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Development of a Method for Computation of Aircraft Safety Control Signal

Abstract

The optimal flight safety management of an aircraft is considered, on the basis of which the signal for parrying the threat of an aviation accident is calculated. In the process of analyzing the factors affecting the flight safety of the aircraft, the psychophysical state of the crew, the serviceability of the aircraft's onboard equipment and the flight weather conditions are separated into separate groups. Based on the performed analysis, a target function of aircraft flight safety management is proposed in the form of a maximum, which is provided by the output signal of the aircraft flight safety management system. The calculation of the control signal is based on a count state of the flight conditions of the aircraft, which allows us to estimate the causal relationship of the factors of threat of the accident, and to determine the control signal with the safety of the vessel. In the course of this work, an algorithm for calculating the aircraft safety control signal has been developed. The results obtained during the work can be used for software and hardware implementation of aircraft flight safety management systems, as well as for the design of systems and complexes of its onboard equipment.

Keywords: *safety control systems of flight, optimal control, aviation accident, control signal, state graph*

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Разработка метода определения сигнала управления безопасностью полета воздушного судна

Рассматривается оптимальное управление безопасностью полета воздушного судна, на базе которого проводится определение сигнала парирования угрозы авиационного происшествия. В процессе анализа воздействующих на безопасность полета воздушного судна факторов выделены в отдельные группы психофизическое состояние экипажа, исправность бортового оборудования летательного аппарата и погодные условия полета. На основе выполненного анализа предложена целевая функция управления безопасностью полета воздушного судна в виде максимума оценки безопасности полета, который обеспечивается выходным сигналом системы управления безопасности полета судна. Определение сигнала управления осуществляется на базе графа состояния условий полета воздушного судна, который позволяет оценить причинно-следственную взаимосвязь факторов угрозы авиационного происшествия, а также определить сигнал управления безопасностью полета судна.

Полученные в процессе выполнения работы результаты могут быть использованы для программно-аппаратной реализации систем управления безопасностью полета воздушных судов, а также при проектировании систем и комплексов его бортового оборудования.

Ключевые слова: *система управления безопасностью полета, авиационное происшествие, оптимальное управление, граф состояний, сигнал управления*

Introduction

The active development of computer technology has significantly influenced the use and modernization of onboard equipment of aircraft (AC), incl. control systems. Here it is necessary to note the complex control systems, which include the systems of remote and automatic control of the vessel, in addition, the intelligent support of the crew using limiting signals [1, 2]. The use of intelligent crew support systems together with the limiting signal system is associated with rather stringent requirements for aircraft flight safety.

Ensuring the safety of aircraft flights [3] is a very urgent scientific and technical task, which is confirmed by statistics: the number of accidents in 2000—2016, about 200 units. Typically, the specified level of aircraft flight safety is ensured by compliance with the requirements for its operation (on the ground and in the air), redundancy, control and reconfiguration of critical systems of its equipment. However, 83 % of aviation accidents occur due to the human factor, 15 % — due to failures and malfunctions of aviation equipment, 2 % — due to external influencing factors [3]. Consequently, most of the accidents occur due to the human factor, as well as equipment failures. In this case, an accident can occur due to the influence of a single factor or their combination. For example, failure of the aircraft hydropower system (a single factor) can lead to a catastrophic situation. Further, the wrong actions of the aircraft crew in bad weather conditions can lead to an aircraft accident, and its presence is due to the influence of a combination of two or more factors.

Thus, the development of modern means of parrying the threat of an aviation accident should be made taking into account the combination of factors affecting the safety of the flight of the vessel. However, these means should have the functions of recognition, prediction of threat of the accident, warning her crew availability and advise the crew of how it can parry or output of the control signal in the mating system and the device avionics of the aircraft.

Currently, there are various ways and devices to warn the crew about the threat of an accident. For example, the method of supporting the aircraft operator in dangerous situations [3] allows an expert system to assess the performance of on-Board equipment and the actions of the crew, followed by predicting an emergency and notifying the crew of its presence. It is worth noting that the technical implementation of this method allows you to notify the crew of the threat of an aviation accident and does not issue a control signal to the means of parrying the threat.

Therefore, countering the threat of an accident should be carried out by means of aircraft flight safety control, the control signal of which will reduce the negative influence of external and internal influencing factors on the aircraft flight conditions.

Formulation of the problem

The purpose of this work is to develop a method for calculating the safety control signal of an aircraft flight, the implementation of which will minimize the threat of an aircraft accident and ensure a high level of safety of the aircraft flight.

To achieve the goal, you must complete the following steps:

a) analyze the factors affecting the safety of the aircraft;

b) define the safety objective of the ship's flight;

c) develop a method for calculating the aircraft safety control signal;

and d) simulate the flight safety control signal.

Description and analysis of factors affecting the safety of aircraft flight

Controlling an aircraft is a complex technical process that is influenced by various factors. These include internal influencing factors (condition of onboard equipment, load-bearing and load-bearing structural elements of the aircraft, crew). When assessing the threat of an accident, it is also necessary to take into account external influencing factors (terrain, weather conditions of the flight, other air traffic participants, etc.). Moreover, each type of influencing factors is divided into groups, the characteristics of which are presented in table.

It can be seen from the table that each group is characterized by a set of input variables that assess the state of the factors and their impact on the aircraft flight. These factors are poorly formalized, so the input variables must be represented as a linguistic variable. Moreover, each linguistic variable is set on a set of fuzzy values "*Fatigue*" that belong to a certain space-time region. For example, the linguistic variable "Fatigue" is defined by three sets $[-1 \div -0.5]$; $[-0.5 \div 0.5]$; $[0.5 \div 1]$. Moreover, the set $[-1 \div -0.5]$ — characterizes high crew fatigue; $[-0.5 \div 0.5]$ — average; $[0.5 \div 1]$ — high.

The fuzzy values of linguistic variables determined during registration are fed to the input of the flight safety control system (FSCS). This system is part of the aircraft onboard equipment complex. The actions of the aircraft security management system are related to the recognition of the threat of an aviation accident, with the subsequent assessment of its consequences, as well as with the prediction of the direction of its development and with informing the pilots about the threat using the means of sound

Characteristics of parameters that affect flight safety

№	Group	Parameter	Measurement method	Linguistic variables
1	Psycho-physical state of the pilot	Fatigue	By pupil response sensor, strain gauges	Low f_1 Middle f_2 High f_3
		Attention	Pupil reaction sensor	High k_1 Average k_2 Low k_3 Scattered k_4
		Preparation level	Pilot test tasks	High f_1 Average f_2 Low f_3
		Stress	Pupil reaction sensor	No k_1 Low k_2 Average k_3 High k_4
2	Aircraft condition	Failure of functionally significant elements	Means of signaling and failure indication	Insignificant f_1 Emergency f_2 Catastrophic f_3
		Deformation of load-bearing structure elements	Load measurement sensors	Absent k_1 Insignificant amount k_2 Essential k_3 Critical k_4
		Aircraft controllability and stability	Characteristic of the control object	High f_1 Average f_2 Low f_3
		Error in the aircraft control system software	Detecting failure of the aircraft control system function	No k_1 Insignificant amount k_2 Essential k_3 Critical k_4
3	Weather conditions	Headwind	Change of aircraft flight parameters	Week f_1 Average f_2 Strong f_3
		Side wind	Change of aircraft flight parameters	Week f_1 Average f_2 Strong f_3
		Visibility	Photocells	Good k_2 Bad k_1

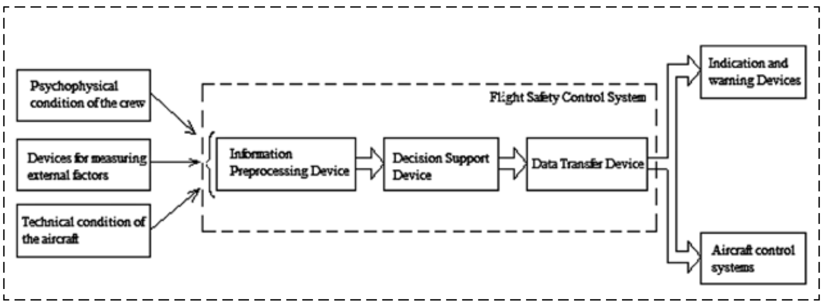

Fig. 1. Structural diagram of an aircraft FSCS flight

and light indication. The block diagram of the system (Fig. 1).

In accordance with the structural diagram, the core of the aircraft SMS is a device for supporting decision-making by the crew, which is connected with devices for preliminary processing and information transfer. On the basis of preliminary data processing, electrical signals are generated about the output of the values of the controlled variables from the specified intervals. This allows the threat of an accident to be detected and its consequences assessed. Then, based on the preliminary processing information, the decision support device generates data on the possible directions of the threat development, which it warns the crew about using the output device. At the same time, the decision support device also generates recommendations for the pilot to neutralize the threat of an accident.

Thus, the system based on two-level recognition of aircraft flight conditions and predicting the development of an accident reduces the likelihood of a false conclusion about its presence and consequences. It is expedient to implement the data preprocessing device on the basis of programmable logic integrated circuits using fuzzy logic algorithms.

Determination of the target safety function of the aircraft flight

According to the analysis of the safety of the aircraft flight, the assessment of the quality of its control is carried out on the basis of the flight conditions under the influence of external and internal factors. Then the input variables of the mathematical model for assessing the safety of aircraft flight will be the variables characterizing the psychophysical state of the crew, weather conditions of the ship's flight, the technical condition of the ship and its onboard equipment. In this case, the output variable of the model is the assessment of the safety conditions of the aircraft flight. Considering that the input and output variables of the aircraft flight safety assessment model are complex non-deterministic and difficult to formalize, then the apparatus of fuzzy logic should be used as the mathematical apparatus of the model.

The general view of the mathematical model for assessing the flight conditions of an aircraft can be represented by the expression:

$$\forall t \in [t_s; t_f] : Y_i(t) \subseteq F_i[X_1(t), X_2(t), X_3(t), u(t), t] \quad (1)$$

where $X(t)$ are input variables of the flight safety assessment model, $Y_i(t)$ is the output variable of the model (aircraft flight safety assessment), $F_i[X_1(t), X_2(t), X_3(t), u(t), t]$ — objective flight safety management function

A necessary condition for the safety of an aircraft flight is a high psychophysical state of the crew, technical serviceability of the aircraft and its onboard equipment, good weather conditions, then the objective function will take the following form:

$$F_i[X_1(t), X_2(t), X_3(t), u(t), t] \to \max. \quad (2)$$

Initial conditions:

$$F_0[X_1(t), X_2(t), X_3(t), u(t), t] = Y_0. \quad (3)$$

Objective function constraints are as follows:

$$A \leqslant F_i[X_1(t), X_2(t), X_3(t), u(t), t] \leqslant B \quad (4)$$

where A, B are the maximum and minimum admissible values [0.5:1.0] of the objective function in the range [0.5: 1.0], which are determined from the possible conditions of the aircraft flight.

Thus, the optimal control of the aircraft flight safety must ensure that the condition for the maximum of the objective function (2) is satisfied under its given initial and boundary conditions.

Development of a method for calculating the aircraft flight safety control signal

In the process of aircraft control, the safety of its flight changes, the assessment of which $Y(t) \in [0; 1]$ is carried out depending on the values of internal and external influencing factors of flight safety ($X_1(t)$ is the psychophysical state of the crew, $X_2(t)$ is the technical the state of the control object, $X_3(t)$ is the weather conditions of the flight). At the same time, countering the threat of an aviation accident is carried out as follows:

1) the pilot by independent actions prevents the threat of an aviation accident, which is performed with the crew's decision support system disabled, voice translators, etc.

2) the pilot on the recommendations of decision support prevents the development of the threat of an aviation accident, which occurs under the condition of a positive psychophysical state of the crew and a working safety management system, a voice translator and other means of issuing recommendations to the crew;

3) aircraft control systems fend off the threat of an aircraft accident without the participation of the crew with its low psychophysical state, minor failures of onboard equipment.

Assessment of the quality of parrying the threat of an accident is carried out as follows:

1) crew actions are sufficient to parry an accident and $Y(t) \to 1.0$;

2) the actions of the crew are not enough to parry an accident and $Y(t) < 0{,}8$;

3) the actions of the aircraft control systems are sufficient to parry an accident and $Y(t) \to 1.0$;

4) the actions of the aircraft control systems are not enough to parry an aircraft accident and $Y(t) < 0{,}8$;

5) correct issuance of recommendations to the crew on countering the threat of an aviation accident and, as a result, the actions of the crew correspond to clause 1 of this list;

6) incorrect issuance of recommendations to the crew on countering the threat of an accident and, as a result, the actions of the crew correspond to clause 2 of this list.

At the same time, each action to counter the threat of an aviation accident can lead to an improvement, deterioration and absence of changes in the safety of the aircraft flight. Then the aircraft flight safety control signal can take the following values:

1) $u(t) = [-1:0)$ — deterioration of aircraft flight safety;

2) $u(t) = 0$ — no changes in aircraft flight safety from the control action;

3) $u(t) = (0:1]$ — improvement of aircraft flight safety.

Considering that the problem of optimal control of aircraft flight safety is solved within the framework of the creation of a safety control system for the flight of an aircraft, then we will accept two methods of countering the threat of an aircraft accident:

a) the threat is countered by the action of the crew on the recommendation of the decision support device — $z_1(t)$;

b) the threat is countered by automatic control systems — $z_1(t)$ at $X_1(t) \to \max$.

Thus, the general view of aircraft flight safety management can be represented by the ratio:

$$u(t)=\begin{cases} f(z_1(t)),\ at\,k=0; \\ f(z_2(t)),\ at\,k=1, \end{cases} \tag{5}$$

where $k=\langle X_1(t), X_2(t)\rangle$ — conditions for turning on the automatic parrying of the threat of an accident based on the psychophysical state of the crew and the state of the onboard equipment.

Let $z_i(t)\in G$, where $G\subseteq(g_1, g_2)$, then using expression (5) and a mathematical model for assessing the safety of an aircraft flight (1):

$$z_i(t)=f\left(g_{1i}, g_{2i}\right)= \\ =\langle Y(t); X_1(t); X_2(t); X_3(t), k(t)\rangle,\ i=1,\ldots,n \tag{6}$$

where G is the set of control actions to counter the threat of an aviation accident; g_1, g_2 — subsets of manual and automatic control to counter the threat of an accident, respectively; g_{1i}, g_{2i} — elements of a subset of manual and automatic control in countering the threat of an aircraft accident.

Thus, the solution to the optimal control problem for aircraft flight safety consists in finding the variable $z_i(t)\in G$ in accordance with expression (2) and ensuring that the condition $Y(t)\to\max$ is satisfied. The problem can be solved under the following initial and boundary conditions:

$$u(0)=z_0=0;\ \ 0<u(t)<1. \tag{7}$$

The calculation of the aircraft flight safety control signal can be carried out on the basis of the graph of the state of the aircraft flight conditions, which is described by the Kolmogorov — Chapman equations. The graph of the state of the aircraft flight conditions (Fig. 2), where 0 — no emergency conditions for the aircraft flight, 1 — difficult flight conditions with deterioration of the aircraft onboard equipment and weather conditions of the flight; 2 — difficult flight conditions with deterioration of the psychophysical state of the crew and weather conditions of the flight; 3 — emergency flight conditions with deterioration of the aircraft onboard equipment and weather conditions of the flight; 4 — emergency flight conditions with deterioration of the psychophysical state of the crew and weather conditions of the flight; 5 — catastrophic flight conditions; $z_{11}(t)$ — countering the threat of an accident by the actions of the crew in difficult conditions of aircraft flight; $z_{13}(t)$ — countering the threat of an accident by actions of the crew in emergency conditions of aircraft flight; $z_{15}(t)$ — countering the threat of an aircraft accident by the actions of the crew in the event of a threat of disaster $z_{22}(t)$ — countering the threat of the aviation automatic control system of the aircraft in difficult conditions of aircraft flight; $z_{24}(t)$ — countering the threat of the aviation automatic control system of the aircraft in emergency conditions of aircraft flight; c_{11} — indicator of transition of aircraft flight conditions from state 0 to state 1; c_{13} — indicator of transition of aircraft flight conditions from states 0 and 1 to state 3; c_{15} — indicator of transition of aircraft flight conditions from states 1 and 3 to state 5; c_{22} — indicator of transition of aircraft flight conditions from state 0 to state 2; c_{24} — indicator of transition of aircraft flight conditions from states 0 and 2 to state 4; c_{25} — indicator of transition of aircraft flight conditions from states 2 and 4 to state 5; c_{23} — indicator of transition of aircraft flight conditions from state 2 to state 3; c_{14} — indicator of transition of aircraft flight conditions from state 1 to state 4; c_{35} — indicator of transition of aircraft flight conditions from state 0 to state 5.

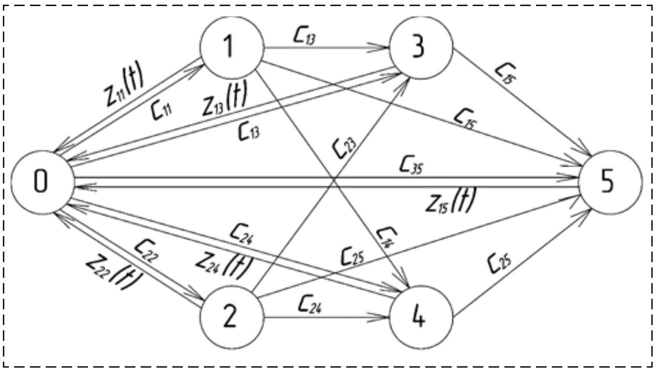

Fig 2. Aircraft flight safety graph

The figure shows that the state of the aircraft flight conditions are interconnected by the direct transition of one state to another, as well as by the transition through an intermediate state. For example, an emergency flight condition for an aircraft (3) can arise from without an emergency flight condition (0) and as a result of a worsening of difficult flight conditions (1 and 2). In this case, the signal to counter the threat of an accident must ensure the transition of the current flight condition to the non-emergency mode of the aircraft flight, which will ensure the specified speed of the aircraft flight safety control system.

Using the Kolmogorov — Chapman equations and the graph of the aircraft flight safety state, it is possible to compose a system of equations for the rate of change of the flight safety assessment in its various states (the system of flight safety control system):

$$\frac{dY_0(t)}{dt} = z_{11}(t)Y_1(t) + z_{13}(t)Y_3(t) +$$
$$+ z_{15}(t)Y_5(t) + z_{24}(t)Y_4(t) + z_{22}(t)Y_2(t) -$$
$$- (c_{11} + c_{22} + c_{35} + c_{13} + c_{24})Y_0(t);$$
$$\frac{dY_1(t)}{dt} = c_{11}Y_0(t) -$$
$$- (c_{13} + c_{14} + c_{15})Y_1(t) - z_{11}(t)Y_1(t);$$
$$\frac{dY_2(t)}{dt} = c_{22}Y_0(t) - \quad (8)$$
$$- (c_{23} + c_{24} + c_{25})Y_2(t) - z_{22}(t)Y_2(t);$$
$$\frac{dY_3(t)}{dt} = c_{13}\left(Y_1(t) + Y_0(t)\right) - z_{13}(t)Y_3(t);$$
$$\frac{dY_4(t)}{dt} = c_{24}\left(Y_2(t) + Y_0(t)\right) - z_{24}(t)Y_4(t);$$
$$\frac{dY_5(t)}{dt} = c_{15}\left(Y_3(t) + Y_1(t)\right) +$$
$$+ c_{25}\left(Y_4(t) + Y_2(t)\right) + c_{35}Y_0(t) - z_{15}(t)Y_5(t),$$

where $Y_0(t)$, $Y_1(t)$, $Y_2(t)$, $Y_3(t)$, $Y_4(t)$, $Y_5(t)$ is the assessment of the aircraft flight safety in normal, difficult, emergency and catastrophic flight conditions.

Thus, the calculation of the aircraft flight safety control signal consists in solving the system of equations (8) for the current aircraft flight condition for the given initial and boundary conditions of the control signal (7), the known aircraft flight condition state, as well as indicators of the transition between aircraft flight conditions.

Simulation of the aircraft flight safety control signal

In the process of performing the work, the simulation of the aircraft flight safety management system was carried out in terms of assessing the threat of an aviation accident and calculating the safety control signal of its flight. In the first case, the aircraft flight conditions are assessed based on information characterizing the state of external and internal factors that affect the safety of the ship's flight and, based on fuzzy logic methods, a conclusion is drawn about the threat of an accident. Then, according to the data of the threat of an accident, the signal of the aircraft flight safety control is calculated, the action of which is aimed at countering the threat of an accident.

In fig. 3 (see the fourth side of the cover) shows the results of modeling the threat of an aviation accident.

In the process of modeling the threat of an aviation accident, the following flight conditions were obtained:

— with linguistic variables equal to "1", the value of flight conditions is "0.8", which corresponds to an accident-free flight regime, therefore, there is no threat of an accident (Fig. 3a);

— with linguistic input variables equal to mean values, the flight conditions will correspond to a complex state, i.e. under the influence of a combination of influencing factors, aircraft control is created and becomes much more complicated (Fig. 3b).

Suppose that during the time T = [tн; tк], the flight safety conditions changed from state 0 to state 1 without transition to other aircraft flight safety states, then the system of flight safety equations (8) will take the following form:

$$\frac{dY_0(t)}{dt} = z_{11}(t)Y_1(t) - c_{11}Y_0(t);$$
$$\frac{dY_1(t)}{dt} = c_{11}Y_0(t) - z_{11}(t)Y_1(t). \quad (9)$$

To solve the system of equations (9), it is necessary to introduce the total characteristic of the flight safety assessment (K) for accident-free and difficult flight conditions, which can be represented by the expression:

$$Y_1(t) + Y_0(t) = K. \quad (10)$$

The solution of the system of equations (9) taking into account (10) with respect to Y_0 (t) takes the following form:

$$\frac{dY_0(t)}{dt} = z_{11}(t)(K - Y_0(t)) - c_{11}Y_0(t); \quad (11)$$

$$\frac{dY_0(t)}{dt} = Kz_{11}(t) - (c_{11} + z_{11}(t))Y_0(t); \quad (12)$$

$$\frac{dY_0(t)}{dt} + (c_{11} + z_{11}(t))Y_0(t) = Kz_{11}(t). \quad (13)$$

A particular solution to equation (13):

$$Y_0(t) = \frac{Kz_{11}(t)}{c_{11} + z_{11}(t)}. \quad (14)$$

General solution of equation (13):

$$Y_0(t) = Ce^{-(c_{11}+z_{11}(t))t}. \quad (15)$$

Using expressions (14) and (15), the solution to equation (13) can be written in the form:

$$Y_0(t) = Ce^{-(c_{11}+z_{11}(t))t} + \frac{Kz_{11}(t)}{c_{11} + z_{11}(t)}; \quad (16)$$

$$C = -\frac{Kz_{11}(t)}{c_{11} + z_{11}(t)}. \quad (17)$$

Thus, the transition of aircraft flight safety from state 1 to state 0 has the following form:

$$Y_0(t) = \frac{Kz_{11}(t)}{c_{11} + z_{11}(t)}[1 - e^{-(c_{11}+z_{11}(t))t}] \quad (18)$$

where $c_{11} = Y_1(t)/Y_0(t)$.

Using the Taylor series expansion $e^{-(c_{11}+z_{11}(t))t}$ we get:

$$Y_0(t) = \frac{Kz_{11}(t)}{c_{11} + z_{11}(t)}[z_{11}(t) + c_{11}]t. \quad (19)$$

Let us express the variable $z_{11}(t)$ from expression (18):

$$z_{11}(t) = \left|\frac{a(t)c_{11}}{K - a(t)}\right| \quad (20)$$

where $a(t) = Y_0(t)/t$.

Based on expression (20), it is possible to determine changes in the safety control signal of an aircraft flight with a deterioration in the psychophysical parameters of the crew and external influencing factors. It is known from work [1] that $Y_0(t) = 1$ and $Y_1(t) = 0{,}5$. Then $K = 1{,}5$, $c_{11} = 0{,}5$. Suppose that $T = [0:0.5]$ h.

Substituting the known values into expression (20), we get:

Fig. 4 that the change in the aircraft safety control signal under difficult control conditions is $z_{11}(t) = [0:2]$ and has a continuously increasing character. It should be noted that the control signal counteracts the threat of accident for 0.325 h, then the action of the signal is aimed at maintaining a trouble-free flight condition. Further processing of the signal consists in its normalization in accordance with the level of control signals of the aircraft onboard systems. The results obtained can be used in the development of software for the flight safety control system.

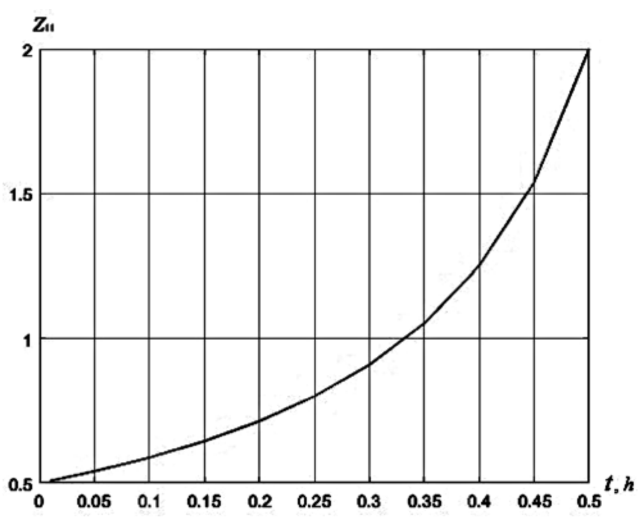

Fig. 4. Change of flight safety control signal

Conclusion

As a result of the work, the analysis of external and internal influencing factors influencing the safety of the aircraft flight was carried out, on the basis of which the target safety function of the aircraft flight was determined. In this case, the optimal control of flight safety consists in ensuring the maximum of the objective function for its given initial and boundary conditions. To solve this problem, a method is proposed for calculating the safety control signal of an aircraft flight, the action of which is aimed at ensuring a high level of aircraft flight safety and minimizing the threat of an aircraft accident. The calculation of the aircraft flight safety control signal is based on the graph of the state of aircraft flight conditions and its mathematical model based on the Kolmogorov — Chapman equations.

The proposed method for calculating the aircraft flight safety control signal is advisable to use in the algorithms and software of the aircraft SMS.

Referance

1. **Sapagov V. A., Anisimov K. S., Novozhilov A. V.** Fail-safe Computing System for Integrated Flight Control Systems, *Trudy MAI,* vol. 45, available at: http://www.mai.ru/science/trudy/ (Accessed: 01.03.2017) (in Russian).
2. **Obolensky Ju. G. et al.** Remote control systems and steering gears: structures and developments, *Vestnik MAI,* 2016, vol. 20 (2), pp. 161—171 (in Russian).
3. **Black G. Th., Moorhouse D. J.** Flying Qualities Design Requirements for Sidestick Controllers, 1979, 186 p., available at: http://contrails.iit.edu/reports/9304.
4. **Popov Ju. V.** Safety indicators of aviation flights, Available at: http://agps-2006.narod.ru/ttb/2014-6/10-06-14.ttb.pdf (Accessed: 04.02.2017) (in Russian).
5. **Zheltov S. Yu., Fedunov B. E.** Operational Goal-Setting in Anthropocentric objects from the Viewpoint of the Conceptual Model called Etap: I. St ructures of Algorithms for the Support of Crew Decision-Making, *J. Comput.Syst.Sci.*, 2015, vol. 54, no. 3, pp. 384—398.
6. **Levin D. N., Grif M. G.** Formalization of Ergonomic Indicators During Research Data-Control Field of the Aircraft Cockpi, *2019 Modern Safety Technologies in Transportation (MOSATT)*, Kosice, Slovakia, 2019, pp. 94—97.
7. **Fedunov B. E., Prokhorov M. D.** Conclusion on precedent in knowledge bases of onboard intellectual systems, *Iskusstvennyj intellekt i prinjatie reshenij,* 2010, no.3, pp. 63—72 (in Russian).
8. **Bolshakov A. A., Kulik A. A., Sergushov I. V.** (2016). Development the control system algorithms functioning of flight safety for the aircraft of helicopter type, *Izvestija Samarskogo nauchnogo centra RAN*, 2016, vol. 18, no. 1, pp. 358—362 (in Russian).
9. **Kuklev E. A.** Safety management of aircrafts based on fuzzy assessments of risks of abnormal flight conditions, *Nauchnyj vestnik MGTU GA,* 2016, no. 226, pp. 199—205 (in Russian).
10. **Rezchikov A. F. et al**. Diagnostics of operators' dangerous states in case of critical events' combinations in man-machine systems, *Vestnik komp'juternyh i informacionnyh tehnologij*, 2017, no. 8(158), pp. 48—56 (in Russian).