ИНФОРМАТИКА, ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА И УПРАВЛЕНИЕ

СИСТЕМНЫЙ АНАЛИЗ, УПРАВЛЕНИЕ И ОБРАБОТКА ИНФОРМАЦИИ

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DEVELOPMENT OF AN ALGORITHM FOR PREDICTING AN EMERGENCY SITUATION ON BOARD AN AIRCRAFT

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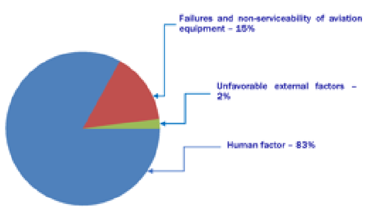
An algorithm for predicting an emergency situation on board an aircraft is proposed. Its principle of operation is aimed at determining the values that characterize the change in variables that affect the safety of air flight of an aircraft. This information is used to evaluate the predicted air flight conditions of an aircraft. The advantage of the proposed algorithm is to increase the effectiveness of threat identification. In addition, the degree of influence of the identified incident during the air flight of an aircraft is determined. For this purpose, the variation of the variables under consideration is predicted, which determine the degree of safety of an aircraft's air flight. The paper presents the results of modeling the operation of an algorithm for predicting an emergency situation of an aircraft flight when changing the flight of an aircraft under difficult initial conditions. The modeling took into account the change in the psychophysical state of the crew and the technical condition of the control object. The proposed algorithm makes it possible, based on forecasting, to identify the threat of an air accident, as well as to parry it based on the appropriate actions of the crew, as well as the aircraft's automatic control system. For implementation, it is advisable to use the appropriate software and hardware complexes that are part of the onboard equipment of an aircraft.

Keywords: flight safety control system, aircraft, decision support device, emergency forecasting

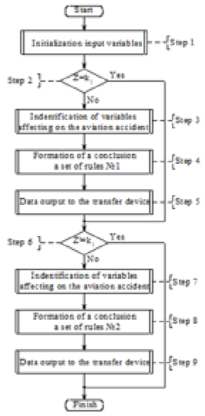
Graphical annotation (Графическая аннотация)

Improving the safety of aircraft flight is a national economic problem



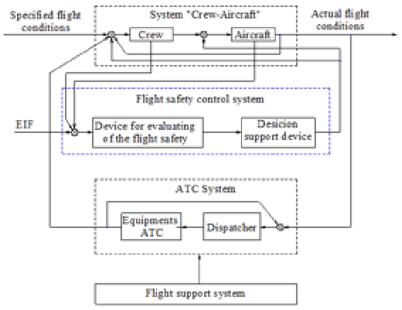
Повышение безопасности полетов воздушных судов является национальной экономической проблемой

Block diagram of decision support algorithm for parrying the threat of aviation accident



Структурная схема алгоритма поддержки принятия решений для парирования угрозы авиационного происшествия

Intelligent aviation system



Интеллектуальная авиационная система

РАЗРАБОТКА АЛГОРИТМА ПРОГНОЗИРОВАНИЯ АВАРИЙНОЙ СИТУАЦИИ НА БОРТУ ВОЗДУШНОГО СУДНА

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Предложен алгоритм прогнозирования аварийной ситуации на борту воздушного судна. Его принцип действия направлен на определение значений, которые характеризуют изменение переменных, влияющих на обеспечение безопасности воздушного полета авиационного судна. Эта информация используется для оценки прогнозируемых условий воздушного полета авиационного судно. Достоинство предлагаемого алгоритма заключается в увеличении результативности при идентификации угрозы. Кроме этого, определяется степень влияния идентифицированного происшествия при воздушном полете авиационного судна. Для этого осуществляется прогнозирование варьирования рассматриваемых переменных, которые определяют степень безопасности воздушного полета авиационного судна. В работе представлены результаты моделирования работы алгоритма прогнозирования аварийной ситуации полета воздушного судна при изменении полета авиационного судна при сложных начальных условиях. При моделировании учитывалось изменение психофизического состояния экипажа и техническое состояние объекта управления. Предложенный алгоритм позволяет на основе прогнозирования осуществлять идентификацию угрозы воздушного происшествия, а также парирование его на основе соответствующих действий экипажа, а также системы автоматического управления авиационного судна. Для реализации целесообразно применять соответствующие программно-аппаратные комплексы, входящие в состав бортового оборудования авиационного судна.

Ключевые слова: система управления безопасностью полета, авиационное судно, устройство поддержки принятия решений, прогнозирование аварийной ситуации

Introduction. Recently, aviation specialists have been successfully implementing research aimed at synthesizing safety control systems for the flight of an aircraft in order to increase its level [1–5].

Usually, hardware-software redundancy is used to solve this problem. In addition, algorithms are used to construct reconfigurations of the complexes of the used onboard equipment of an aircraft vessel. It should be noted that these approaches are not guaranteed to achieve the required level of safety. This is due to the fact that so-called external factors and the psychophysical state of the crew also have a very significant impact on the flight state of an aircraft.

The considered factors that have an impact on the safety of air flight are determined by a set of variables. Moreover, their set of values can be measured indirectly or explicitly using fuzzy methods. During flight, the magnitude of the threat of an emergency may vary with changes in the values of specific factors that can affect the degree of safety of air flight, taking into account the actions of the crew. Therefore, it is necessary to take into account the variation in the threat of a particular emergency. At the same time, its identification and forecast on the aircraft ship is carried out in real time. When implementing this approach, it is possible to timely detect, as well as to counter the identified threat of a specific emergency. When choosing or developing a method for predicting the threat of a specific emergency, it is necessary to take into account its further implementation in the form of a hardware and software complex of the corresponding flight safety management system of an aircraft. The system allows you to identify the degree of an accident, issue warning signals about its presence to the crew, as well as neutralize it by aircraft flight control systems.

A method has been developed for advice to aircraft operators in case of emergencies [3]. This method uses an expert system, the knowledge base of which contains information to form recommendations for identifying the degree of operability of the onboard systems used, as well as recommended actions for the aircraft crew. This information is used to predict the occurrence of an emergency, as well as to generate appropriate messages for ship operators. This method has a disadvantage, which is associated with the lack of a procedure for forming an accurate characteristic upon the onset of an emergency. This, in turn, is due to the lack of mathematical modeling of the emergency process of an aircraft flight.

Another way to ensure the safety of aircraft flight is the "Automated highly intelligent system for ensuring the safety of aircraft flights" [4]. This system was developed by specialists of the M.M. Gromov. The functioning of the proposed system makes it possible to prevent an emergency situation. In this case, information is used to predict the variation of conditions, as well as an assessment of going beyond the permissible limits of the characteristics of flight conditions. To accomplish this, an expert system is used, which allows identifying emergency situations using the model of the considered controlled object. In the proposed highly intelligent system, the main disadvantages are associated with the requirement to use significant computer power to perform the required mathematical modeling of the aircraft flight.

In addition, the forecast of the variation of characteristics that determine the safety of air flight based on fuzzy methods is not applied. The implementation of the algorithm for predicting an emergency situation will allow to counter it in a timely manner by the actions of the crew or automatic control systems, while significant computer power of the onboard equipment complex is not required.

Problem statement. This work is devoted to the development of an algorithm for predicting an aircraft emergency situation. The proposed algorithm should make it possible to identify the variation in the threat of an accident, as well as to inform the crew of the aircraft in a timely manner about this threat.

The peculiarity of the algorithm lies in the application of a forecast of the variation of variables that determine the degree of threat of an emergency on a selected forecast time interval using a fuzzy model. To achieve the above goal, it is necessary to solve the following tasks:

1) analyze the input variables in the crew decision support device (DSS);

2) develop an algorithm for predicting an emergency situation on board an aircraft;

4) conduct simulation of the prediction algorithm.

Analysis of the input variables of the crew decision support device. The complex for managing the safety of an aircraft flight is a hardware and software tool that is used to recognize, predict and parry an identified threat of an emergency [6].

The flight safety management system includes devices for preliminary identification of the threat of an emergency, decision support and information output to the on-board systems of the aircraft. The decision support device, using data characterizing the flight conditions of the aircraft, as well as the forecast of their variation and the response of aircraft operators to the threat of a certain emergency, generates an advice to the pilot to counter it. When determining the situation associated with the absence of the required actions of aircraft operators to fend off the threat of an emergency, the control of the aircraft is transferred to the automatic system. In Figure 1 shows a functional diagram of the proposed complex for decision support.

Shown in figure 1 diagram demonstrates the following. Signals after data preprocessing are transmitted to the input of the device. These signals describe the influencing internal and external factors. These factors can be conditionally subdivided into 3 subgroups: the psychophysical state of the crew, the technical state of the control object and the weather conditions of the flight. The values of the input variables of the device are presented in a linguistic format, which allows them to be processed by means of fuzzy logic used as part of a prediction block and a set of rules. At the same time, using a mathematical forecasting model, the degree of variation of the air flight conditions during the existence of an emergency $T \in [t_0; t_{end}]$ threat is calculated, where t_0 is the beginning of the moment of the threat of an aviation accident, t_{end} is the end time of the threat of an aviation accident. The output values of predicting the variation of the air flight $X'(t)$ conditions of the aircraft in conjunction with the input information of the decision support complex are processed on the basis of a set of rules of the developed knowledge base of the DSS. Further, advice is formed to the aircraft operator to fend off the threat of an emergency situation or neutralize it using an automatic system.

Thus, the developed DSS complex allows the pilot to adjust the actions of the pilot to neutralize the threat of an emergency, which is achieved by using the method of predicting its change, taking into account the actions of the crew.

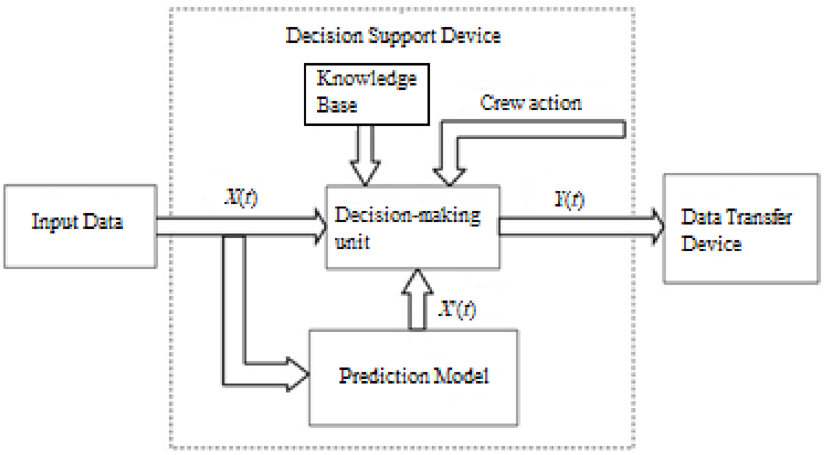

Figure 1 – Functional scheme decision support device

Here $X(t)$ – array of input data after preprocessing; $X'(t)$ – is the input data array that is obtained on the basis of data after preprocessing; $Y(t)$ – output values from decision support units that describe the instructions given to the pilot to avert the risk of an emergency or to parry signals by on-board automated systems.

According to the studies presented in [7], the flight conditions of the controlled object depend on the state of the influencing factors $X_1(t)$, $X_2(t)$, $X_3(t)$. These factors are described by a variety of characteristics that take into account variations in the psychophysiological variables of the state of the aircraft operators, the state of the controlled object, as well as external factors that affect the aircraft. Based on the measurement of the values of the variable, the form (profile) of the variation function is formed at a certain time interval, which specifies the beginning and end of the flight. The forecast of the implementation of the threat of an aircraft accident $X'(t) = X'_{critical}(t)$ is associated with the identification of the time value for which the identified value of the air flight conditions is associated with the critical value from the beginning to the end of the threat of an aircraft accident. In this case, the considered interval, determined by the beginning and the end of forecasting, is formed on the basis of the occurrence and completion of certain rather difficult air conditions of the aircraft flight, the considered catastrophic or emergency situations.

According to the studies presented in [7], the flight conditions of an aircraft are determined by the values of the influencing factors $X_1(t)$, $X_2(t)$, $X_3(t)$. Each of the influencing factors is characterized by a set of variables describing the change in the psychophysical state of the crew, the state of the control object, and weather conditions. At the same time, by recording the values of a variable, a profile of the function of its change is created for a given period of time, namely from the beginning to the end of the flight. Predicting the threat of an emergency situation consists in determining the moment of time at which the assessment of the flight condition takes critical values $X'(t) = X'_{critical}(t)$ from the beginning to the end of the threat of an accident. Then the interval of the beginning and the end of the prediction is $[t_{beg.\ of\ the\ pred.}: t_{end.\ of\ the\ pred.}]$ can be determined by the the appearance and completion of a complex airplane flight conditions, emergency and catastrophic situations. Considering that changes in the values of external and internal factors affecting the safety of an aircraft is $[t_{beg.\ of\ the\ pred.}: t_{end.\ of\ the\ pred.}]$ are random and clearly defined, then methods of engineering analysis, optimal forecasting and the results of studies of the psychophysiological state of the crew should be used to predict them. Thus, the change in the psychophysical state of the crew over a certain period of time is estimated on the basis of data on changes in human psychomotor functions during their prolonged physical and monotonous load. The next step is to determine the time when the values of the controlled variable become critical and have an impact on the threat of an incident.

Thus, predicting the threat of an accident contains three main stages: determining the change in controlled variables over a period $[0: t_{beg.\ of\ the\ pred.}]$, building their dependencies in the forecast time section, identifying the critical values of the considered characteristics in the predicted interval with calculating the values of the time of their occurrence. At the same time, the considered controlled variables are characterized by individual time dependence. They are identified based on a certain formation method as well as the predicted interval. Table 1 shows the variables affecting the safety of aircraft flight.

Table 1 – List of variables affecting the threat of an emergency

Group	Variable	Current variable designation	Representation of the variable change function	T_{pred}
The psycho-physical state of the crew	Fatigue	$x_{11}(t)$	Building on the database of the psycho-physical state of the crew before its flight	$T = 1$ hour
	Attention	$x_{12}(t)$		
	Level of training (competence)	$x_{13}(t)$		
	Stress	$x_{14}(t)$		
Aircraft condition	Failure of functionally significant elements	$x_{21}(t)$	Building on the basis of on-board equipment failure analysis	$T = 1$ hour
	Deformation of the power fragments of the aircraft	$x_{22}(t)$	Fixation of information on the variation of characteristics of the flight conditions of the aircraft	
	Controllability and stability of an aircraft vessel	$x_{23}(t)$	Identified during the flight in the event of equipment failures in the control system of the aircraft	
	Error in the software of the aircraft control system	$x_{24}(t)$	Building on the basis of software failure analysis	
External influencing factors	Headwind	$x_{31}(t)$	Prediction of changes in values during the flight time interval. Meteorological forecast from the control point	$T = 15$ minutes
	Visibility	$x_{32}(t)$		
	Side wind	$x_{33}(t)$		

It follows from the table that it is advisable to form the functions used, associated with a change in psychophysiological characteristics, before the flight. At the same time, it is advisable to identify the level of training of aircraft operators based on an assessment of the level of training of crew members [8]. We also note that the variation in the state of the aircraft due to failure and its effect on the components that are functionally significant, errors in the software complex of the aircraft's control system are identified during its construction using the methods of system and engineering analysis. At the same time, the moments of occurrence of critical situations during its management, as well as the moments of their occurrence, are revealed. Usually, this requires the formation of a fault tree of the components of the on-board complex used, as well as the construction of a software package for the distribution of emerging failures on a time scale.

In addition, there is a variation in the controllability and stability of the object under study due to failures of components that are functionally significant, as well as the software complex. Weather conditions are described by the corresponding functions, which are determined by the generated forecasts of meteorological conditions, as well as their subsequent variations during air flight.

It should also be noted that the stability of the structural components of the aircraft structure in relation to deformations also has a certain effect on flight conditions. This during an air flight is recorded by a set of sensors in the process of measuring the arising power loads on the aircraft. In this case, a forecast is carried out based on the estimates of the previous and current values of the stability of the power components of the aircraft.

As a result of using the proposed method for predicting the threat of an aviation accident, it is possible to identify the cause that affects its presence at a given time interval, as well as to formulate recommendations for the pilot to eliminate the accident. A distinctive feature of the method is the use of a profile – functions of changing each controlled variable that affects the flight conditions of the vessel, which improves the quality of parrying an aircraft accident.

Development of an algorithm for predicting an emergency situation on board an aircraft. The proposed method is implemented by an algorithm for predicting an emergency situation by the software and hardware of the crew decision support device. The block diagram of the algorithm for predicting the threat of an air accident is shown in figure 2.

The flowchart of the algorithm contains the following main steps:

Step 1. Initialization of input variables of functions $X_1(t)$, $X_2(t)$, $X_3(t)$, where $X_1(t)$ – psychophysical condition of the crew; $X_2(t)$ – aircraft condition, $X_3(t)$ – weather conditions.

Step 2. Verification of the condition that the assessment of flight conditions $Y(t)$ corresponds to the threat of an emergency in the time segment $[t_{\text{beg. of the pred.}} : t_{\text{end. of the pred.}}]$.

Step 3. Formation of the type of functions controlled by the characteristic on the investigated interval $[t_0 : t_{\text{end. of the pred.}}]$

Step 4. Determination of the amount of variation of the controlled characteristics using the dependence of the type of functions, the calculation of the critical value of the controlled characteristic and the time point in time ($t_{\text{beg. the crit.}}$). Entering the obtained values into the database of the aircraft safety management system.

Step 5. Assessment of flight safety changes on the time period $[t_{\text{beg. of the pred.}} : t_{\text{end. of the pred.}}]$.

Step 6. Checking the condition that the predicted value corresponds to the critical value (catastrophic and emergency state) $Y^*(t)$.

Step 7. Determining the point in time at when $Y^*(t) = Y_{\text{critical.}}$.

Step 8. Data transmission $T_{\text{crit. of the pred.}}$, $Y_{critical}$ to a decision support device.

The proposed algorithm implements the method for predicting an aircraft accident using information on the variation in the values of influencing, controlled characteristics. In this case, the DSS generates advice to the crew for initialing the threat of an air accident using the information that is issued by the proposed algorithm. Further, in the absence of the required response from the aircraft crew members to the advice from the DSS, the automatic safety control system generates an appropriate electrical signal to neutralize the dangerous aviation event.

Simulation of an accident prediction algorithm. Suppose that the flight of an aircraft is accompanied by difficult conditions, then, according to the method for assessing flight conditions [9, 10], the influencing factors take the following values, characterized by linguistic variables (table 2).

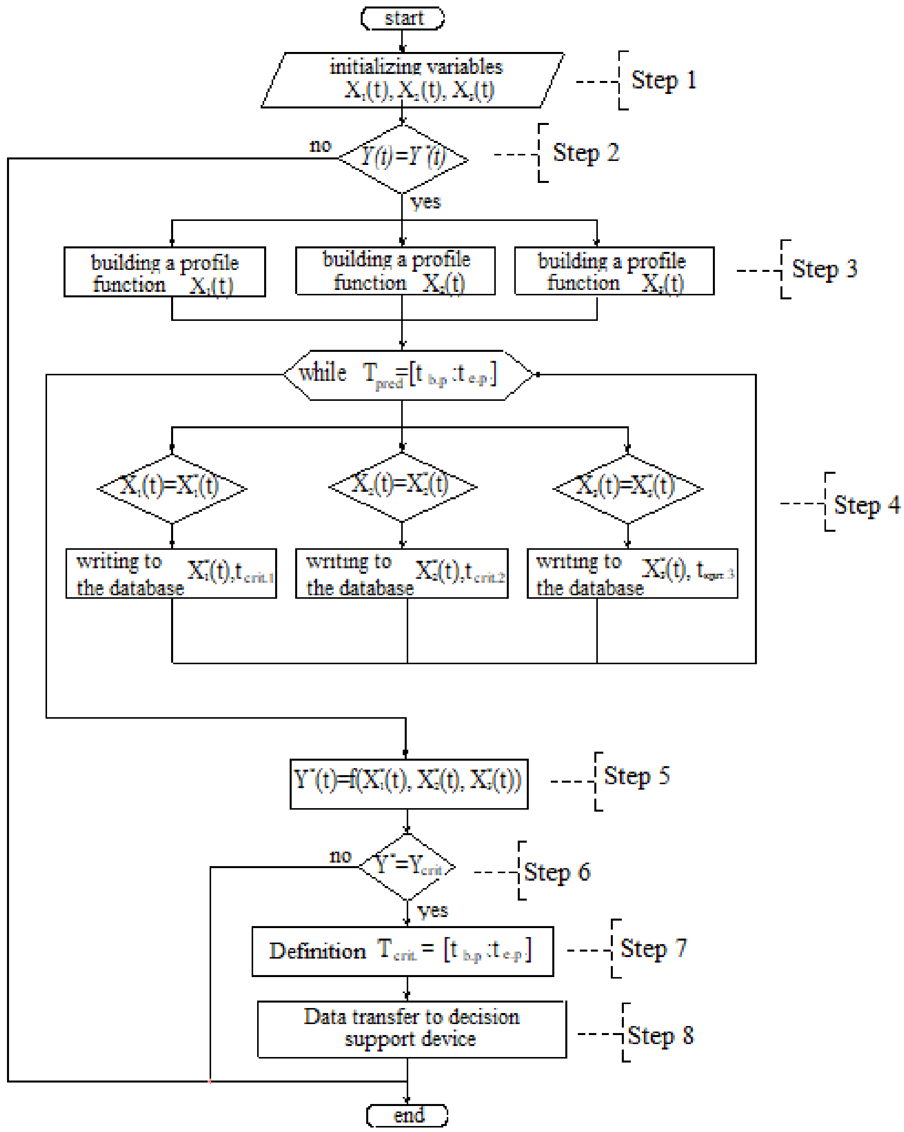

Figure 2 – Block diagram of the proposed algorithm for predicting the occurrence of an aircraft emergency

Table 2 – Variables of influencing factors for complex aircraft flight conditions

Group	**Variable**	**The value of the controlled characteristic at the moment of time $t_{begin\ of\ the\ pred.}$**	**Values of the controlled parameter at the time interval $[t_{begin.\ of\ the\ pred.}:t_{end.\ of\ the\ pred.}]$**
Psychophysical characteristics of an aircraft pilot	Fatigue	medium	hight
	Attention	medium	low
	Level of training (competence)	medium	medium
	Stress	not	not
Aircraft condition	Failure of functionally significant elements	insignificant	emergency
	Deformation of the power fragments of the aircraft	irrelevant	emergency
	Controllability and stability of an aircraft vessel	medium	low
	Error in the software of the aircraft control system	not visible	not visible
External influencing factors	Headwind	slow	slow
	Visibility	slow	slow
	Side wind	good	good

Consider an example in which the weather conditions for an aircraft flight are good enough. In this case, insignificant failures of the controlled functional components are observed. The crew pilots have average values of psychophysiological characteristics. Then, in accordance with the main stages of the proposed algorithm for predicting an air accident, it is required to form the type of function of controlled characteristics. Their variation in the investigated area [$t_{\text{beg. of the pred.}}$:$t_{\text{end. of the pred.}}$] is shown in figures 3–5.

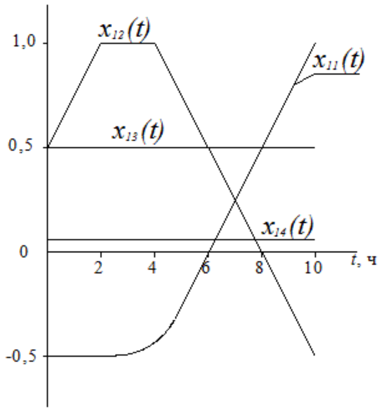

Figure 3 – Function profile $X_1(t)$

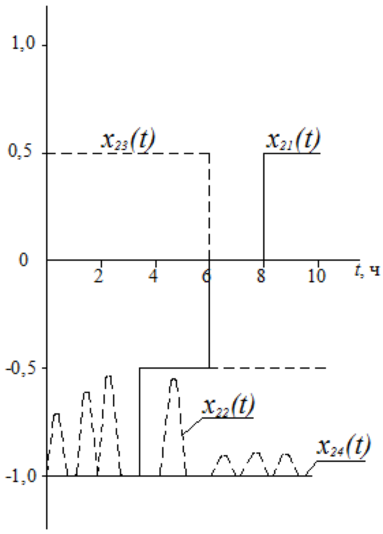

Figure 4 – Function profile $X_2(t)$

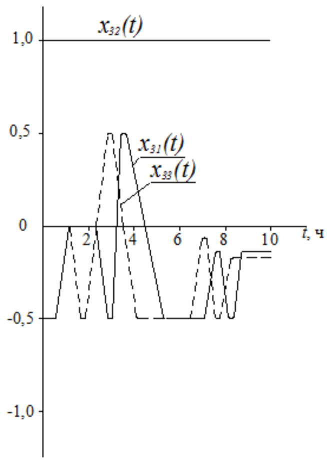

Figure 5 – Function profile $X_3(t)$

As follows from figure 3, the variables of the crew's psychophysical condition $X_1(t)$ have the following time distribution:

– fatigue $x_{11}(t)$, which is presented in the investigated time section [0 ÷ 6] hours, correlates with a rather low level $[-0.5 \div 0]$, then, due to very long physical exertion, it increases from 0 to 1.0 in the predicted interval $T_{prediction} = [6 \div 10]h$;

– the amount of attention $x_{12}(t)$ on the time interval [0 ÷ 6] hours is associated with a high value of the decrease to the value of the border, defined as the average level of 0.5, then, in accordance with the results of forecasting, due to rather monotonous loads, it decreases to 1.0 on the time interval $T_{prediction} = [6 \div 10]h$;

– the degree of training of aircraft operators $x_{13}(t)$ during the flight does not change among the crew members;

– the amount of stress $x_{14}(t)$ in the flight of the aircraft is not observed by the operators.

In figure 4 shows the characteristics, the change of which over time determines the weather conditions for the flight of an aircraft.

Variables characterizing the state of an aircraft $X_2(t)$ they are changed as follows (figure 4):

– failure of the components of the control system of the aircraft $x_{21}(t)$, which are functionally significant, in the time interval $T_{prediction} = [6 \div 10]h$, which is the so-called insignificant state $x_{21} = [0 \div 0{,}5]$. Taking into account the fact that the next failure of such a component of an element can initiate the emergence of an emergency state of an aircraft, therefore, on the segment it is shown as an emergency state;

– the magnitude of the arising deformations of the force components $x_{22}(t)$ in the time interval [0 ÷ 6] h is random, i.e. absent. Taking into account the fact that the quantity has a random distribution, then using statistical forecasting, we calculate the variation on in the time interval $T_{prediction} = [6 \div 10]h$ where it is not observed;

– the controllability value $x_{23}(t)$ of the aircraft on the time interval [0 ÷ 6] hours, which characterizes the so-called average state [0.5 ÷ 0]. Taking into account that the failure of an element that is functionally significant leads to a change in the controllability of the aircraft, the assessment of its state in the predicted interval $T_{prediction} = [6 \div 10]h$ will decrease from average to a value estimated as low;

– the magnitude of the error $x_{24}(t)$ in the software package, during the flight is not observed.

In figure 5 shows the characteristics, the change of which over time determines the weather conditions for the flight of an aircraft:

– wind values (head and side) $x_{31}(t)$, $x_{32}(t)$, in the time interval [0 ÷ 6] hours, they are associated with the transition from the state, defined as weak, thus $[-0.5 \div 0]$ to a value defined as an average [0 ÷ 0.5], as well as the reverse transition to a weak state. Thus, the temporal distribution of these characteristics $x_{31}(t), x_{32}(t)$ appears to be random. Therefore, a statistical forecast $x_{31}(t), x_{32}(t)$ is used, on its basis the values are calculated, on a time interval, while the wind, both head and side, is not observed in this time interval $T_{prediction} = [6 \div 10]h$;

– the characteristic of visibility on the time interval [0 ÷ 6] h means the so-called good state, while changes are not observed, therefore, for this time interval $T_{prediction} = [6 \div 10]h$ also does not vary.

In addition, the value of the mean-square error in predicting the variation of characteristics $x_{22}(t)$, $x_{31}(t)$, $x_{33}(t)$, on the time interval $[t_{\text{beg. of the pred.}} : t_{\text{end. of the pred.}}]$, obtained in accordance with relation (1), does not exceed 3%. Next, the time of the appearance of critical values is calculated based on the variation of the controlled characteristics on the prediction time interval, which is shown in the table 2. Then, on the basis of the proposed intelligent method for determining the magnitude of the threat of an air accident, we calculate on the time interval $Y^*(t) = 0{,}5$ at $t = T_{critical} = [8 \div 10]h$. The results obtained indicate the transition of a rather difficult situation of an aircraft during the flight to the emergency stage at the investigated time interval from the moment of its beginning.

Consequently, based on the use of a variety of prediction methods, including an intelligent method, varying the parameters affecting both internal and external characteristics on the flight conditions of an aircraft, it is possible to predict the change in the value of the assessment of the threat of an aircraft accident.

Conclusion. The paper proposes an original algorithm for predicting the occurrence of an accident on an aircraft. Based on the result of the algorithm, the corresponding information is formed, according to which the pilots receive data on the deterioration of flight conditions, which allows them to neutralize the emerging threat to the aircraft within a given time interval. In this case, the algorithm, in contrast to the existing ones, forms a complex value for assessing the variation of the influencing, both internal and external factors, which determine the safety of flight conditions on the basis of calculating the profile of these factors.

The article describes the results of the performed computational experiment of the proposed algorithm, which confirmed its adequacy and the need for application. So, in accordance with the obtained results of computer modeling, with a deterioration in the psychophysical characteristics of pilots and insignificant failures of components that belong to the onboard equipment of an aircraft, there is a threat of an air accident at a given forecast time interval. At the same time, using the advice (recommendations) of the decision support system for the crew members, as well as using the automatic aircraft system, it is possible to parry the identified threat.

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