UDC 629.735.05:519.226

[1]**Volodymyr Kharchenko,** Prof.
[2]**Valery Chepizhenko,** Sn. Researcher
[3]**Yuriy Zaitsev,** Head of the Department

IMPACT OF POLY-LINGUISTIC LOAD ON AIR TRAFFIC CONTROL AND MONITORING QUALITY

National Aviation University
[1]E-mail: kharch@nau.edu.ua
[2]E-mail: chiv@nau.edu.ua
[3]E-mail: vtnik@nau.edu.ua

Abstract. *We have defined the structure and basic characteristics of the poly-linguistic audio-acoustic channel within the framework of controller – pilot communication, and set limits of poly-linguistic load impact on air traffic control.*

Keywords: controller, dynamic flight status, linguistic interaction, operator model, poly-linguistic audio-acoustic channel, time delay.

Introduction

One of the main features of the modern air traffic system is consolidation of all its participants to ensure maximum security. This feature is essential for creation, existence and operation of the air navigation environment and is basic for the synthesis of its component behaviors. The quickest solution to the air traffic safety problem follows from the regulatory and other documents of the world's leading organizations [1–3], notably: International Civil Aviation Organization (ICAO), European Organization for the Safety of Air Navigation (EUROCONTROL), National Agency of Space and Aeronautics (NASA).

The usual air safety problem is gaining today a fresh impetus due to an increase in air traffic, expansion of aircraft operation and the range of issues aviation is facing in the given conditions.

The projections below [4–6] show a rise in annual air traffic 5 to 7 percent. This refers to increasing topological complexity of conflicts and consequently, stricter requirements for air control quality.

The analysis of abnormal situations, accidents and incidents caused by linguistic misunderstanding and semantic distortions in verbal interaction between air traffic operators shows a profound impact of the linguistic load on communication (information channel) between crew members and controllers that leads to deterioration in air traffic performance and affects flight safety.

Review of latest publications

The study into the controller-pilot audio-acoustic channel generally highlights its mono structure [7]. Therefore, the results of the studies do not suggest any conclusion about the degree of a linguistic component impact on the quality of Air Traffic Control (ATC) and monitoring.

However, the recent studies [8–10] indicate that the interaction between pilot-controller data components has different levels of their dominance that makes the audio-acoustic channel somewhat different from the mono one. In Ukraine we use a poly-linguistic audio-acoustic channel in controller-pilot communication.

The poly-linguistic structure is based on several factors: two commonly used languages in Ukraine (Russian and Ukrainian), an adjacent air traffic control complex with Russian as working language (Russian Federation and most CIS countries), and the International ATC System (English for professional purposes) [8; 11].

The poly-linguistic structure of the controller-pilot audio-acoustic channel will hereinafter be cited as the audio-acoustic channel with several language components sharing common logic and purpose – to ensure effective air traffic control.

Identification of Unsettled Issues

The analysis of recent studies shows a lack of an effective scientific and methodological instrument:

– to determine a structure and characteristics of the controller – pilot poly-linguistic audio-acoustic channel;

– to establish an influence pattern for the poly-linguistic load on air traffic control characteristics;

– to develop efficient methods for increasing capacity and reliability of controller-pilot communication and avoid the effect

The **purpose** of the article is to specify the structure and characteristics of the controller-pilot poly-linguistic audio-acoustic channel, and to outline proposals against negative effect of the poly-linguistic load on the air traffic control.

Description of the Basic Material (Idea)

Establishment of structure and characteristics of poly-linguistic audio-acoustic channel.

The poly-linguistic audio-acoustic channel was established when studying controller competency in abnormal situations [10].

To determine and study characteristics of the poly-linguistic audio-acoustic channel we adopted the following technology: the examinee was being displayed graphic stimuli to choose two of the three; if the answer is false, each subsequent exposure, beginning with the initial one, is increasing or reducing if the answer is correct. The time of stimuli differentiation is being recorded to set the level of functional mobility level in nervous processes [8−10].

The examinee is given the task consisting of three consecutive programs:

- program A is Ukrainian language;
- program B is Russian language;
- program C is English.

The speed of data processing is measured by three types of verbal information. Then they compare the same parameters received for each program and determine how suitable the examinee is for an air traffic controller on international airlines and in abnormal situations.

The comparative histogram shows that percentage rate of the examinees capable of fast data processing and rendering (grades 8 to 12) in increased workload exceeds that of the control group; air controllers with slow data processing and rendering (grades 1 to 3) were not identified [12−14].

Thus, to operate in abnormal conditions the examinee must achieve 8 to 12 grades in data processing and rendering. Applicants (persons) with 4 to 7 grades are eligible conditionally, while those attained lower than 4 grades are turned away (fig. 1).

Based on the statistical methods of data processing and nervous processes all the examinees were classified according to the 12-grade scale taking into account the average arithmetic values and the average square deviations σ of these indicators

$$\sigma = \sqrt{\frac{\sum_{i=1}^{k}(x_i - \bar{x})^2 P_i}{n-1}},$$

where $\sum_{i=1}^{k}$ is the sign of product deviation power, option x_i of their average $\bar{x}$ to weight P_i of the deviations from 1st to k class;

n is volume.

If the examinee receives high grades (8-12) in A, B programs, he is good for working as operator of fast data processing and rendering operator in abnormal conditions (air traffic controller in Ukraine and the CIS countries).

Getting high grades in the C program the examinee fits for data processing in English (air traffic controllers on international flights), while low grades (1 to 3) in the C program do not allow operating international flights [8; 10; 13; 15].

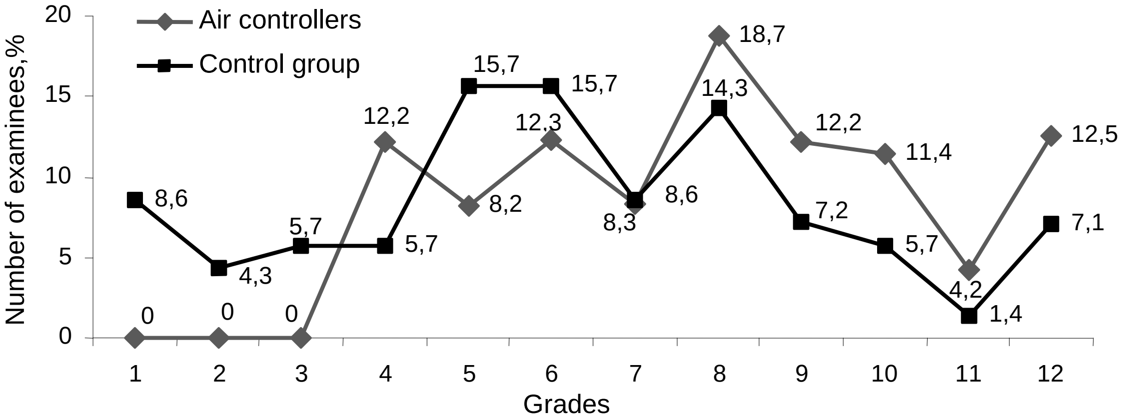

Fig. 1. Comparative histogram for differentiation between examinees working in abnormal conditions and the control group under the 12-grade scale of data processing and rendering speed

Low grades in the A and B programs mean the examinee slowly processes data when experiencing emotional stress, and, at large, cannot be employed as air traffic controller even for local destinations.

Every controller in Ukraine actually uses the poly-linguistic channel in English for international flights or Russian for domestic flights. Ukrainian is used to validate translation if the Ukrainian language is the mother tongue for a controller.

The structure of the poly-linguistic channel:

a) controller – native language Ukrainian or Russian depending on a birth place and a workplace;

b) commonly spoken language, Ukrainian or Russian (with the above mentioned reasons);

c) professional English language.

Time frame for reconstruction of a Dynamic Flight Status (DFS) in ATC.

1. Reconstruction of the ATC dynamic flight status in Russian:

a) controller's native language is Russian;

b) commonly spoken language is Ukrainian;

c) professional English language:

$$\tau_{DFS} = \sum_{s=1}^{N} \left(r_{DFS}^{1,s} + r_{DFS}^{2,s} + r_{DFS}^{3,s} \right),$$

$$\tau_{DFS_1} = \sum_{s=1}^{N} k_{DFS}^{s} \left(\tau_{DFS_1}^{1,s} + \tau_{DFS_1}^{2,s} \right), \qquad (1)$$

where $r_{DFS}^{1,s}$ is time required for reconstruction of the dynamic flight status in Russian;

$r_{DFS}^{2,s}$ is time required for partial validity check to reconstruct the dynamic flight status (influence of Ukrainian and articulation differences);

$r_{DFS}^{3,s}$ is time for acute translation of the dynamic flight status in English involved s aircraft;

$s = \overline{1, \mathrm{N}}$ is number of aircraft (if ATC needs duplicating by international standards at crew's request or other reasons);

k_{DFS}^{s} is coefficient of time spent depending on pilot's language competence;

$\tau_{DFS_1}^{1,s}$ is time required for report perception and understanding (request, confirmation) by s crew;

$\tau_{DFS_1}^{2,s}$ is time for data transmission to s crew;

a) controller's native language is Ukrainian;

b) Russian is a commonly spoken language;

c) professional English language:

$$\tau_{DFS_2} = \sum_{s=1}^{N} \left(r_{DFS_2}^{1,s} + r_{DFS_2}^{2,s} + r_{DFS_2}^{3,s} \right),$$

where $r_{DFS_2}^{1,s}$ is time required for reconstruction of the dynamic flight status in Russian (ATC operation under the regulations of the Russian Federation and certain CIS countries);

$r_{DFS_2}^{2,s}$ is time required for parallel reconstruction of the dynamic flight status in Ukrainian (validated translation is not communicated);

$r_{DFS_2}^{3,s}$ is time required for making accurate translation of the dynamic flight status in English, including s aircraft;

$s = \overline{1, \mathrm{N}}$ is number of aircraft (aircraft transition to international ATC zone).

Coefficient of time spent depending on pilot's language competence k_{DFS}^{s} see formula (1);

a) controller's native language is Ukrainian;

b) Russian is a commonly spoken language;

c) professional English language (aviation English) [8−11; 13].

The controller-pilot audio-acoustic channel is of a bilingual structure. If the controller is capable of fast data processing and rendering in English, he may conduct air traffic control according to international rules:

$$\tau_{DFS_3} = \sum_{s=1}^{N} \left(r_{DFS_3}^{1,s} + r_{DFS_2}^{2,s} \right),$$

where $r_{DFS_3}^{1,s}$ is time required for reconstruction of the dynamic flight status in professional English (in ATC under international rules).

The coefficient for time spent is similar to the above mentioned.

2. Compulsory reconstruction of the dynamic flight status in English:

a) controller's first language is Ukrainian or Russian (depending on a birth place and a workplace);

b) commonly spoken language, Ukrainian or Russian (with the above mentioned reasons);

c) professional English language:

$$\tau_{DFS_4} = \sum_{s=1}^{N} \left(r_{DFS_4}^{1,s} + r_{DFS_4}^{2,s} + r_{DFS_4}^{3,s} \right),$$

where $r_{DFS_4}^{1,s}$ is time required for reconstruction of the dynamic flight status in Russian (not communicated);

$r_{DFS_4}^{2,s}$ is time required for reconstruction of the dynamic flight status in Ukrainian (not communicated);

$r^{3,s}_{DFS_4}$ is time required for making accurate translation of the dynamic flight status in English, including s aircraft.

The coefficient for time spent is similar to the above mentioned [10; 13−15].

In modeling, professional English is considered a constant due to its most universal and adequate interpretation of dynamic flight status. The variables in this complex are language competences of a pilot and a controller, as well as their psychological and emotional characteristics. The Russian language is defined as a specialized language with limited regional restrictions. Russian is used in ATC in the territory of the Russian Federation and the CIS countries, although the basic rules of air traffic control in the Russian Federation differ from international ones.

Ukrainian is defined as variable linguistic value, practically unsuitable for ATC.

Lengthy delays in simulating the dynamic flight status are vital for air traffic control. The distinctive feature of the controller – pilot audio-acoustic channel is an incomplete reply and a quite conventional and situational language flow. This type of speech requires highly accurate display of situational time intervals.

Analysis of the poly-linguistic load on air traffic control efficiency (quality)

To study the effect of operators' delay on air traffic services we'll consider a simple control loop (fig. 2).

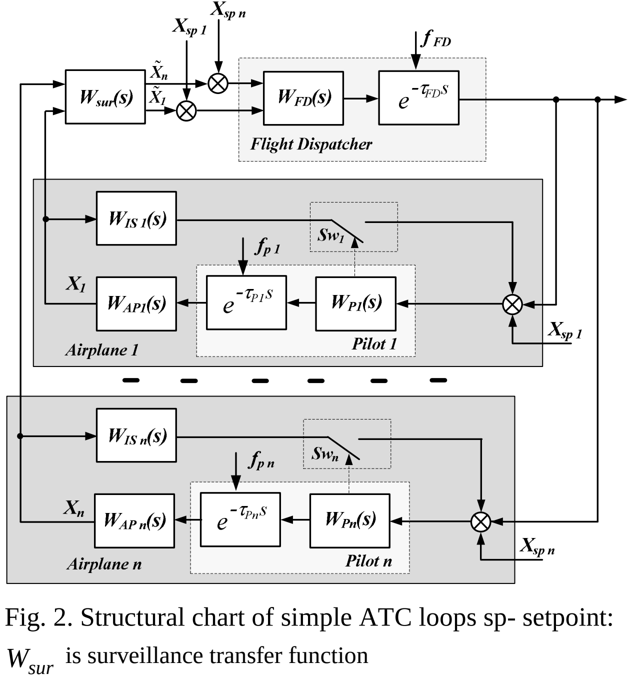

Fig. 2. Structural chart of simple ATC loops sp- setpoint: W_{sur} is surveillance transfer function

Under the primitive control loop we mean the smallest closed loop of air traffic control system, including a controller, communications and surveillance tools, a pilot and a plane. The division of the primitive loop into smaller elements is not advisable as it breaches the conditions for solutions of functional tasks assigned to the air traffic control system [8; 15].

The phase coordinate control system for each aircraft in the control traffic area consists of two primitive control loops: inner and outer (fig. 2).

The inner control loop is formed by transfer functions which give a formal description of:

- an i-aircraft dynamic in a particular flight mode W_{APi};
- psycho-physiological characteristics of pilot performance W_{Pi} within aircraft control loop;
- dynamics of on-board information system W_{ISi} in receiving, processing and delivering data about aircraft phase coordinates to the pilot [8; 14; 16].

In abnormal situations caused by equipment failures or pilot's distrust in the data from the on-board information system the inner loop opens (fig. 1 depicts the process as a switch). In this case the air traffic control system is managed by the outer control loop including a controller, a pilot and a plane. Fig. 2 features controller's psycho-physiological performance as transfer function W_{FD}.

To carry out an analytical study into the influence of the poly-linguistic load on qualitative characteristics of the controller – pilot performance in the primitive control loop it is convenient to use an operator's mathematical model as part of the control system.

Today there are plenty of models describing human behavior in the control loop (see table).

Mathematical model of man – operator control loop

Model	Equation	Model parameter value	Reference
1	$W(s)=K$	$K=5...100$	[1]
2	$W(s)=\dfrac{Ke^{-\tau s}}{T_1 s+1}$	$K=5...9$ $\tau=0{,}1\ldots0{,}3$ $T_1=0{,}1...1$	[1; 2]
3	$W(s)=\dfrac{Ke^{-\tau s}(T_2 s+1)}{(T_1 s+1)(T_3 s+1)}$	$K=5...100$ $\tau=0{,}1\ldots0{,}3$ $T_1=0{,}1...1$ $T_2\geq0{,}1$ $T_3\leq25$	[1–3]

Note: $s=a\pm jb$ – complex number of Laplace transform

The parameters of the above models reflect man – operator physiological features:

K is the operator gain system is set depending on an input frequency range. The higher frequency component, the lower operator gain is. So, the man – operator enters derivative signals keeping control margin at 40 - 80^0;

T_1 is time of effector's (motor) delayed action;

T_2 is indicates person's ability to anticipate changes in input signal (differentiate);

T_3 is indicates man – operator's integrating capacity.

Model 1 is not used in practice because of severe air traffic control restrictions. The analysis of models 2 and 3 shows that transfer functions contain pure delay links characterized by time delay τ.

This parameter specifies delay in the man – operator response to input data [18].

As shown above, the delay strongly depends on the poly-linguistic load. Consequently, the delay is a general characteristic integrally reflecting the impact of the poly-linguistic load on the air traffic control loops.

In general, the delay time in the controller – pilot closed loop is a complicated function depending on dynamics of set and actual parameters of aircraft movement and on external disturbances.

The external disturbances occurred due to variations in the controller-pilot audio-acoustic data channel under the poly-linguistic factors described above are shown in fig. 1 by f_p and f_{FD} signals respectively [17; 19; 20].

As known from the theory of automatic control, delay elements in the control loop do not influence accuracy of input signal processing, but significantly affect the phase margin I the system.

The assessment of the impact of transient delays on qualitative characteristics of the primitive control loop in view of the poly-linguistic load on the operator is given below. The primitive open loop transfer function (fig. 1) is as follows:

$$W(s) = W_{FD}(s)\cdot e^{-\tau_{FD}s}\cdot W_P(s)\cdot e^{-\tau_P s}\cdot W_{AP}(s)\cdot W_{sur}(s) = \\ = W_{FD}(s)\cdot W_P(s)\cdot W_{AP}(s)\cdot W_{sur}(s)\cdot e^{-(\tau_{FD}+\tau_P)s}. \qquad (2)$$

The aircraft transfer function in the autopilot pitch altitude control is as follows [4]:

$$W_{AP}(s) = \frac{K_H\omega_\alpha^2}{t_a s(s+\omega_1)(s^2+2\xi\omega_2 s+\omega_2^2)},$$

where $t_a, \omega_1, \omega_2, \omega_\alpha, \xi, K_H$ are model parameters.

To describe the controller – pilot psycho-physiological characteristics let's use model 3 in table.

In addition, we assume that $W_{sur} = 1$.

Application of the algebraic criteria in the study of primitive loop stability characteristics represented in model 1 is challenging due to the high-order characteristic equation obtained by the expansion of the delay transfer function component in power series, and the high-order polynomial of the transfer function's denominator (2).

There are methods reducing components (members) with sufficient accuracy of delay elements' approximation, for example, number Pada. However, it is more convenient to study the system with time delay using the Nyquist frequency method [16−18].

The approach of Boeing 737 regional passenger plane served as a model experiment.

The modeling was conducted in the MATLAB integrated computing environment using the capabilities of the Control System Toolbox package [5].

The modeling has shown negativity of all performance equation roots (fig. 3) of the limit open-loop system ($\tau_i = 0$).

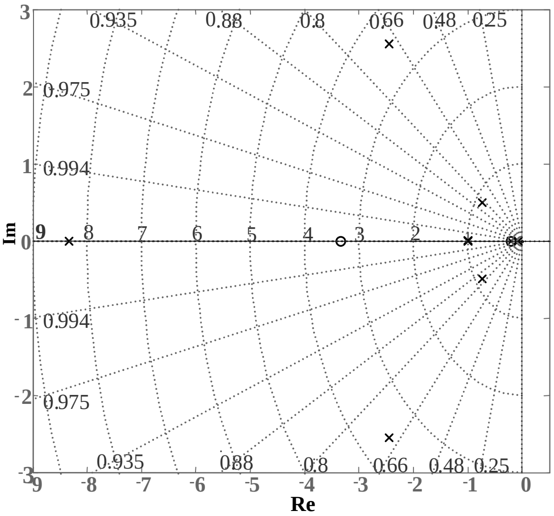

Fig. 3. Location of characteristic equation roots in open loop system (2)

This has led to the conclusion about its stability [17].

The study in the systems with delay has demonstrated a significant reduction in the system stability with unsteady control parameters.

This concerns both the ATC system characterized by air traffic intensity in the control zone, meteorological characteristics of the environment, flight patterns and other parameters of ATC radio data transmission devices.

The factors are shown in fig. 1 as parallel connected models to the controller model, each model combines a pilot model and an aircraft model multiplicatively [16; 18; 20].

Fig. 4 demonstrates the family Nyquist curves for system (2).

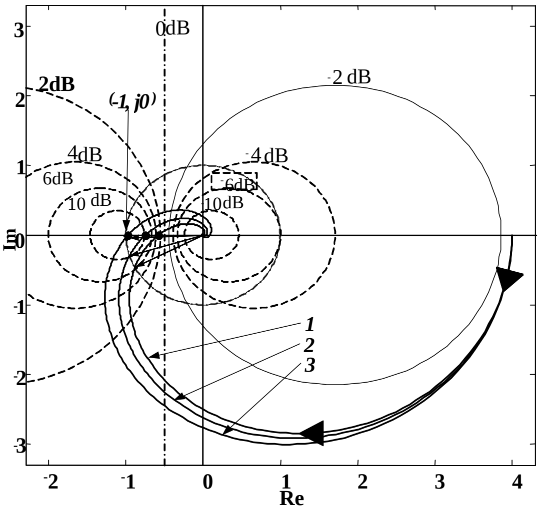

Fig. 4. Nyquist curves for different values of delays $\tau_p + \tau_{FD}$:

1 – 0.6 s;
2 – 2 s;
3 – 4 s

Its analysis indicates loss of systems' stability with a four-second delay.

Conclusions

1. Characterization of the poly-linguistic channel in the interaction with the components comes up with recommendations for reducing load on controller's short-term and long-term memory and increasing efficiency and reliability of the controller – pilot communication.

2. The analysis of the existing man-operator mathematical models shows that the delay is a general characteristic integrally reflecting the impact of the poly-linguistic load on the air traffic control loops.

3. The transient delays caused by the poly-linguistic loads on the primitive control loop seriously undermine stability margin that may switch to the off-design critical unstable modes.

4. To eliminate these negative effects one should adjust phase characteristics of the primitive control loop components.

References

1. *World* Wide CNS/ATM Systems Implementer // ICAO, RIO Conference 1998.

2. *Demystifying* CNS/ATM // Report CANSO CNS/ATM Working Group, Final Version. June 1999.

3. *Циркуляр* ICAO 9750-AN/963, 2007.

[*ICAO* Circular 9750-AN/963, 2007.] (in Russian).

4. *Hoekstra, J.; Ruigrok, R.; Gent, R.* 2000. Free Flight in a Crowded Airspace? – Napoli: 3rd USA/Europe Air Traffic Management R&D Seminar, 13-16 June.

5. *Cloerec, A.*; *Zeghal, K.; Hoffman, E.* 1999. Traffic Complexity Analysis To Evaluate The Potential For Limited Delegation Of Separation Assurance to the Cockpit. – IEEE Trans: 5.A.5-1 - 5.A.5-8.

6. *EUROCONTROL*. Long-Term Forecast of Flights (2004–2025). 2004. 32 p.

7. *Крыжановский, Г.А.* Введение в прикладную теорию УВД. – Москва: Машиностроение, 1984. – 364 с.

[*Kryzhanovskiy, G.A.* 1984. Introduction to Applied Theory of Air Traffic Management. Moscow. Engineering. 364 p.] (in Russian).

8. *Зайцев, Ю.В.* Порівняння лексико-семантичних процесів взаємодії фахових термінів у мовному потоці при моніторингу та керуванні повітряного руху // Вісник НАУ. – 2002. – № 3(14). – С. 92–94.

[*Zaitsev, Yu.V.* 2002. Comparison of lexical-semantic interaction in specialist terminology for air control and monitoring communication. – Proceedings of the NAU. N 3 (14): 92–94.] (in Ukrainian).

9. *Зайцев, Ю.В.* Експертна оцінка та математичне моделювання класифікації часової затримки у процесі мовної взаємодії у контурі «диспетчер - пілот» // Вісник Інженерної академії України. – 2008. – № (1). – С. 12–15.

[*Zaitsev, Yu.V.* 2008. Expert evaluation and mathematical modeling of time delays in controller-pilot communication and interaction. – Proceedings of the Engineering Academy of Ukraine. N (1): 12–15.] (in Ukrainian).

10. *Бабак, В.П.; Харченко, В.П.; Захараш, М.П.; Матюха, О.В.; Макаренко, М.В.; Панченко, В.М.; Зайцев, Ю.В.; Захарчевська, І.К.* Патент України 65512. Спосіб визначення професійної придатності для роботи різними мовами в умовах психоемоційного навантаження. 15.09.2004.

[*Babak, V.P.; Kharchenko, V.P.; Zakharash, M.P.; Matyuha, O.V.; Makarenko, M.V.; Panchenko, V.M.; Zaitsev, Yu.V.; Zaharchevska, I.K.* Patent of Ukraine 65512. Method of determining professional competence to use different (other) languages under emotional stress 15.09.2004.] (in Ukrainian).

11. *Зайцев, Ю.В.* Людський чинник – домінанта рівня експлуатаційної безпеки управління повітряним рухом // Вісник НАУ. – 2004.– № 4(22). – С. 33–36.

[*Zaitsev, Yu.V.* 2004. Human factor as dominant of operational safety in air traffic control. – Proceedings of the NAU. N 4 (22): 33–36.] (in Ukrainian).

12. *Унгарян, С.Г.; Маркович, Е.Д.; Волевач, А.И.* Анализ и моделирование систем управления воздушным движением. – Москва: Транспорт, 1980. – 205 с.

[*Ungaryan, S.G.; Markovich, E.D.; Volevach, A.I.* 1980. Analysis and Modeling of Air Traffic Management Systems. Moscow. Transport. 205 p.] (in Russian).

13. *Харченко, В.П.; Остроумов, І.В.; Зайцев, Ю.В.* Багатопараметрична класифікація спектра польотних ситуацій // Вісник НАУ. – 2008. – № 4 (37). С. 3–8.

[*Kharchenko, V.P.; Ostroumov, I.V.; Zaitsev, Yu.V.* 2008. Multi-spectral parametric classification of flight situations. – Proceedings of the NAU. N 4 (37): 3–8.] (in Ukrainian).

14. *Харченко, В.П.; Зайцев, Ю.В.;. Рудас, С.І.; Аргунов, Г.Ф.* Кореляція безпеки управління повітряним рухом з рівнем мовної фахової підготовки авіадиспетчерів // Вісник НАУ. – 2011. – № 2 (47). – С. 21–26.

[*Kharchenko, V.P.; Zaitsev, Yu.V.; Rudas, S.I.; Arhunov, G.F.* 2011. Correlation of air traffic management safety with controllers' language training. – Proceedings of the NAU. N 2 (47): 21–26.] (in Ukrainian).

15. *Зайцев, Ю.В.; Ільченко, В.М.* Кількісна оцінка семантичних зв'язків (мережі) в каналі мовного зв'язку «земля – повітря» // Вісник Інженерної академії України. – 2008. – № (1). – С. 12–15.

[*Zaitsev, Yu.V.; Ilchenko, V.M.* 2008. Qualitative evaluation of semantic relations (networks) in air-to-ground communications. – Proceedings of the Engineering Academy of Ukraine. N (1): 12–15.] (in Ukrainian).

16. *Асланян, А.Э.* Системы автоматического управления полетом летательных аппаратов. – Киев: КВВАИУ, 1984. – 436 с.

[*Aslanyan, A.E.* 1984. Automatic flight control devices. Kyiv. Kyiv Military Institute of Radio Engineers. 436 p.] (in Russian).

17. *Боднер, В.А.* Системы управления летательными аппаратами. – Москва: Машиностроение, 1973. – 506 с.

[*Bodner, V.A.* 1973. Flight control systems. Moscow. Engineering. 506 p.] (in Russian).

18. *Дьяконов, В.; Круглов, В.* MATLAB. Анализ, идентификация и моделирование систем: специальный справ. – Санкт-Петербург: Питер, 2002. – 448 с.

[*D'yakonov, V.; Kruglov, V.* 2002. MATLAB. System analysis, identification and modeling. Manual. St.Petersburg. Piter. 448 p.] (in Russian).

19. *Присняков, В.Ф.; Приснякова, Л.М.* Математическое моделирование переработки информации оператором человеко-машинных систем. –Москва: Машиностроение, 1990. – 248 с.

[*Prisnyakov, V.F.; Prisnyakova, L.M.* 1990. Mathematical modeling of man-machine operator data processing. Moscow. Engineering. 248 p.] (in Russian).

20. *Громов, Ю.Ю.; Земской, Н.А.; Лагутин, А.В.; Иванова, О.Г.; Тютюнник, В.М.* Системы автоматического управления с запаздыванием. – Тамбов: Тамбовский государственный технический университет, 2007. – 76 с.

[*Gromov, Yu.Yu.; Zemskiy, N.A.; Lagutin, A.V.; Ivanova, O.G.; Tiutiunnik, V.M.* 2007. Automatic Control Systems with Delay. Tambov. Publishing House of Tambov State Technical University. 76 p.] (in Russian).

Received 28 March 2012.