Research Article

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Risk factors for the operational safety assessment when implementing performance-based navigation (PBN)

Abstract

The paper considers the influence of human performance on the capacity of air traffic control system for the improvement of the airspace structure based on Performance Based Navigation (PBN) characteristics. The aim of the study is to address the risk factors are considered necessary for the Flight Operational Safety Assessment (FOSA when implementing PBN and also to address the need for Air Traffic Management (ATM) to apply FOSA. FOSA ensures that in respect of a particular set of operating conditions, system capability of air traffic control and environmental conditions is evaluated for all situations and, if necessary, steps are taken to reduce risk for meeting criteria of safety. In the process of the research mathematical modeling and the method of expert evaluations used. When we research the risks associated with ongoing operations at landing were assessed, in the transition from RNAV schemes to the flight along the most classical routes, it was revealed that the air traffic controllers affected by a large number of negative factors (i.e. change of the separation minima, the complication of flight conditions, reduced time in decision making), which can be accounted for through the coefficients of workload of air traffic controller. Consequently, measures to reduce risks to meet the criteria of safety when testing schemes of maneuvering in the terminal area can be concretize.

Volume 2 Issue 6 - 2018

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Received: September 04, 2018 | **Published:** November 23, 2018

Nomenclature

λ	=	aircraft per hour
μ	=	aircraft per hour
t	=	hour
N	=	quantity of aircraft
dt	=	time step
Fy	=	value of the factor of fatigue

Introduction

The Performamce Based Navigation (PBN) concept was introduced to reduce exhaust emissions, minimizing the impact on the environment and reduction of engine noise by reducing the length of the routes. Ecology improves due to the fact that in the organization of flights in the airspace the requirements associated with the environment are given the same level of priority, similarly the requirements for increased capacity airspace. The routes of aircraft in the terminal area should be plotted with minimum impact on the environment, optimal flight efficiency, and safe obstacle clearance. At the same time, the system of air traffic control solves problems to ensure Air Traffic Management (ATM) for all routes in the complex. From the point of view of the air traffic control, unit airspace structure should also take into account the interaction between flows of arriving and departing aircraft. These different goals are not mutually controversial. It is possible to build routes in the terminal area and to implement the most obviously conflicting objectives. Care must be taken to select points of intersection of the routes of departure and arrival in order to avoid possible interference with the arriving and departing aircraft. In Russia the PBN concept is introduced in accordance with the Plan of implementation of PBN in airspace of the Russian Federation (Protocol dated 15.11.2013 No. 3-62-etc.). Guidance for the use of PBN, in airspace, is included in Doc.9992 AN/494 and Guidelines for operational approval based navigation (PBN), Doc. 9997. The process of improving the airspace structure provides for the testing of schemes of maneuvering in the terminal area. The aim of the study is the need to address the risk factors are considered necessary for the Flight Operational Safety Assessment (FOSA when implementing PBN and also to address the need for ATM to apply FOSA. The application of FOSA ensures that in respect of a particular set of operating conditions, system capability of air traffic control and environmental conditions is was evaluated for all situations and, if necessary, steps were are taken to reduce risk for meeting criteria of safety.

Methodology

Previous researches indicate that disruptions in the air traffic work of controller, leading to dangerous air proximity and other violations of the separation minima occur with intensity (λ) equal to 26-30 aircraft per hour, depending on the structure of the simulated area.[1] In the General case, the capacity of the airport depends on air space management; equipment capabilities and air traffic controllers. Human capabilities are severely limited compared with the possibilities of the hardware. In this case, the capacity of controller (etco) $\mu_c \leq 30$ aircraft per hour, which is 10-15 less than the allocated airspace capacity μ_{area} and capacity automated systems μ_{AS}. An indicator of workload can be calculated by the percentage of time spent on direct management of the aircraft flow control, to the share of the working time of the controller.

$$K_{OCC} = t_{OCC} / t_{WORK} \qquad (1)$$

t_{OCC}– total time of employment; t_{WORK} -time or interval that determines the workload.

The controller's capacity means the ability of an air traffic controller to ensure safe operation of the maximum possible flow of aircraft using existing technical means, in particular the airspace structure and set of navigation aids. Experimental analysis of the activities of air traffic controllers determined the upper limit of the allowable load of the air traffic controller K≤0,75 and rational utilization K≤0,55. The occupancy factor

$$K_{OCC} = K_0(N)\lambda + K_{P.C.S.}(N) \qquad (2)$$

$K_0(N)$ –is the indicator defined by the average time on control over one aircraft, in the absence of a conflict situation; $K_{P.C.S.(}N)$ – a measure of workload determined by time spent on the control of one aircraft in a conflict situation; $N=\lambda T_{MIDL}$–the number of aircraft which are simultaneously under control of the controller;

$$N=\lambda T_{MIDL} \qquad (3)$$

λ–the intensity of air traffic

The values of λ and T, corresponding to K_{OCC} are accepted as a standard ($\mu=\{\lambda_{NORM}, N\}$). Today applied a function in automated systems Arrival Management (AMAN), which allows to increase the capacity of the airfield area as a result of automation of processes of forming the flow of arrival aircraft converging at fix. But today AMAN tools are not a means of conflict resolution and intelligent control. The air traffic controller determines the instructions corresponding to the recommendations of the AMAN by a delay (or acceleration): vectoring, the extension of the route, the speed change, special procedures. That is, decision making for conflict resolution lies with the air traffic controller, regardless of the level of automation. In the analysis of measures to reduce risks there were considered cases of emergencies, covering a wide range of complex risks, for example, failure of Ground Basic Augmentation System (GBAS) or Global Navigation Satellite System (GNSS), resulting in different critical points (for example, plot the Initial Approach Fix(IAF) at the beginning of the procedure when there is potentially a long exit from the schema, or above the Decision Altitude/Decision Height (DA/DH). This raises a range of risks associated with current operations approach, especially with the transition from (RNAV) (area navigation) flight classic routes. This is especially important if you experience a short-term conflict situation, when time to violate minimum separation is less than 80-120 seconds.

Results

In the process of the research mathematical modeling and the method of expert evaluations used. When the risks associated with ongoing operations at landing were assessed and evaluated, in the transition from RNAV schemes to the flight along the most classical routes, it was revealed that the air traffic controllers affected by a large number of negative factors (i.e. change of the separation minima, the complication of flight conditions, reduced time in decision making), that can be accounted for through the coefficients of workload of air traffic controller. The introduction of the coefficients of workload can be seen as an increase in the intensity of error flow of air traffic controller. In case of exceeding threshold values of the employment of air traffic controller there may be after emergency situation at some time t_y, a controller fatigue begin grows over time (i.e. Fy. – the current value of fatigue factor, $Fy._{NOM.}$ –the nominal value of the factor of fatigue).

k–coefficient of proportionality; K_{OCC}.Y–the coefficient of workload fatigue. Monitoring of specific air traffic controller allowed us to obtain his average number of errors, believing that an air traffic controller has not changed, is aware of the particular upcoming moment and the difficulties that will be present.[2]

Putting the K_y in one of the summands and, for certainty, $t_{y_1} \overset{t}{\in}, t$ can be written:

$$P(t) = \int_{ty}^{t} e^{-Knf\lambda t} dt = \int_{ty}^{t} e^{-kt\lambda t^2} dt = \int_{ty}^{t} e^{\frac{-t^2}{\frac{1}{\lambda k}}} dt = \begin{bmatrix} \dfrac{t}{\frac{1}{\sqrt{\lambda k * 2}}} = u \quad t = \dfrac{u}{\sqrt{\lambda k^2}} \\ dt = \dfrac{1}{\sqrt{\lambda t * 2}} du^{\alpha} = \sqrt{2\lambda k * t_y} \end{bmatrix} =$$
$$= \int_{u}^{\beta} e^{\frac{-u^2}{2}} \frac{du}{\sqrt{\lambda k 2}} = \frac{\sqrt{2\pi}}{\sqrt{2\pi\sqrt{2\lambda k}}} = \int_{\alpha}^{\beta} e^{\frac{-u^2}{2}} du = \sqrt{\frac{2\pi}{2\lambda k}} \left(\frac{1}{\sqrt{2\pi}} \int_{\alpha}^{\beta} e^{\frac{-u^2}{2}} du \right) \qquad (5)$$

The expression in brackets is the integral expression

$$\left(\frac{1}{\sqrt{2\pi}} \int_{\sqrt{2\lambda kt_y}}^{\sqrt{2\lambda kt}} e^{\frac{-t^2}{2}} dt \right) \sqrt{\frac{\pi}{\lambda k}} = \sqrt{\frac{\pi}{\lambda k}} \left[F\left(\sqrt{2\lambda kt}\right) - F\left(\sqrt{2\lambda kt_y}\right) \right] \qquad (6)$$

The function λ (t) consists of a set of piecewise smooth functions with discontinuities of the first kind. The law of air traffic controllers error detection is an exponential law. The probability of faultless operation of the air traffic controller can be obtained by integration.

$$P(t) = \left(1 - \frac{e^{-\lambda_1 t_1}}{\lambda_1} \right) + \left(\frac{e^{-\lambda_2 t_1}}{\lambda_2} - \frac{e^{-\lambda_2 t_y}}{\lambda_2} \right) + \sqrt{\frac{\pi}{\lambda k}} \left[F\left(\sqrt{2\lambda kt_2}\right) - F\left(\sqrt{2\lambda kt_y}\right) \right] +$$
$$+ \left[F\left(\sqrt{2\lambda kt}\right) - F\left(\sqrt{2\lambda kt_2}\right) \right] t \in (t_2, t_3) \qquad (7)$$

This interval is not fully expressed in elementary functions and can be computed numerically using the mathematical package or spreadsheet. For the simulation of potentially conflict situations there is used an integrated control simulator. The exercises were developed, which model a conflict situation arising in the event of an emergency. In one monitoring exercise an arbitrary number of conflicts of various kinds were included. As experts there were involved air traffic controllers (students and instructors). With the help of integrated air traffic control simulator "Expert" there was modeled an area of airport Kurumoch Samara. There were considered landing approach charts in the airport on RW 33. When performing approach on the RNAV routes, the flow of aircraft from the North-East and North-West direction were directed to the IAF point, and from a southerly direction to a point IF. The flow of aircraft does not overlap (Figure 1) when performing approach under the classical scheme the flows of aircraft have complex intersections (Figure 2).

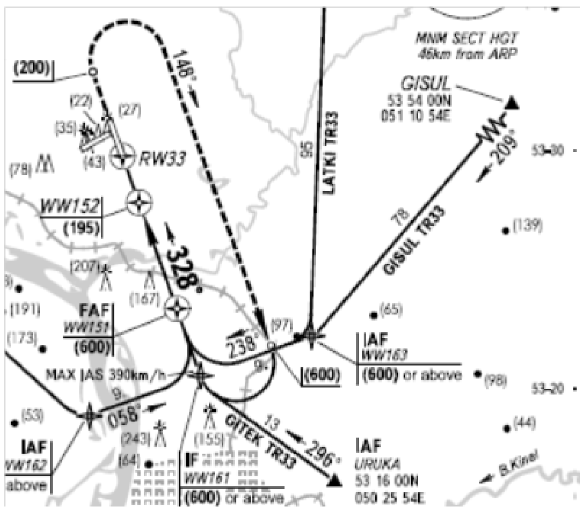

Figure 1 Part of the circuit on the final approach on the classic routes, the airport KURUMOCH RWY 33.

In case of GBAS failure and changes in Required Navigation

Citation: Borisov V. Risk factors for the operational safety assessment when implementing performance-based navigation (PBN). *Aeron Aero Open Access J.* 2018;2(6):390–392. DOI: 10.15406/aaoaj.2018.02.00070

Performance (RNP) downwards the shifting flows of aircraft through more complex fly path. As a result, the load on the air traffic controller increased in the simulation of GBAS failure and reduced the effectiveness of calculate potentially conflict situations. Therefore, if you implement a new RNAV approach for approaches with separation of aircraft, it can result in a significant change in the system of air traffic control, with consequences for the workload of controllers (Table 1).

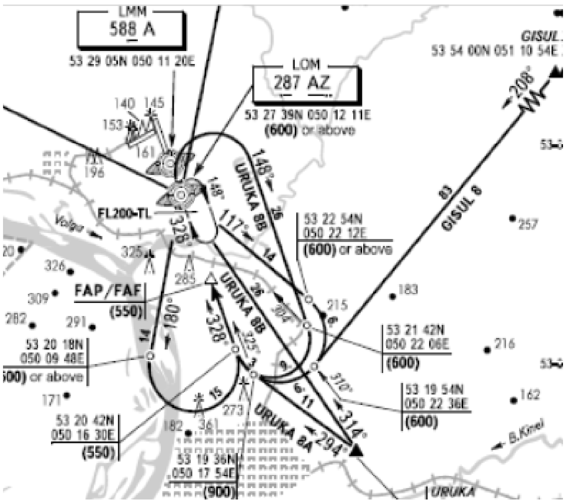

Figure 2 Part of the scheme of landing approach on the classic routes, the airport KURUMOCH RWY 33.

Table 1 Averaged errors of air traffic controllers

Session time	Instructors	Cadets
In 30 minutes	0,4	0,7
In 1 hour	0,5	0,9
In 1 hour 30 minutes	0,9	1,3
In 2 hour	1,1	1,8

The presence of the restricted airspace in the charts of approach to the airfield with various navigation specifications (RNP), the sudden decrease in accuracy of performance of flight N-the number of aircraft simultaneously, greatly increases the workload of the air traffic controller. In the initial period of time the increase does not impact the effectiveness of decision-making on conflict resolution. But in the future, the probability of error P(t) linearly increases. Therefore, if you implement a new RNP approach for approaches with separation of aircraft, it can result in a significant change in the system of air traffic control, with consequences for the workload of controllers.[3–5] To study the reaction of air traffic controllers to the risk factors identified in the framework of FOSA, we need to make modeling in real-time format. However, in cases where the new scheme RNAV approach involves only minimal ATC changes, such ATC simulations may not be needed. In the case of implementation of RNAV approach where the main safety issues relate to separation from other aircraft, possibly in busy airspace, airport, additional useful FOSA results can include an analysis of the adequacy of the procedures for air traffic control mixed mode (RNAV approach and other types of approach), including ways to identify aircraft with different capabilities on approach and ways of providing management with potentially different trajectories during go-around. Measures to reduce risks to meet the criteria of safety when testing schemes of maneuvering in the terminal area can be concretize to solving the following tasks:

a. In the presence of various schemes (i.e. RNAV and classic schemes) in the area of approach area the optimization of airspace should include maximum pairing of these schemes, including changes to the previously published classical charts of approach and landing;
b. Changes in technology and of work time controller with the crew of the aircraft;

We recommend manufacturers to include in the software of controlling the flow of aircraft AMAN, as the input of operational data, changes in RNP downward, e.g., due to failure of ground equipment GBAS.

Conclusion

The human error and procedural aspects are due to the influence risk factors in other functional areas FOSA. It is very difficult to assign a single severity level or to quantify the parameter deviations in the event of such risk factors. Thus, an attempt was made to describe the consequences of major qualitative risk characteristics. The obtained data allow considering the effect of fatigue on probability of error-free operation of the air traffic controller and numerically evaluating the risks of these factors. In addition there is possibility to quantitatively manage the risk. This information can be used in the decision-making process regarding whether measures taken are sufficient to reduce the risk to an acceptable level.

Acknowledgments

None.

Conflicts of interest

Author declares that there is no conflicts of interest.

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