Enhancement of the syllabi for modern electricity supply and lighting equipment of airports, modern GPS/GNSS use in radionavigation and surveillance and others.
MLAT-Multilateration and Airborne Collision Avoidance System (ACAS)	Improved operations through enhanced en-route trajectories. Improved flow performance through planning based on a network-wide view	Help to be organized the problem-solving process during implementation by facilitating trade offs	Integration of the new systems and technologies in the syllabi's where teaching TCAS and MLAT systems different modifications

Table 3. Methodology for derivation and validation of the new taxonomy

Change: new system or technology	Impact on air traffic control (ATC)	Impact on pilots	Impact on ATM engineers/ technicians	Risks
Cockpit layout - A liquid-crystal displays (LCD)	No impact	Better quality picture	Different principle of operations	Incompatibility with other systems
New functionality-CPDLC	Additional tool to use when air traffic intensity is low New operational procedures New functional window to pay attention to	Additional tool to use when air traffic intensity is low One more system to pay attention to New operational procedures	Complicated programming of the system, necessity to understand key issues, functions required by ATC and pilots (layout, message types, formats of messages, response times etc.)	Missed information due to inappropriate programming of messages Inability by technical personnel to fix issue due to lack of knowledge in pilotage or ATC
New flight parameters displayed or available – angle of attack	No impact	Additional parameter available which might influence safety of a flight	New parameter to distinguish, calculate and fix if necessary	Inappropriately shown parameter

New software tool for air traffic controllers- AMAN	New ATC tool which helps in approach phase to organize air traffic. But needs additional training to start using it and training when system becomes operational so that controllers are able to control traffic in case of failure of this system	Possibly shorter approach trajectories	New software functionality which can become inoperative	Air traffic controllers unable to work normally without this system. Engineers unable to understand problem of system's functionality which is vital for controllers because of lack of knowledge in air traffic control
Circle around radar blip to indicate which aircraft calls Air Traffic Controllers (ATCO)	Faster response time to a call from a pilot Easier to determine which aircraft calls	Possible faster reaction from ATCO	New item on list which should be checked New item on the list which can malfunction	ATCOs get used to the indication, unable to keep time of response within normal limits when the function is not available
New navigation aids available - Ground Based Augmentation System (GBAS) Landing System (GLS) - Performance Based Navigation (PBN) approaches	New approach trajectories, which are more flexible to environment and layout of an aerodrome	New flight trajectories	Use of additional systems (Global Positioning System GPS + GBAS), system compatibility	Systems incompatible

Table 4. Data-driven risk assessment and modelling for effective interconnection of inno-vative on-board and ATM technologies taking into account human factors

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