APPROVED

Head of department

S.V. Pavlova

“___”___________2021

GRADUATION WORK

(EXPLANATORY NOTES)

FOR THE DEGREE OF MASTER

SPECIALITY 173 “AVIONICS”

Theme: Influence of the factor resonance phenomenon at piloting an aircraft on flight safety

Done by: student of the AV-209Ma group, Olena Volodymyrivna Bernatska

(student, group, surname, name, patronymic)

Supervisor: ______PhD, Polozhevets H.A.____________________

(scientific degree, academic rank, surname, name, patronymic)

Consultant on ‘Labor protection’: ___________ Kovalenko V.V.

(signature) (surname, name, patronymic)

Consultant on ‘Environmental protection’: ___________ Dmytrukha T.I

(signature) (surname, name, patronymic)

Standard controller: ___________ Levkivskyi V.V.

(signature) (surname, name, patronymic)

Kyiv 2021

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

ФАКУЛЬТЕТ АЕРОНАВІГАЦІЇ, ЕЛЕКТРОНІКИ ТА ТЕЛЕКОМУНІКАЦІЙ

КАФЕДРА АВІОНІКИ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
___________С.В.Павлова
«__»_________2021 р.

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА
ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«АВІОНІКА»

Тема: Вплив явища факторного резонансу при пілотуванні літака на безпеку польотів

Виконала: студентка групи АВ-209Ма, Бернацька Олена Володимирівна
(студент, група, прізвище, ім'я, по-батькові)

Керівник: ______к.т.н, Положевець Г.А.___________________
(наукова ступінь, вчене звання, прізвище, ім'я, по-батькові)

Консультант розділу 'Охорона праці': ________ Коваленко В.В.
(підпис) (прізвище, ім'я, по-батькові)

Консультант розділу 'Охорона навколишнього середовища': ___________ Дмитруха Т.І
(підпис) (прізвище, ім'я, по-батькові)

Нормоконтролер: ___________ В.В. Левківський
(підпис) (прізвище, ім'я, по-батькові)

Київ 2021

NATIONAL AVIATION UNIVERSITY

Faculty of Air Navigation, Electronics and Telecommunications

Department of avionics

Specialty 173 ‘Avionics’

APPROVED

Head of department

S.V. Pavlova

“___”____________2021

TASK

for execution graduation work

O.V Bernatska

1. Theme of graduation work is the ’Influence of the factor resonance phenomenon at piloting an aircraft on flight safety’, approved by order 1945/ст of the Rector of the National Aviation University of 22 September 2021.

2. Duration of which : 18 October 2021 to 31 December 2021.

3. Background to the work: Modern problems of analysis of flight information and prevention of aircraft accidents ; Analysis and development of factor models response based on processing flight information.

4. Content of explanatory notes: List of conditional terms and abbreviations; Introduction; Chapter1:; Chapter 2: ; Chapter 3: ; Chapter 4:;Chapter 5 ; Conclusions; References;

5. The list of mandatory graphic material: tables, figures, charts, graphs.

6. Planned schedule

7.

№	Task	Duration	Signature of supervisor
1.	Validate the rationale of graduate work theme	18.10.2021	
2.	Carry out a literature review	19.10.2021 – 25.10.2021	
3.	Develop the first chapter of diploma	26.10.2021 – 01.11.2021	
4.	Develop the second chapter of diploma	02.11.2021 – 10.11.2021	
5.	Develop the third and fourth chapter of diploma	11.11.2021 – 18.11.2021	
6.	Develop the fifth chapter of diploma	19.11.2021 – 11.12.2021	
7.	Tested for anti-plagiarism and obtaining a review of the diploma	12.12.2021	

Consultants individual chapters:

Chapter	Consultant (Position, surname, name, patronymic)	Date, signature	
		Task issued	Task accepted
Labor protection	Ph.D., Associate Professor Kovalenko V.V.		
Environmental protection	Ph.D., Associate Professor Dmytrukha T.I		

ABSTRACT

Explanatory notes to bachelor work ‘Influence of the factor resonance phenomenon at piloting an aircraft on flight safety’contained 76 pages, 23 figures, 7 tables, 20 references.

The object of the research - processes of interaction of operational factors taking into account the phenomenon of factor resonance.

The purpose of the degree of master – development of models for the interaction of operational factors taking into account factor resonance to increase the degree of flight safety.

Research Method– Research is based on information theory and probability theory, general and mathematical statistics and engineering-psychological methods, a general theory of control processes to identify the nature and mechanisms of the emergence of the “field of inevitability”.

The scientific novelty of the research:

- *For the first time*: developed methodological framework for the analysis of the "area of inevitability" based on the operational map.

- *Improved*: The revealed forms of factor resonance and their analysis prevent the action of factor overlays by creating recommendations for the operation of aircraft.

Keywords: HUMAN FACTOR, FACTOR RESONANCE , ERROR, ANALYTICAL MODELS, FLIGHT SAFETY, AIR ACCIDENT.

CONTENTS

LIST OF CONDITIONAL TERMS AND ABBREVIATIONS

AA - Aircraft Accident

AM – Analytical Models

FOP - Flight Operations Manual

FO - Factor Overlays

FR - Factor Resonance

FRP - Factor Resonance Phenomenon

FS- Flight Safety

FSFR - the First Signs of Factor Resonance

HF - Human Factor

ICAO - International Civil Aviation Organization

RP - Resonance Processes

TALNF - Tasks of Accounting for a Large Number of Factors

INTRODUCTION

Aviation is always associated with a certain risk, as well as any human activity. But in aviation, the risk that ended in failure is especially impressive, as it relates to the life and health of people.

Therefore, in aviation, each incident is subject to analysis, and the flight services periodically publish reports on flight accidents with an analysis of the reasons, the correctness of the crew's actions and recommendations for their prevention.

The legality of the flight is of paramount importance: the availability of a license, the absence of deviations from the requirements of the flight manual and other documents. There is no other way if we want to keep the process of flight activities in a legal manner, which will ensure flight safety in most cases.

The purpose of the graduate work development of models for the interaction of operational factors taking into account factor resonance to increase the degree of flight safety.

Following tasks should be done to achieve this purpose, the:

1. To study the impact of operational factors on flight safety and identified the number of operational factors that lead to the "area of inevitability" of the disaster.
2. To develop a structural-analytical model for the analysis and prevention of AP, taking into account the interaction of operational factors.
5. Develop a methodology for determining the first signs of factor resonance to prevent the emergence of the "area of inevitability."

The object of the research is processes of interaction of operational factors taking into account the phenomenon of factor resonance.

The subject of the research is processing flight information in the "field of inevitability" for modeling accident incidents.

Research Method – Research is based on information theory and probability theory, general and mathematical statistics and engineering-psychological methods, a general theory of control processes to identify the nature and mechanisms of the emergence of the “field of inevitability”.

The scientific novelty of the research:

- **For the first time**: developed methodological framework for the analysis of the "area of inevitability" based on the operational map.

- **Improved**: The revealed forms of factor resonance and their analysis prevent the action of factor overlays by creating recommendations for the operation of aircraft.

Validation of obtain results:

1. Modern problems of analysis of flight information and prevention of aircraft accidents.
2. Analysis and development of factor models response based on processing flight information.
3. Experimental research results by polyparametric factor resonance .

CHAPTER 1

ANALITICAL MODELS

1.1 Markov processes

We will consider models in which a change in the state of the system $z(t) \in Z$ is described by a homogeneous Markov random process. This is due to the exceptional value that Markov processes have for modeling systems of various classes, especially queuing systems, economic processes, reliability networks, etc. There are even special methods that allow you to "markovize" arbitrary random processes, replacing them in some sense with equivalent Markov processes [1]. Further, without loss of generality, it is assumed that the state of the system is described by the vector $z(t)$ with a finite number of components taking values from a countable set Z. Random process $z(t)$ is called Markovian if for arbitrary moments of time $t > t_1 > t_2 > . . . > t_k$, $\tau > 0$ and corresponding states m, n, n^1, n^2 , . . . , $n^k \in Z$ transition probability

$$P(z(t + \tau) = m|z(t) = n, z(t_1) = n ' , z(t_2) = n^2, . . . , z(tk) = n\ k) =$$
$$P(z(t + \tau) = m|z(t) = n) = P_{n\to m} (n, m, \tau, t).$$

In other words, the process $z(t)$ is called Markov if the behavior of the system after the moment t depends only on the state $z(t)$ and does not depend on how the system got into this state. A Markov process is called stationary if the transition probability $P_{n\to m} (n, m, \tau, t)$ does not depend t. The behavior of a system described by a stationary Markov process is completely specified by two objects: 1) the vector of initial distributions P_z (0); 2) probabilities $P_{n\to m}$ (n, m, τ).

According to the formula for the total probability, the probability that at the moment $t + \tau$ the system will be in a state $z(t) = m$, is equal to

$$P_m (t + \tau) = \sum_{n\in Z} P_{n\to m} (n, m, \tau) P_n (t).$$

When $t = \Delta t$ we have

$$P_m (t + \Delta t) =\sum_{n\in Z} P_{n\to m} (n, m, \Delta t) P_n (t). \qquad (1.1)$$

Let Λ_m, $\Lambda_{n\to m}$ (n, m) – transition intensities determined by the relations

$$\Lambda_m = \Lambda_m(m) = \lim_{\Delta t \to 0} \frac{1 - P_{m\to m}(m,m,\Delta t)}{\Delta t},$$

$$\Lambda_{n\to m} = \Lambda_{n\to m}(n, m) = \lim_{\Delta t \to 0} \frac{P_{n\to m}(n,m,\Delta t)}{\Delta t}, \; n \neq m.$$

Assuming that $\Lambda_m = \sum_{n \in Z \setminus \{m\}} \Lambda_{n\to m}(n, m) < \infty$ (at the end Z this inequality holds), from which we obtain

$$P_{m\to m}(m, m, \Delta t) = 1 - \Lambda_m(m)\Delta t + O(\Delta t),$$

$$P_{n\to m}(n, m, \Delta t) = \Lambda_{n\to m}(n, m)\Delta t + O(\Delta t).$$

Substituting these expressions in (1.1) and directing Δt to zero, we arrive at the differential equations for the probabilities of the ratio of the system:

$$\frac{dP_m}{dt} = -\Lambda_m P_m(t) + \sum_{n \in Z \setminus \{m\}} \Lambda_{n\to m} P_n(t) =$$

$$- \sum_{n \in Z \setminus \{m\}} \Lambda_{n\to m} P_m(t) + \sum_{n \in Z \setminus \{m\}} \Lambda_{n\to m} P_n(t) \qquad (1.2)$$

with initial conditions $P_m(0) = P_m^0$. With specific expressions for Λ_m and $\Lambda_{n\to m}$ this system can be solved analytically or numerically.

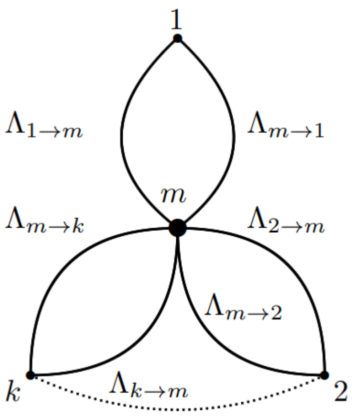

Fig. 1.1. State graph

Equations (1.2) can be given a visual geometric meaning using the state graph. To every state $z \in Z$ the top of the graph is matched. Two peaks n and m connected by an arc (arrow) if there is a non-zero transient intensity $\Lambda_{n\to m}(n, m)$. In fig. 1.1 given a fragment of such a graph for the vertex m. Differential equations can be written directly from the graph. For this, the derivative of the probability of a given state is written on the left m. On the right, each term is the product of the intensity $\Lambda_{i\to j}(i, j)$ on the probability of the state from which the corresponding arrow goes, $m \in \{i, j\}$. The term has a plus sign if the corresponding arrow is directed to the vertex m, and minus sign - otherwise.

1.2 Failure Queuing System

Let the service system consist of M devices (devices, channels).

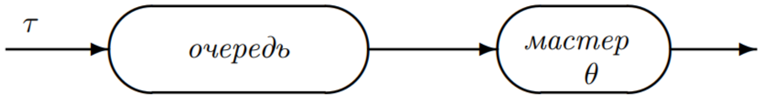

Fig. 1.2. Service with failures

Each claim (claim) arriving for service occupies one of the free machines, on which it is serviced for some random time τ_k. If, when a request arrives, all channels are busy, then the request leaves the system unserved (they say that it was refused). It is required to build a probabilistic model of the system to determine the mean value $m\ (T)$ busy, channels at a time T.

We will consider the number of occupied devices as the state of the system $m(m \in 0 : M)$, so $P_m\ (t)$ – the probability that the system is in a state m. Suppose the time interval τ_n, through which the requirements enter the system, is distributed according to the exponential law with the parameter λ:

$$\mathrm{F}_{\tau_n}\ (x) = P(\tau_n < x) = 1 - e^{-\lambda x}\ ,$$

and the service time interval τ_k – according to the same law, but with the parameter μ:

$$\mathrm{F}_{\tau_k}\ (x) = P(\tau_k < x) = 1 - e^{-\mu x}.$$

This means that the flow of requests entering the system and the flow of requests leaving served from one machine are Poisson. These streams have the following properties:

1) lack of aftereffect. This means that the law of distribution of the number of claims received after a certain moment of time t, does not depend on how and how many requirements have entered the system up to this point;

2) ordinariness. According to this property, the probability of occurrence of more than one event per time interval is negligible, i.e. this probability is $O(\Delta t)$;

3) stationarity. The probability of occurrence in any k disjoint intervals $\mathrm{m}_1, \ldots, \mathrm{m}_k$ requirements depends only on the number and lengths of the intervals (but not on the location on the time axis).

Poisson flows also have one more important property: the sum of Poisson flows again forms a Poisson flow with an intensity equal to the sum of the intensities of the component flows. In particular, the quantity $\tau_{об}$, equal to the time interval between departures of two consecutively served claims m occupied offices, distributed by law

$$F_{\tau_{об}} = P(\tau_{об} < x) = 1 - e^{-m\mu x}\ .$$

Hence it follows that the quantity m is Markov and the probabilities $P_m\ (t)$ are determined by equations (1.2), where the intensities $\Lambda_{i\rightarrow j}$ expressed through λ, μ and m.

Note that according to the property of ordinariness for $|i - j| > 1$ $\Lambda_{i\rightarrow j}\Delta t = 0$. This means that the transition of the system from state i to state j, if $|i{-}j| > 1$ cannot be realized, because otherwise, for the time Δt there would be more than one event. In this regard, the state graph will have the form shown in Fig. 1.2.

Here:

$$\Lambda_{m\rightarrow m-1} = \Lambda_{m\rightarrow m-1}\ (m) = \mu m,$$

$$\Lambda_{m\rightarrow m+1} = \Lambda_{m\rightarrow m+1}\ (m) = \begin{cases} \lambda, & 0 \le m < M \\ 0, & m = M, \end{cases} \qquad (1.3.)$$

$$\Lambda_{m-1\rightarrow m} = \Lambda_{m-1\rightarrow m}\ (m) = \begin{cases} \lambda, & 0 < m \le M \\ 0, & m = M, \end{cases}$$

$$\Lambda_{m+1\rightarrow m} = \Lambda_{m+1\rightarrow m}\ (m) = \begin{cases} \mu(m+1), & 0 \le m < M \\ 0, & m = M. \end{cases}$$

Substituting (1.3.) Into system (1.2.), We obtain a system of differential equations fully consistent with the state graph:

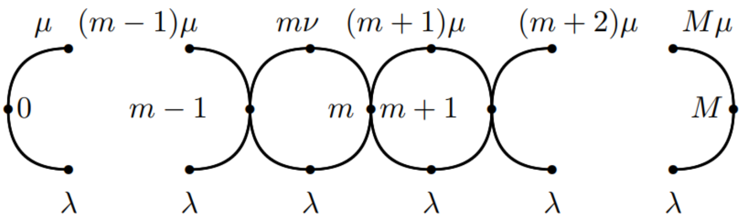

Fig. 1.3. State graph for a multichannel service system

$$\frac{dP_m}{dt} = -\ (\lambda{+}\mu m)\ P_m + \lambda\ P_{m-1} + \mu\ (m{+}1)\ P_{m+1},\quad m \in 0 : M - 1. \qquad (1.4.)$$

$$\frac{dP_m}{dt} = -\ \mu M\ P_M + \lambda\ P_{M-1}.$$

This system can be solved, for example, with the initial conditions $P_0 = 1$, $P_m (0) = 0$, if $m > 0$, and then find the mathematical expectation of the number of occupied machines:

$$E(m(T)) = \overline{\mathrm{m}}\ (T) = \sum_{\mathrm{m}\in 0:M} m\, P_m\ (\mathrm{t}).$$

Apparently, such an approach is possible if the number of equations in (1.4) is not very large. And, in general, methods that for determining individual characteristics of a distribution (in our case, the mathematical expectation) require the construction of the entire definition as a whole, apparently, cannot be considered economical. Let us compose a differential equation directly for $\overline{\mathrm{m}}\ (t)$. To this end, each equation for P_m in (1.4) we multiply by m and then add them all [2]. Then we get

$$\frac{\mathrm{d}\overline{\mathrm{m}}}{dt} = -\lambda \sum_{\mathrm{m}\in 1:M-1} m\, P_m - \mu \sum_{\mathrm{m}\in 1:M-1} m^2\, P_m + \lambda \sum_{\mathrm{m}\in 1:M-1} m\, P_{m-1} + \mu \sum_{\mathrm{m}\in 1:M-1} (m-1)m\, P_{m+1} - \mu M^2\, P_m + \lambda M\, P_{M-1}\,.$$

Changing the summation limits, passing in all terms to P_m and performing the corresponding mutual annihilation, as a result, we obtain only one equation

$$\frac{\mathrm{d}\overline{\mathrm{m}}}{dt} = \lambda(1 - P_m) - \mu\, \overline{\mathrm{m}}, \quad \overline{\mathrm{m}}\ (0) = 0. \qquad (1.5.)$$

As you can see, in order to determine $\overline{\ }$m, in this case, knowledge is required P_m, those. again came to the need to solve system (1.4). Fortunately, in many cases (especially for large values) the probability P_m can be neglected.

Let $m\ (t)$ be the number of busy machines at time t. Let's see how it changes over time Δt. It is obvious that it can decrease by one with the intensity $\Lambda_{m\to m-1}\ (m)$, increase by one with intensity $\Lambda_{m\to m+1}\ (m)$ or stay the same. So

$$m(t+\Delta t) = m(t) - \Lambda_{m\to m-1}\ (m)\Delta t + \Lambda_{m\to m+1}\ (m)\Delta t + O(\Delta t). \qquad (1.6.)$$

From here $E(m(t + \Delta t)) = \overline{\mathrm{m}}\ (t + \Delta t) = \overline{\mathrm{m}}\ (t) - E(\Lambda_{m\to m-1}\ (m))\Delta t + E(\Lambda_{m\to m-1}\ (m))\Delta t$. Because $\Lambda_{m\to m+1}\ (m)$ according to (1.3.) takes zero value with probability P_m , то $E(\Lambda_{m\to m+1}\ (m)) = \sum_{\mathrm{m}\in 0:M-1} \lambda\, P_m = \lambda(1 - P_m)$,

$$E(\Lambda_{m\to m-1}\ (m)) = \mu\overline{\mathrm{m}}.$$

Substituting the obtained expressions in (1.6), we again obtain (1.5) by passing to the limit.

Note that the appearance of the probability P_M in equation (1.5) is explained by the fact that the actual flow of requirements into the system, when all machines are busy, is equal to 0, and not λ. The question of the possibility of neglecting it most often depends on the goals of the study and the physical properties of the system itself.

1.3. Single-channel queuing system with waiting

The system has one channel with a service rate μ.

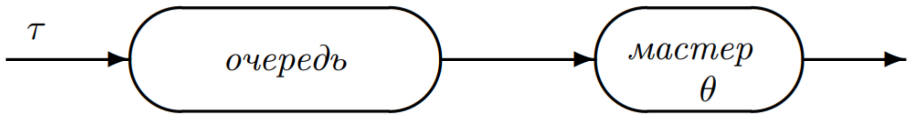

Fig. 1.4. Queue service

Arriving with intensity λ when the machine is busy, the requests are queued, and the request can leave the queue without waiting for the start of service with the intensity ν (after a while τ_0). The queue can grow indefinitely. It is assumed that all flows of customers are Poisson (distributions of times τ_k, τ_0, τ_n – exponential). It is required to find the average value $\bar{n}$ (T) queue at a point in time.

As a state, we choose the number of requests in the system, so that P_n means the probability that $n-1$ a request is in the queue and one is in service. The state graph is shown in Fig. 1.3 and, as in the previous case, it is assumed that, according to the property of ordinariness, the transitions of the system from the state n can be carried out only to the neighboring ones.

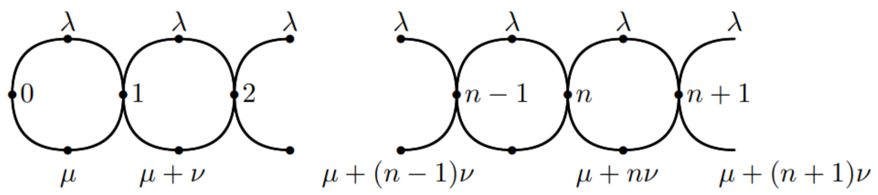

Fig. 1.5. State graph for a multichannel waiting queuing system

State graph for a multichannel waiting queuing system:

$$\Lambda_{n\to n-1} = \Lambda_{n\to n-1}\,(n) = \begin{cases} \mu + (n-1)\nu, & n > 0, \\ 0, & n = 0, \end{cases}$$

$$\Lambda_{n\to n+1} = \Lambda_{n\to n+1}\,(n) = \lambda, \tag{1.7.}$$

$$\Lambda_{n-1\to n} = \Lambda_{n-1\to n}\,(n) = \begin{cases} \lambda, & n > 0 \\ 0, & n = 0, \end{cases}$$

$$\Lambda_{n+1\to n} = \Lambda_{n+1\to n}\,(n) = \mu + n\nu.$$

Substituting them into equation (1.2), we obtain

$$\frac{dP_0}{dt} = -\lambda P_0 + \mu P_1, \qquad (1.8.)$$

$$\frac{dP_n}{dt} = -(\lambda + \mu + (n-1)\nu)\, P_n + \lambda P_{n-1} + \mu P_{n+1}, \;\; n > 0,$$

$$P_0\,(0) = 1, \;\; P_n\,(0) = 0, \;\; n > 0.$$

This system has an infinite number of equations. Although in practice it is always possible to limit oneself when solving it to some finite number of them, nevertheless, a direct solution in order to determine the average number of requirements in the system

$$E(n(T)) = \overline{\mathrm{n}}\,(T) = \sum_{\mathrm{n}>0} \mathrm{n}P_n$$

meets some difficulties.

To obtain a differential equation for $\overline{\mathrm{n}}\,(t)$, as before, we multiply the left and right sides of the n-th equation from (1.8) by n, and then sum:

$$\frac{d\overline{\mathrm{n}}}{dt} = -\sum_{\mathrm{n}>0} (\lambda + \mu + (\mathrm{n}-1)\mu)\mathrm{n}P_n + \sum_{\mathrm{n}>0} \lambda_n P_{n-1} + \sum_{\mathrm{n}>0} (\mu + +\mathrm{n}\nu)P_{n+1} - \lambda P_0 + \mu P_1.$$

Reducing all terms to a single index n and, if necessary, changing the lower summation limits, we obtain

$$\frac{d\overline{\mathrm{n}}}{dt} = -\nu(\overline{\mathrm{n}} - (1 - P_0)) + \mu(1 - P_0) + \lambda. \qquad (1.9.)$$

Here, as in (1.2.3), the solution of the equation requires prior knowledge of the probability $P_0\,(t)$, obtained as a result of solving system (1.8). However, in a number of cases (small variance of the random variable $n\,(t)$, congestion of the system and, as a consequence, large queues) it can be neglected.

We again obtain equation (1.9) using the intensities (1.7)). We again write down the difference equations for the increment of the number of claims in the time Δt:

$$n(t + \Delta t) = n(t) - \Lambda_{n\to n-1}\,(n)\Delta t + \Lambda_{n\to n-1}\,(n)\Delta t + O(\Delta t).$$

Because $\Lambda_{n\to n-1}\,(n)$ with probability P_0 takes the value 0, then

$E(\Lambda_{n\to n-1}\,(n)) = \sum_{\mathrm{n}>0} (\mu + (\mathrm{n}-1)\nu)P_n = \nu(\overline{\mathrm{n}} - (1 - P_0)) + \mu(1 - - P_0)$;

$E(\Lambda_{n\to n+1}\,(n)) = \lambda$.

Obviously, together with the previous equation, the obtained relations lead to (1.9).

1.4. Probabilistic model of the confrontation process

As the state of the system, we choose a pair - the vector $\langle m(t), n(t)\rangle = mn$, denoting that at the moment t on the side M there are m living units, and on the side N - n living units. Let P_{mn} (t) – the probability that at time t the system is in the state mn; $\lambda\mu$, $\lambda\nu$ – the intensity of decreasing the units of the sides M and N, respectively. We assume that the intervals τ_{μ} and τ_{ν} between two successive destruction of units by one of our units are distributed exponentially with the parameters μ and ν. We will be interested in the average values of the residuals in the groups $\overline{\mathrm{m}}$ (T), $\overline{\mathrm{n}}$ (T) at some point in time T.

We denote P_m^{μ} (t), P_m^{ν} (t) unconditional probabilities that in the groups M and N at the moment of time t there are exactly m (t), n (t) ones. Then

$$P_m^{\mu} = \sum_{\mathrm{n}\in 0:N} P_{mn}, \quad P_m^{\nu} = \sum_{\mathrm{m}\in 0:M} P_{mn} \qquad (1.10.)$$

$$\overline{\mathrm{m}} = \sum_{\mathrm{m}\in 0:M} P_m^{\mu}\, m = \sum_{\mathrm{m}\in 0:M} \sum_{\mathrm{n}\in 0:N} P_{mn}\ \mathrm{m}, \qquad (1.11.)$$

$$\overline{\mathrm{n}} = \sum_{\mathrm{n}\in 0:N} P_n^{\nu}\, n = \sum_{\mathrm{n}\in 0:N} \sum_{\mathrm{m}\in 0:M} P_{mn}\mathrm{n}.$$

Due to the fact that the flows of events in the process under consideration are Poisson, only two transitions are possible from the state mn − to the neighboring states $m, n-1$ and $n-1, m$. Possible transitions for all states of the system are shown on the state graph (Fig. 1.4). We find the transition intensities straight from the graph:

$$\Lambda_{mn\to m-1,n}\ (m, n) = \begin{cases} \lambda\mu\mathrm{m}, & 0 < \mathrm{m} \le \mathrm{M},\ 0 \le \mathrm{n} \le N, \\ 0, & \mathrm{m} = 0, \end{cases}$$

$$\Lambda_{mn\to m,n-1}\ (m, n) = \begin{cases} \lambda\nu\mathrm{n}, & 0 \le \mathrm{m} \le \mathrm{M},\ 0 < \mathrm{n} \le \mathrm{N}, \\ 0, & \mathrm{n} = 0, \end{cases}$$

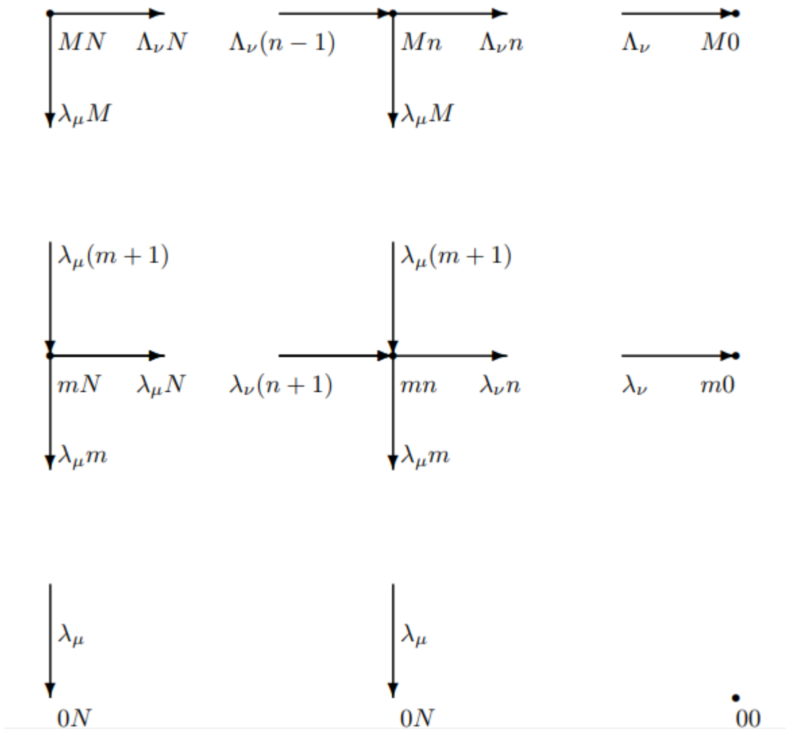

Fig. 1.6. The state graph of the struggle process

and these intensities are equal to zero, respectively, with the probabilities P_0^ν and P_0^μ. Considering that $\lambda\mu$ means which part of the units of the group M is eliminated by all units of the group N per unit time, we obtain

$$\lambda\mu = \frac{\nu n}{m}, \ \lambda\nu = \frac{\mu m}{n}.$$

Substituting these expressions into the previous ones, we find

$$\Lambda_{mn\to m-1,n}\,(m,n) = \begin{cases} \nu n, & 0 < m \le M,\ 0 \le n \le N, \\ 0, & m = 0, \end{cases}$$

$$\Lambda_{mn\to m,n-1}\,(m,n) = \begin{cases} \mu n, & 0 \le m \le M,\ 0 < n \le N, \\ 0, & n = 0. \end{cases} \qquad (1.12))$$

Next, we use the differential equations for the states (1.2):

$$\frac{dP_{mn}}{dt} = -(\nu n + \mu m)\,P_{mn} + \nu(n+1)\,P_{m+1,n} + \mu(m+1)\,P_{m,n+1},$$

$$0 < m \le M, \quad 0 < n \le N;$$

$$\frac{dP_{m0}}{dt} = \mu m P_{m1}, \quad 0 \le m \le M,\ n = 0;$$

$$\frac{dP_{0n}}{dt} = \nu n P_{1n}, \quad 0 \le n \le N,\ m = 0.$$

These equations can be solved with the initial conditions $P_{mn}(0) = 0$, if $m < M$ and $n < N$, $P_{MN} = 1$, after that, to calculate the average values of the residuals, use formulas (1.11). Consider the change in the number of parties M over time Δt:

$m(t + \Delta t) = m(t) - \Lambda_{mn\to m-1,n}\ (m, n)\Delta t + O(\Delta t)$.

Since according to (1.12).

$E(\Lambda_{mn\to m-1,n}\ (m, n)) = \nu \sum_{\mathrm{n}\in 1:N} \sum_{\mathrm{m}\in 1:M} P_{mn}\mathrm{n} + 0P_0^{\nu}$,

then, using the passage to the limit, we obtain

$\frac{\mathrm{d}\overline{\mathrm{m}}}{dt} = -\nu \sum_{\mathrm{m}\in 1:M} \sum_{\mathrm{n}\in 1:N} P_{mn}\mathrm{n} = -\nu \sum_{\mathrm{n}\in 1:N} n \sum_{\mathrm{m}\in 1:M} P_n^{\nu} P_{m|n}^{\nu} =$

$= -\nu \sum_{\mathrm{n}\in 1:N} nP_n^{\nu} \left(\sum_{\mathrm{m}\in 1:M} P_{m|n}^{\nu} + P_{0|n}^{\nu} - P_{0|n}^{\nu}\right) =$

$= -\nu \sum_{\mathrm{n}\in 0:N} nP_n^{\nu} + \nu \sum_{\mathrm{n}\in 0:N} nP_n^{\nu} P_{0|n}^{\nu} =$

$= -\nu\overline{\mathrm{n}} + \nu P_0^{\mu} \sum_{\mathrm{n}\in 0:N} nP_{n|0}^{\nu} = -\nu\overline{\mathrm{n}} + \nu P_0^{\mu} \overline{\mathrm{n}}\ \Big|_{m=0}$.

Here $P_{0|n}^{\nu}$ – the probability that side M is eliminated provided there are exactly n ones on side N, a $\overline{\mathrm{n}}\ \Big|_{m=0}$ – conditional expectation. Quite the same $\frac{\mathrm{d}\overline{\mathrm{n}}}{dt} = -\mu\overline{\mathrm{m}} + \mu P_0^{\nu}\overline{\mathrm{m}}\ \Big|_{n=0}$.

Thus, in this model, too, in order to determine the mean values, knowledge of the probabilities of states is required. If the time T is short and by this moment both groups are still far from complete annihilation, then the probabilities P_0^{ν} and P_0^{μ} are not very different from zero and can be neglected. This is also true in the case when the variances for m and are sufficiently small. The presence of probabilities P_0^{ν} and P_0^{μ} in the equations for the means is explained by the fact that in fact the destruction rates are equal to zero (and not μ or ν), when all enemy units are destroyed.

Unlike previous models, it is assumed that the time is discrete and takes values $t = 0$, 1, 2,... The process of mutual destruction is carried out as follows. At an odd moment in time $t = 1, 3, \ldots$ each unit of side M chooses a victim and destroys it with probability p. Any unit of side N acts similarly at even times $t = 2, 4, \ldots$, however, the probability of destroying the target is q. The described scheme of interaction of groups can be represented by a finite Markov chain, the number of states of which is equal to $(N + 1)\ (M + 1)$. Since the analysis of the model is difficult for large M and, we restrict ourselves to the case when $M = N = 2$.

All possible states of the system form the set $S = \{00, 01, 02, 10, 11, 12, 20, 21, 22\}$, in which the element mn means that at a given time on the side M there are m units, and on the side N – n.

Let's consider the 1-st step. As a result of its implementation, the following outcomes are possible: {20, 21, 22}. The corresponding transition probabilities are

$P_{22\to20} = p^2$,

$P_{22\to21} = p(1-p) + (1-p)p = 2(1-p)p,$

$P_{22\to22} = (1-p)(1-p) = (1-p)^2$.

In the next step, the units of the side M are eliminated. In this case, such outcomes are possible:

$Q_{21\to11} = q$, $Q_{21\to21} = 1-q$, $Q_{22\to02} = q^2$,

$Q_{22\to12} = 2q(1-q)^2$, $Q_{22\to22} = (1-q)^2$.

In the third step, the units of the side N are destroyed again, and so on. The entire process of mutual destruction can be expanded in the form of a tree (Fig. 1.7).

In order to calculate the probability of the system being in a certain state, it is necessary to find all the vertices corresponding to this state, and then determine all the paths from the initial state to the selected ones. After that, compose expressions equal to the products of the transition probabilities along each path, and then sum them up over all the paths. Suppose we are interested in the probability of eliminating all units of side N in three steps. In other words, we need to find the probability of the system getting from state 22 to state m_0 $(0 < m \leq 2)$ in three steps. From fig. 1.7 we immediately find that it is equal to

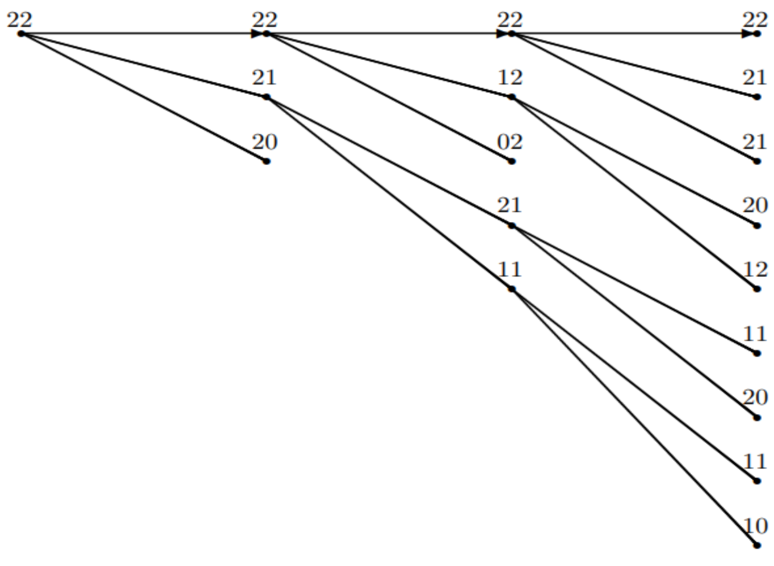

Fig.1.7. The state tree of the struggle process

$P_{22\to20}$ + $P_{22\to22}$ $Q_{22\to22}P_{22\to20}$ + $P_{22\to21}$ ($Q_{21\to21}P_{21\to20}$ + $Q_{21\to11}P_{11\to10}$) = $p^2 + (1-p)^2(1-q)^2\, p^2 + 2(1-p)p[(1-q)(2p - p^2) + qp]$.

End states are marked with circles on the tree. For the same purposes, matrix relations can also be used. Let's construct two matrices $P = \|P_{ij} \to kl\|$ and $Q = \|Q_{ij} \to kl\|$ for all $ij \in S$ and $kl \in S$. The expression at the intersection of the row "i, j" and the column "kl" determines the probability of transition from state ij to state kl. Consider a matrix that is a product of P and Q taken s times:

$$PQPQ\ ...$$

It can be shown that the element at the intersection of row ij and column kl of this matrix is equal to the probability of transition from state ij to state kl in exactly s steps. In particular, the probability of the system entering the state $m0$ in three steps will be equal to the sum of the element (22, 20) of the matrix P and the elements (22, $m0$) of the matrix PQP, $m \neq 0$.

The described representation of the system is clear and simple, but such models can be used only in the case when the number of states of the system is not very large. This remark especially concerns the matrix representation of the model, since in practice the matrices themselves usually have a large number of zeros and their use leads to a large expenditure of computer time [2].

Note that almost any process with continuous time can be reduced to the scheme of a finite Markov chain, for which it is sufficient to divide the simulation interval into intervals Δt and put $p = \mu\Delta t$ and $q = \nu\Delta t$.

1.5. Probabilistic Search and Tracking Model

In many cases, they are interested in the characteristics of the system not in the transient mode of its operation, but in the steady state, at $t \to \infty$. The latter can be given by the so-called limiting distribution, to which the distribution tends $\{Pm(t)|m \in Z\}$ at $t \to \infty$. This marginal distribution does not always exist. If the state graph is connected and the number of states is finite, then, according to Markov's ergodic theorem, the corresponding Markov chain has a limit distribution.

In the next example, we will look for the limiting characteristics of the system. Let M be the number of scouts searching for a given number N of objects ($M \geq N$) in a certain area.

The search is carried out by one scout with an intensity μ. Each scout, having found an object, begins to follow it, while he is not engaged in a new search. In the process of tracking, the scout may lose the object. The intensity of the flow of losses is ν. We will be interested in the average number of found objects in the steady state.

Let n denote the state of the system in which the tracking of n objects is carried out. The transition intensities have the form:

$\Lambda_{n\to n+1}(n) = (N-n)(M-n)\mu, \quad 0 \le n \le N,$

$\Lambda_{n\to n-1}(n) = n\nu, \quad 0 \le n \le N,$

$\Lambda_{n+1\to n}(n) = \begin{cases}(n+1)\nu, & 0 \le n < N,\\ 0, & n = 0,\end{cases}$

$$\Lambda_{n-1\to n}(n) = \begin{cases}(M-n+1)(N-n+1)\mu, & 0 < n \le N,\\ 0, & n = 0.\end{cases} \qquad (1.13)$$

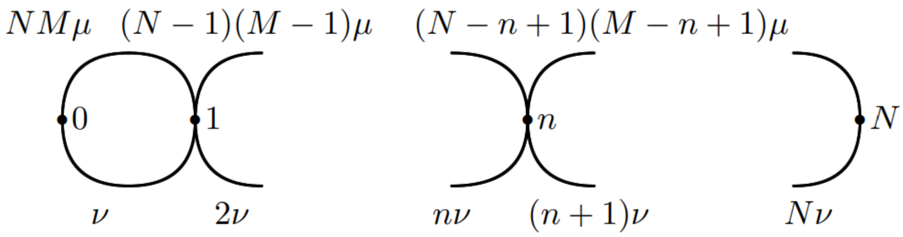

Fig. 1.8. Search system state graph

Substituting these intensities into equations (1.2), we obtain

$$\frac{dP_0}{dt} = -MN\mu P_0 + \nu P_1, \quad n = 0,$$

$\frac{dP_n}{dt} = -n\nu P_n - (N-n)(M-n)\mu P_n + (n+1)\nu P_{n+1} + (M-n+1)(N-n+1)\mu P_{n-1}, \quad 0 < n < N,$

$\frac{dP_n}{dt} = -N\nu P_N + (M-N+1)\mu P_{N-1}, \quad n = N.$

From fig. 1.6 it can be seen that the graph is connected and the number of states is finite. This means that limiting probabilities exist. To find them, we equate the right-hand sides of the obtained equations to 0 w:

$-NM\mu P_0 + \nu P_1 = 0,$

$-n\nu P_n - (N-n)(M-n)\mu P_n + (n+1)\nu P_{n+1} +$

$+(M-n+1)(N-n+1)\mu P_{n-1} = 0, \quad 1 \le n \le N-1,$

$-N\nu P_N + (M-N+1)\mu P_{N-1} = 0.$

Let $\alpha = \mu/\nu$.

Then from the first equation we have

$$P_2 = \alpha MNP_0.$$

We choose an equation for $n = 1$ and from it we find

$$P_2 = \alpha \frac{(\mathrm{M}-1)(\mathrm{N}-1)}{2} P_1.$$

Proceeding in a similar way, we find from the equation for $n - 1$:

$$P_n = \alpha\frac{(\mathrm{M}-\mathrm{n}+1)(\mathrm{N}-\mathrm{n}+1)}{n} P_{n-1}, n = 1, 2, \ldots, N.$$

From here

$$Pn = \alpha^n \frac{(\mathrm{N}-\mathrm{n}+1)(\mathrm{M}-\mathrm{n}+1)}{n} \ldots \frac{\mathrm{NM}}{1} P_0 \frac{\mathrm{n}!}{n!} = \alpha^n \binom{N}{n}\binom{M}{n} P_0 \mathrm{n}!$$

Because $\sum_{\mathrm{n}\in 0:N} P_n = 1$, then $P_0 \sum_{\mathrm{n}\in 0:N} \binom{N}{n}\binom{M}{n}\alpha^n \mathrm{n}! = 1$. So

$$P_n = \frac{\alpha^n\binom{N}{n}\binom{M}{n}\,\mathrm{n}!}{\sum_{\mathrm{n}\in 0:N} \alpha^n\binom{N}{n}\binom{M}{n}\mathrm{n}!}.$$

Finally, using the formula for the mean $\overline{\mathrm{n}}$, finally we have

$$\overline{\mathrm{n}} = \sum_{\mathrm{n}\in 0:N} nP_n = \frac{\sum_{\mathrm{n}\in 0:N} n\alpha^n\binom{N}{n}\binom{N}{n}\mathrm{n}!}{\sum_{\mathrm{n}\in 0:N} \alpha^n\binom{N}{n}\binom{N}{n}\mathrm{n}!}. \qquad (1.14.)$$

Despite the presence of an explicit form for $\overline{\mathrm{n}}$, using this formula is difficult. This is due to the fact that for large n, the numerator and denominator are very large numbers of approximately the same order of magnitude. In this regard, an increase in n for a fixed number of computer discharges leads to a sharp drop in the accuracy of calculations.

1.6. The main assumption of the models of the dynamics of averages

Probabilistic models make it possible to find the distribution of the probabilities of the system being in individual states of the systems, and from them determine the necessary characteristics: mathematical expectations, variances, etc. In some cases, it turns out that it is possible to write approximate equations directly for the characteristics of interest to us. In particular, in the examples considered above, neglecting the probabilities of the stay of the system in boundary states just led to the sought equations. When compiling the equations for the dynamics of averages, a more general assumption is used, including those indicated as a special case.

When constructing a model, it is assumed that the system consists of a certain finite number of elements, which can be divided into groups of homogeneous elements. Further, the equations of the model are usually compiled for each group separately, and the mutual influence of the groups is taken into account through the coefficients of the equations. In this regard, we further assume that the system consists of a group of homogeneous units and that any of them is in one of the states $S_1, S_2, \ldots S_k$. Let the total number of units be M , and the number of units in a state S_i , and $\in 1 : k$, equals m_i $(0 \leq m_i \leq M)$. Then the vector means the state of the system as a whole. Obviously, the total number of states is $(M + l)^k$. This is how many equations need to be written in order to build a probabilistic model to determine the probabilities of stay P_m capable of m. For models of the dynamics of averages, it is enough to compose only k equations − according to the number of states in which one typical element of the system can be. In particular, the following approach is possible. Let x_i^j – a random variable equal to 1 if the j-th unit is in the state S_i . Otherwise, it is equal to 0. The probabilities with which it takes values 1 and 0 are, respectively, equal p_i and $1 - p_i$. Then

$$m_i\ (t) = x_i^1\ (t) + x_i^2\ (t) + \ldots + x_i^M\ (t),$$

$$E(m_i\ (t)) = \overline{m_i}(t) = \sum\nolimits_{\mathrm{j} \in 1:N}\ \mathrm{E}(x_i^j\ (\mathrm{t})).$$

Because $E(x_i^j\ (t)) = p_i\ (t)$, then

$$\overline{m_i}\ (t) = M\ p_i\ (t). \qquad (1.15.)$$

Thus, considering the change in the state of only one element, we can calculate using the probabilistic model of the probability $p_i\ (t)$, $i \in 1 : M$, stay of a typical unit in each state, and then go to mathematical expectations (variances, etc.).

However, one can immediately compose equations for the dynamics of averages, introducing only one assumption about probabilistic models.

Let A_i^- – such a set of states that any unit can pass from the state S_i to others, but A_i^+ – a set of states from which a unit can go to a state S_i . As for A_i^-, so for A_i^+ it can be assumed that $LLLS_i \Rightarrow S_j \neq 0$. We denote $\Omega_{S_i}^-\ (m)$ and $\Omega_{S_i}^+\ (m)$ respectively negative and positive increments of the value m_i per unit of time (increment rate). Then

$$\frac{\mathrm{d}m_i}{dt} = -\Omega_{S_i}^-\ (m) + \Omega_{S_i}^+\ (m), \qquad (1.16.)$$

$$\Omega^-_{S_i}(m) = \sum_{S_k \in A^-_i} \Omega_{S_i \to S_j}(m),$$

$$\Omega^+_{S_i}(m) = \sum_{S_k \in A^+_i} \Omega_{S_j \to S_i}(\mathrm{m}),$$

where $m = m[1 : k]$, and the intensity $\Omega_{S_i \to S_j}(m)$ means how many units go from state i to state j per unit of time, in the general case depends on the vector m.

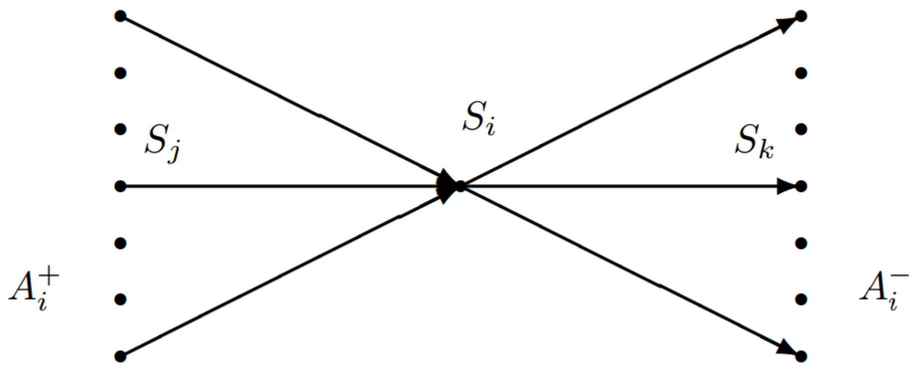

Fig.1.9. The graph for the state S_i

Because $m_i(t)$, $i \in 1 : k$, for a fixed t is a random variable, then its mathematical expectation can be found if we assume that

$$\Omega^-_{S_i}(m) \approx \Omega^-_{S_i}(\overline{\mathrm{m}}), \quad \Omega^+_{S_i}(m) \approx \Omega^+_{S_i}(\overline{\mathrm{m}}), \qquad (1.17.)$$

Finding the mathematical expectation, we obtain a set of differential equations for the means $\overline{m_i}$:

$$\frac{\mathrm{d}\overline{m_i}}{dt} = -\sum_{S_k \in A^-_i} \Omega_{S_i \to S_j}(\overline{\mathrm{m}}) + \sum_{S_k \in A^+_i} \Omega_{S_j \to S_i}(\overline{\mathrm{m}}), \qquad (1.18.)$$

where $i \in 1 : k$.

Relations (1.17) are approximate, therefore the formal solution of equations (1.18) can lead to the fact that $\overline{m_i}(t)$ will take on values that do not correspond to those that exist in the real system. In this regard, for $\overline{m_i}(t)$ when solving (1.18), the range of values $Z \ni \overline{\mathrm{m}}(t)$.

Thus, the essence of the method of dynamics of means is that the equations of the model (1.18). are written immediately for mathematical expectations, taking into account the assumptions (1.17). This assumption assumes that the mathematical expectation of a function can approximately, but with sufficient accuracy for practice, be replaced by a function of the mathematical expectation.

It is convenient to describe the model of the dynamics of means by a state graph, which is somewhat different from the state graph of the probabilistic model. To each state of a unit of the system S_i , $i \in 1 : k$, the vertex of the graph is assigned to which the weight is assigned $\overline{m_i}$, equal to the average number of units in this state. From the state S_i in a state S_j followed by an arrow (arc) with a weight $\Omega_{S_i \to S_j}$, if intensity $\Omega_{S_i \to S_j} \neq 0$. This intensity should mean how many units pass from the state S_i in a state S_j per unit of time. In the general case, it depends on the number of all states. It is assumed that the state S_0 refers to the external environment of the system [3].

The number of equations of the model of the dynamics of means is equal to the number of states $S_1, S_2, \ldots S_k$. To compose an equation corresponding to the state S_k, on the left, the derivative of the weight of the vertex is written $\overline{m_i}$, and on the right is the algebraic sum of the weights of those arcs that are incident to the vertex $\overline{m_i}$. In this case, the weights of the arcs coming from the vertex $\overline{m_i}$, are taken with a minus sign, and the weights of the arcs that enter the vertex $\overline{m_i}$, – plus sign, $i \in 1 : k$.

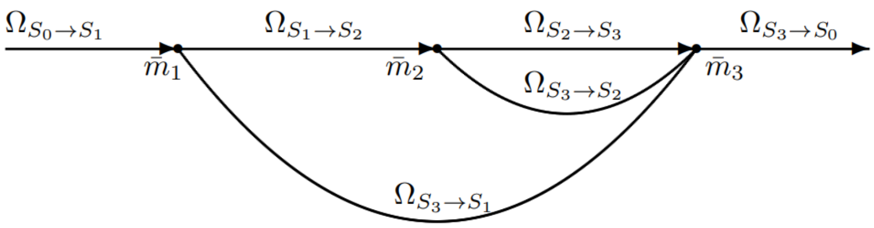

Fig. 1.10. The state graph in the model of the dynamics of means

In fig. 1.16 shows an example of a state graph of a system described by differential equations:

$$\frac{\mathrm{d}\overline{m_1}}{dt} = -\Omega_{S_1 \to S_2}\,(\overline{\mathrm{m}}) + \Omega_{S_0 \to S_1}\,(\overline{\mathrm{m}}) + \Omega_{S_3 \to S_1}\,(\overline{\mathrm{m}}),$$

$$\frac{\mathrm{d}\overline{m_2}}{dt} = -\Omega_{S_2 \to S_3}\,(\overline{\mathrm{m}}) + \Omega_{S_1 \to S_2}\,(\overline{\mathrm{m}}) + \Omega_{S_3 \to S_2}\,(\overline{\mathrm{m}}),$$

$$\frac{\mathrm{d}\overline{m_3}}{dt} = -\Omega_{S_3 \to S_0}\,(\overline{\mathrm{m}}) - \Omega_{S_3 \to S_1}\,(\overline{\mathrm{m}}) - \Omega_{S_3 \to S_2}\,(\overline{\mathrm{m}}) + \Omega_{S_2 \to S_3}\,(\overline{\mathrm{m}}),$$

where $m = \rangle\overline{m_1}, \overline{m_1}, \overline{m_1}\langle$ – system state vector. In some cases, instead of several intensities, the total intensity is set, which transfers units from one state to several others. For example, instead of intensities $\Omega_{S_3 \to S_0}\,(\overline{\mathrm{m}})$, $\Omega_{S_3 \to S_1}\,(\overline{\mathrm{m}})$, $\Omega_{S_3 \to S_2}\,(\overline{\mathrm{m}})$ intensity can be set $\Omega_{S_3}^{-}\,(\overline{\mathrm{m}})$. Then, together with it, the transition probabilities must also be given $p_{S_3 \to S_j}$, $j \in 0 : 2$, so

$$\varOmega_{S_3 \to S_j}(\overline{\mathrm{m}}) = \varOmega_{S_3}^{-}(\overline{\mathrm{m}})\, p_{S_3 \to S_j},\ \ Sum_{\mathrm{j} \in 0:2}\, p_{S_3 \to S_j} = 1.$$

Often not absolute values of intensities are used $\varOmega_{S_i \to S_j}(\overline{\mathrm{m}})$, but relative – $\omega_{S_i \to S_j}(\overline{\mathrm{m}}) = \varOmega_{S_i \to S_j}(\overline{\mathrm{m}}) / \overline{m_i}$, which mean what part of the units passes from the state S_i in a state S_j per unit of time. These intensities should not be confused with each other, especially since at $i \neq 0$ always use absolute values only.

Conclusions to chapter 1:

1. Poisson flows have the following properties: no consequences; ordinariness; stationarity; the sum of the Poisson fluxes again forms a Poisson flux with an intensity equal to the sum of the intensities of the constituent fluxes.
2. Almost any process with continuous time can be reduced to the scheme of a finite Markov chain, for which it is sufficient to divide the simulation interval into intervals Δt and put $p = \mu \Delta t$ and $q = \nu \Delta t$.
3. Probabilistic models make it possible to find the probability distribution of the system being in individual states of the systems, and from them to determine the necessary characteristics: mathematical expectations, variances, etc. When compiling the equations for the dynamics of averages, a more general assumption is used, including those indicated as a special case.

CHATER 2

ASSESSMENT OF THE INFLUENCE OF PERSONAL STAFF ERRORS ON FLIGHT SAFETY

2.1. Statistical data and the role of personnel in providing flight safety

The FL level is laid down in the creation of aviation technology (AT). To maintain this level, personnel in the process of mass operation and use of AT must ensure that the requirements of the general designer for maintenance, modes and conditions of its use are met. However, this does not exhaust the role of the personnel in providing FL. In the process of mass operation and use of AT, the personnel identify the existing flaws in the aircraft design, regulations, manuals for flight and technical operation, methodological instructions for combat use, formulate requirements and proposals for their improvement (changes in regulations, restrictions, etc.). Thanks to these actions of the personnel, the level of FL of aircraft in the process of mass operation increases significantly.

Improvement of aviation technology and methods of its maintenance in the process of mass operation, on the one hand, and the desire of the flight personnel as they master the new technology to make the most of its capabilities, on the other, lead to a change in the distribution of the causes of accidents between personnel and equipment. If the amount of AA due to the fault of the personnel and for reasons of imperfection of technology is taken as 100%, then the upper and lower boundaries of the change in their distribution over the years of operation can be represented by the curves shown in Fig. 2.1. If in the first 1-2 years of operation 60 ... 80% of the accident occurs due to imperfect technology (20 ... 40% due to the fault of the personnel), then after 12-14 years of operation - only 15 ... 30% (70 ... 85% due to the fault personnel). From this it follows that the relative increase in the share of AA due to the fault of the personnel over the years of operation of the equipment is natural [4].

In addition to flight crews, flight control personnel, aviation engineering service, material and aerodrome technical support service, communications and radio technical support service, medical service, paratrooper service and air fire service take part in flight support. The approximate distribution of AA between different groups serving frontline aviation aircraft is presented in Table. 2.1. In this table, aircraft accidents caused by personnel are taken as 100%..

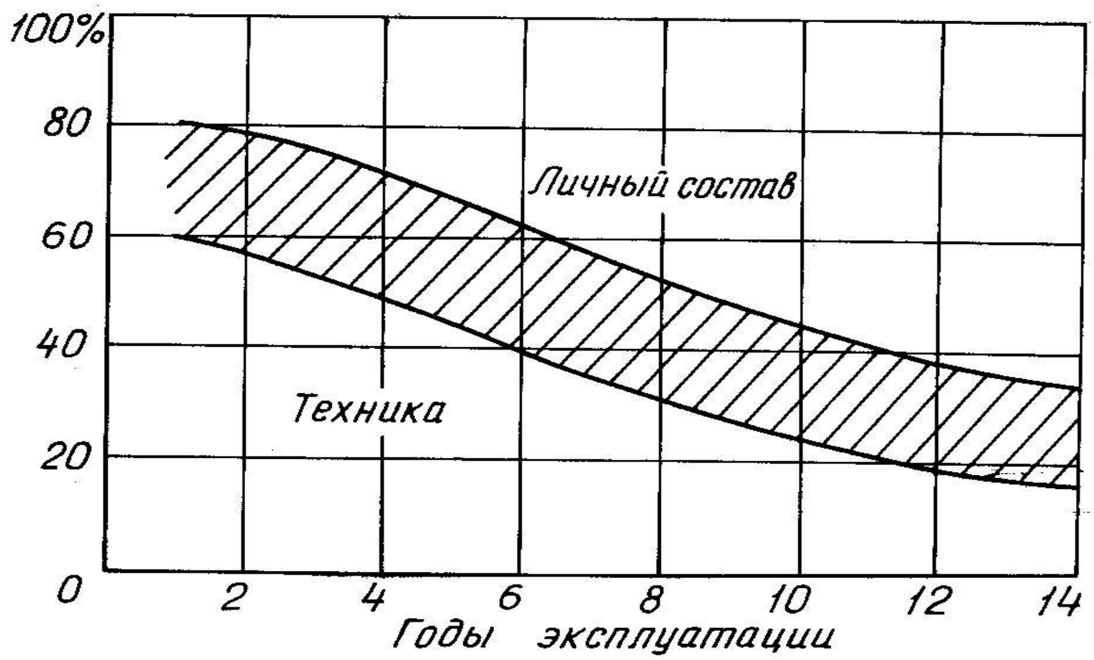

Fig. 2.1. Distribution of AP between different groups serving aircraft

From an examination of table 2.1, it may formally seem that, since the complete elimination of an accident due to the fault of the engineering and technical staff (ETS) does not solve the problem of ensuring the safety and security, then its effect on the prevention of accident is small. In fact, the role of the aviation engineering service in ensuring flight safety is exceptionally great. As you know, the main tasks of the IAS are the maintenance of aviation equipment in constant serviceability and combat readiness, timely preparation for flights and ensuring its trouble-free operation in flight. Statistical data on aircraft failures and malfunctions show that in the process of preparing equipment for flights, carrying out routine and other types of work, 96% of failures and malfunctions are identified and eliminated. However, some of them (4%) appear or appear in flight. At the same time, 97.5% of failures and malfunctions manifested in flight have no consequences and only 2.5% lead to consequences. Of the total number of aircraft failures and malfunctions due to the fault of the ETS personnel, leading to consequences, 57% pose a threat to flight safety, and 0.5% lead to an accident. These data indicate, on the one hand, the effectiveness of the technical operation system adopted in military aviation, and on the other hand, the annual rather large (8 ... 11%)

number of FS due to the fault of the ITS personnel causes an urgent need to further improve the operation of IAS units. ARP and aviation safety industry enterprises.

Table 2.1

№	Cause of the accident	%
1	Violations and Omissions in Flight Management (VFM)	16...24
2	Violations and omissions (erroneous actions) in air traffic control and flight management (VFM)	10...16
3	Violations and erroneous actions of the flight crew (VFC)	40...60
4	Violations and omissions in medical (VOM), meteorological (VOM) and radio engineering (VORE) flight support	6...7
5	Violations and Omissions in Aerodrome Flight Operations (VOAFO)	3…6
6	Violations and omissions in aviation engineering support of flights (VAEF)	8…11

From the analysis of the statistical data on accident, given in Table 2.1, it would be wrong to conclude that such a large percentage of accidents due to the fault of the flight personnel is explained only by their indiscipline, low level of training, although this is indirectly reflected in these statistics.

It should be borne in mind that different groups of personnel also have different roles in ensuring the efficiency and safety of aircraft flights. The pilot has a special role: performing the task, he counteracts the consequences of equipment failures, the impact of adverse external conditions, corrects not only his own mistakes, but also the mistakes of other operators. Overloading the pilot with information, his high psycho-physiological load, insufficient degree of correspondence of the technical properties to the capabilities of the pilot-operator significantly reduce the reliability of his work and to some extent explain the relatively large number of accidents caused by the flight crew.

There are functions that a pilot can perform accurately for a long time with a probability close to unity. He confidently parries the mistakes he makes when performing these functions. Obviously, in the case under consideration, the FS level, determined by the reliability of the pilot's work, will be high. The reliability of the pilot-operator is significantly reduced if he is entrusted with performing functions that do not correspond to his capabilities, or if the deficiencies in the dynamic properties of the aircraft and its control system require the pilot to take unusual or unnatural actions to compensate for these deficiencies. In the cases under consideration, the pilot is more likely to make a mistake and has less opportunity to counter its consequences [5].

In a number of cases, when investigating an accident, it is assumed that if no equipment failures are detected, the impact of external hazards and errors of other operators is not recorded, then the cause of the accident is the pilot's error. With such a system of investigation, some part of the accident (up to 30 ... 40%) caused by the discrepancy between the properties of the aircraft and the capabilities of the pilot (for example, poor stability and controllability characteristics, etc.) are unreasonably attributed to errors of flight personnel.

2.2. Causes of wrong actions of the aircraft

Usually, the errors of the pilot's actions are understood as incorrect, disproportionate, uncoordinated or untimely movement of the control levers, which leads to a deviation of the flight parameters beyond the permissible values. Any control process consists of the following four sequentially performed operations (elements):

1) receiving information about the tasks (goals) of management;

2) receiving information about the current values of flight parameters;

3) analysis of the information received and decision-making;

4) execution of the adopted decision.

A pilot error can originate on any of these elements and, despite different root causes, lead to the same consequences: incorrect or untimely movement of the levers control and, as a result, undesirable changes in flight parameters. Therefore, in order to develop effective measures to prevent erroneous actions of flight personnel, it is necessary to be able to find on which element (or elements) of the pilot's control process the error was made and what caused it: incorrect distribution or switching of attention, ignorance of how to act in the situation, untimely or inept execution of the decision. Unfortunately, all the elements, representing a single management process, in some cases imperceptibly pass one into another, as a result of which it is not always possible to single out and reliably evaluate which of the four elements and which one was a mistake.

The pilot receives information about control tasks mainly in preparation for flight and partially in flight. The more deeply the flight task and possible options for its implementation are worked out, the more confidently the pilot acts in flight, the less likely he makes mistakes. Flight preparation is the most time-consuming process that requires considerable time, regardless of the class and position of the pilot.

Practice shows that a lot of organizational, educational, and sometimes just routine work does not always allow the management staff to pay due attention to personal preparation for flights. It is not surprising that more than 50% of the accident accounted for by the management flight personnel.

The pilot receives information about the current values of the flight parameters mainly from the readings of the instruments and partly visually - from the overview of the outside of the cockpit space. The lack of generally accepted principles for the selection of information necessary for control and the types of its presentation, the rational placement of instruments and fittings in the cockpit, as well as the lack of standardization of instrument panels leads to the fact that the pilot is given a lot of unnecessary, untimely, without visual presentation of information to the detriment of the necessary information. Only on aircraft of the fourth generation began to pay increased attention to the problem of selecting the necessary information and methods of its presentation.

When the third element of the control process is performed, the pilot analyzes the received information and develops a solution to ensure the required movement of the aircraft. Depending on the task being performed, he must select the parameters to be monitored and the correct sequence for monitoring their change. The more parameters the pilot has to control, the more time is required for analysis and, consequently, the more delay the decision on the control action is made.

When making a decision, the pilot can make two types of errors: an error in building a maneuver (an error in a large movement) and an error in bringing the aircraft to the desired overload values. n_y , angle □ and □ (error in small movement). Despite the close relationship of small and large movements, errors in the control of these movements lead to different consequences. If an error in constructing a maneuver (in the absence of severe airspace restrictions) mainly reduces the combat effectiveness of an aircraft, then errors in controlling small traffic can lead to an overshoot of the permissible values of such defining parameters as n_y and □ . Correction of an error in building a maneuver, as a rule, requires an off-design change in the angle of attack and overload, in some cases going beyond the permissible values.

The properties of the “control system – aircraft” contour, that is, stability and controllability, and the convenience of the arrangement of fittings in the cockpit, have a decisive influence on the error-free actions of the flight personnel when executing the adopted decision. Any deviation from the standardized characteristics of stability and controllability makes it difficult for the pilot to accurately pilot and inevitably reduces the level of FS. The problem is complicated by the fact that, firstly, not all anomalies in the change in stability and controllability characteristics are reflected in the flight manual, especially when the operating limits are exceeded, and secondly, the flight crew does not have practical skills to control an aircraft in near-limiting modes.

The actions of the pilot in the execution of the decision are monitored by flight recorders. Analysis of the flight parameters records shows that usually the aircraft's output to the required value, for example, overload, can be schematically represented as consisting of two types: trial and corrective (Fig. 2.2, a). At the first cycle, the pilot evaluates the aircraft's response to the deflection of the handle (stabilizer), at the second, in accordance with this response, he performs corrective control to bring the aircraft to the desired overload [6]. Depending on the intrinsic properties of the aircraft and the training of the pilot, the corrective stroke is performed by one or several movements of the handle (stabilizer).

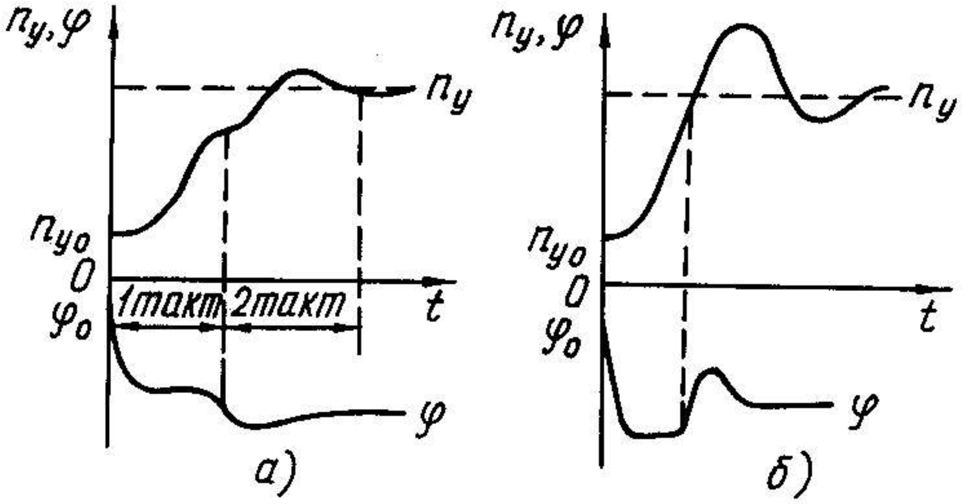

Fig. 2.2. Schematic representation of the aircraft output to the required value

When implementing the adopted solution, two types of errors are most characteristic: a significant excess of the recommended rate of increase in the overload and too slow reaching the desired overload. The first type of error is associated with the pilot's desire to compensate for the late decision-making or the desire to speed up (force) the implementation of a maneuver. In these cases, the pilot, as a rule, achieves the desired overload in one stroke with a significant overload overload, followed by a deflection of the stabilizer to reduce the overload (Fig. 2.2, b). With this style of piloting, there is a high probability of exceeding the permissible values of the angle of attack. □ or overload n_y . Depending on the aerodynamic layout, this may be accompanied by a loss of stable operation of the power plant, pick-up, loss of lateral control, and in some cases a stall. A slow increase in the overload worsens the characteristics of the maneuver, forcing in the second part of the maneuver to compensate for the off-design increase in the overload, which can also lead to adverse consequences.

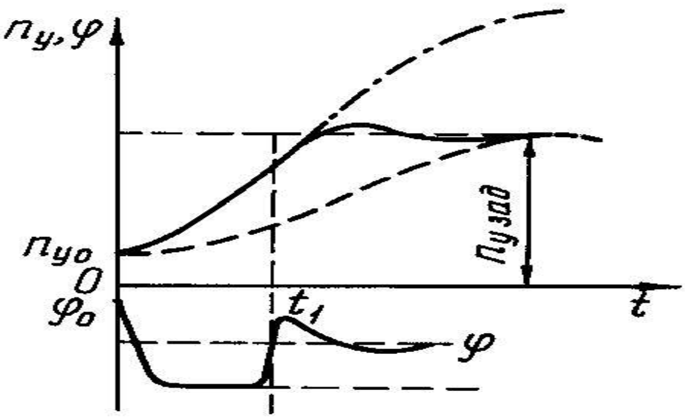

Fig. 2.3

An abrupt, unexpected for the pilot, exit to a large overload can occur with low overload stability, when gradients $P_B^{n_y}$ and $x_B^{n_y}$ are too small and it is difficult for the pilot to measure the required handle movements. Even if the pilot succeeded in doing this, the aircraft, due to its low speed (large oscillation period), would extremely slowly reach the specified overload (dashed line in Fig. 2.3). To speed up the transition to a new overload value for an unstable aircraft, the pilot is forced to deflect the stabilizer by an amount greater than is required for balancing on n_{y_3}. With such a deflection of the stabilizer, the overload would change as shown in Fig. 2.3 with a dot-and-dash line. To prevent exceeding the specified overload value, the pilot must at the time t_1 reduce the deflection of the stabilizer. In this case, the deflection of the stabilizer and the overload will change as shown in Fig. 2.3 with a solid line[7]. This style of piloting, requiring the handle to be tilted in one direction or the other, is dangerous by involuntary swinging, which is typical for unstable or unstable overload aircraft.

2.3. Intervention time of the pilot in the control in the event of technology failures

The delay time of the pilot's intervention in control is understood as the time interval from the moment of the occurrence of the failure to the beginning of the pilot's actions to eliminate the consequences of the failure. In what follows, for brevity, the time t_B will be called the intervention time. It is random in nature and is influenced by numerous factors. In general, the intervention time consists of the time to detect a failure or its consequences Δt_0 , time to recognize the refusal and make a decision on actions in a special situation $\Delta t_п$, the time lag at the beginning of these actions after the decision has been made (neuromuscular lag) $\Delta t_н$, that is t_B= $\Delta t_0 + \Delta t_п + \Delta t_н$. Depending on the informative value of the instruments and the alarm system, the psychophysiological properties of the pilot, the intervention time can vary over a fairly wide range - from several tenths to tens of seconds.

If a failure leads to a rapid change in the motion parameters, the pilot detects the fact of the failure by acceleration sensations and reflexively intervenes in the control [8]. In this case $\Delta t_п$= 0 and t_B= $\Delta t_0 + \Delta t_н$.

Processing the data of special studies made it possible to establish a number of regularities in the characteristics of the intervention time, determined by acceleration sensations:

1. The intervention time under optimal conditions cannot be less than a certain minimum value, which is assumed to be 0.13 s.

2. In the event of equipment failures leading to the disturbed movement of the aircraft, the main stimuli causing a response are: in the pitch channel - the rate of change in the normal overload $n_{y_{\text{cp}}}$, in the roll channel - angular acceleration $\omega_{\text{x}_{\text{cp}}}$,. For these stimuli, not instantaneous values corresponding to the current time t are taken, but average values are calculated over the time interval t_B, that is:

$$n_{y_{\text{cp}}} = \frac{\Delta n_y}{t_B};\quad \omega_{\text{x}_{\text{cp}}} = \frac{\Delta \omega_x}{t_B},$$

where $\Delta n_y, \Delta\omega_x$ – changes in the specified parameters over time t_B.

3. The mathematical expectation of the intervention time depends on the stimuli as follows (Figure 2.4):

for pitch channel

$$m_{i_B} = a_T + \frac{b_T}{n_{y_{\text{cp}}}} = 0{,}296 + \frac{0{,}086}{n_{y_{\text{cp}}}}, \quad (2.1)$$

for roll channel

$$m_{i_B} = a_K + \frac{b_K}{\omega_{\text{x}_{\text{cp}}}} = 0{,}251 + \frac{0{,}072}{\omega_{\text{x}_{\text{cp}}}}, \quad (2.2)$$

Where $\omega_{\text{x}_{\text{cp}}}$ measured in $1/s^2$.

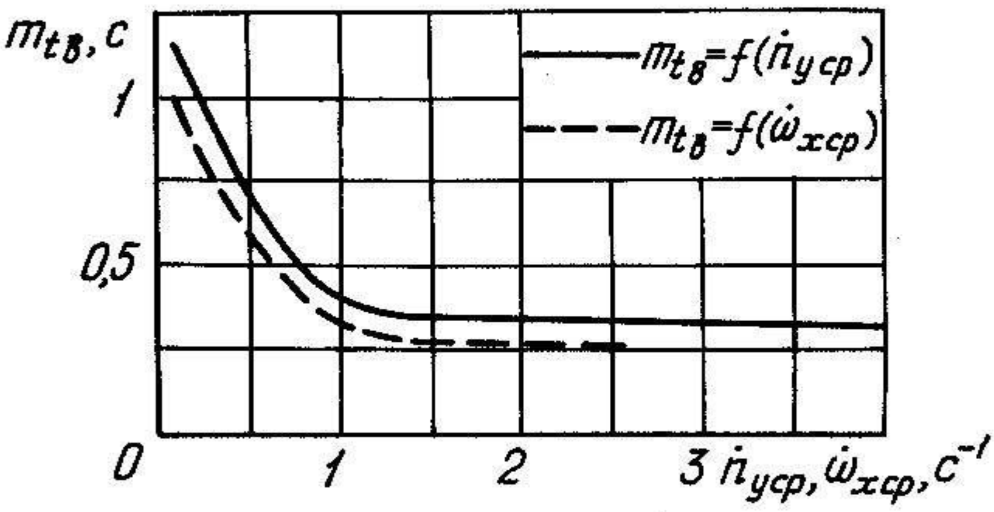

Fig. 2.4. Dependence of the mathematical expectation of the intervention time on stimuli

Expressions (2.1) and (2.2) show that with an increase in the level of the stimulus, the intervention time on average decreases and tends to the minimum value a_T or a_K.

4. The spread of the intervention time values, characterized by the standard deviation σ_{t_B}, has the following relationship with expectation:

for pitch channel

$$\sigma_{t_B} = c_T(m_{t_B} - 0{,}13) = 0{,}45(m_{t_B} - 0{,}13); \qquad (2.3)$$

for roll channel

$$\sigma_{t_B} = c_K(m_{t_B} - 0{,}13) = 0{,}5(m_{t_B} - 0{,}13); \qquad (2.4)$$

This means that the more the pilot lags on average with the intervention in control, the greater the scatter of the intervention times.

5. With a fixed level of stimulus, the time t_B^* , где $t_B^* = t_B - 0{,}13$, is subject to a log-normal distribution law with a probability density

$$\begin{cases} f(t_B^*) = \frac{1}{t_B^*\sqrt{2\pi D}} exp\left[-\frac{(lnt_B^* - lnt_{B0}^*)^2}{2D}\right] & \text{at } t_B^* > 0; \\ f(t_B^*) = 0 & at\ f(t_B^*) < 0, \end{cases} \qquad (2.5)$$

Where $lnt_{B0}^* = M[lnt_B^*]$ – expected value, a D= D[lnt_B^*] – variance of quantity lnt_B^*.

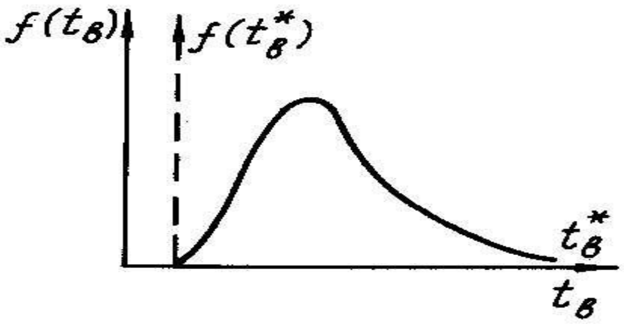

Fig. 2.5. Log normal distribution of time t_B^*

Thus, according to the normal law, the quantity lnt_B^* .

Log normal time distribution curve t_B^* (or t_B) shown in fig. 2.5.

Distribution parameters t_{B0}^* and D related to parameters $m_{t_B}^* = m_{t_B} - 0{,}13$ and $\sigma_{t_B}^* = \sigma_{t_B}$ by the following relations:

$$D = 2\ln\sqrt{(\frac{\sigma_{t_B}}{m_{t_B}^*})^2 + 1} = 2ln\sqrt{c^2 + 1};$$

(2.6)

$$t_{B0}^{*} = \frac{m_{t_B}^{*}}{\sqrt{(\frac{\sigma_{t_B}}{m_{t_B}^{*}})^2+1}} = \frac{m_{t_B}^{*}}{\sqrt{c^2+1}}$$

Taking into account expressions (2.3) and (2.4), we obtain

for pitch channel

D = 0,184, $\quad t_{B0}^{*} = 0{,}912\left(m_{t_B} - 0{,}13\right);$ (2.7)

for roll channel

D = 0,223, $\quad t_{B0}^{*} = 0{,}895\left(m_{t_B} - 0{,}13\right);$ (2.8)

From the above results, the following conclusions can be drawn:

variance of a random variable lnt_B^{*} does not depend on the level of irritants;

the parameters of the distribution law (2.5) will be quantitatively determined if the numerical value m_{t_B}.

Let us denote by x_{cp_i} irritants $n_{y_{\text{cp}}}$, $\omega_{y_{\text{cp}}}$. In this case, the quantity m_{t_B} can be defined as a solution to a system of two equations:

$$\begin{cases} x_{cp_i} = \frac{\Delta x_i(t)}{t}; \\ t = a_i + \frac{b_i}{x_{cp_i}}. \end{cases} \qquad (2.9)$$

The first equation gives the dependence of the time variation of the accelerating stimulus. Change settings $\Delta x_i(t), \Delta n_y(t), \Delta\omega_x(t)$ by solving differential equations of motion of the aircraft under certain perturbations $M_{z_B}(t), M_{x_B}(t)$ upon failure. The second equation in system (2.9) corresponds to expressions (2.1) and (2.2). The solution of the system of equations (2.11) is carried out graphically (Fig.2.6).

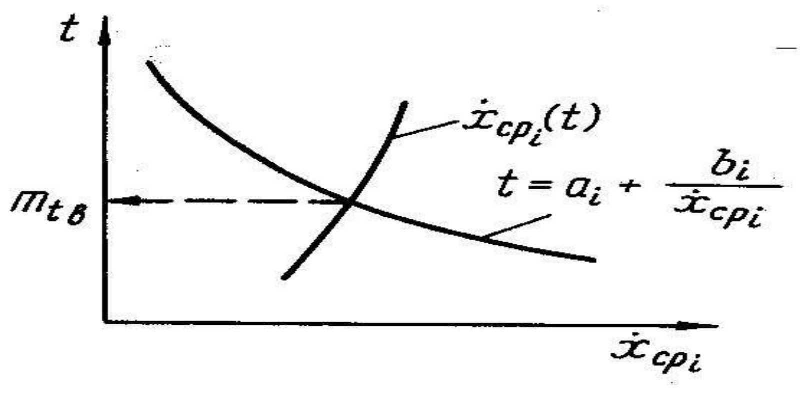

Fig. 2.6 Graphical solution of a system of equations

Conclusions to chapter 2:

1. The FS level is laid down in the creation of aviation technology (AT). To maintain this level, personnel in the process of mass operation and use of AT must ensure that the requirements of the general designer for maintenance, modes and conditions of its use are met.
2. To develop effective measures to prevent erroneous actions of flight personnel, it is necessary to be able to find on which element (or elements) of the pilot's control process an error was made and what caused it: incorrect distribution or switching of attention, ignorance of how to act in the situation, untimely or inept execution the decision taken.
3. Depending on the informative value of the instruments and the alarm system, the psychophysiological properties of the pilot, the intervention time can vary over a fairly wide range - from several tenths to tens of seconds. If a failure leads to a rapid change in the motion parameters, the pilot detects the fact of the failure by acceleration sensations and reflexively intervenes in the control.

CHAPTER 3

RESULTS OF EXPERIMENTAL STUDIES ON POLYPARAMETRIC FACTOR RESONANCE

3.1. Hazard (risk) assessment of multiplicative and additive factor overlay based on information processing of technical means

The development of an accident (AC) can occur either with a sequential (additive) effect of factors - a model of the "ICAO factor chain" type, or with a simultaneous effect on the crew of groups of factors (factor multiplications, the effect of interaction of factors). In this case, the properties and regularities of the FRP will be different.

Consider this difference between additive Σ and multiplicative Π factor phenomena.

Given: $\alpha_{\max_0} = 10^{\circ}$, $n = 10$, $\eth_i = 0.5$, $\Delta x = 1$

$$\alpha_{\hat{O}\text{Ð}} = \frac{n\alpha^3_{\max_0}}{\alpha^2_{\max_0} + \ddot{I}_{i=1}^{n} p_i \Delta H(\Delta t)^2} = \frac{10 \cdot 1000}{100 + 0{,}00195 \cdot 1} = 99{,}9981043,$$

$$\alpha_{\hat{O}\text{Ð}} = \frac{n\alpha^3_{\max_0}}{\alpha^2_{\max_0} + \sum_{i=1}^{n} p_i \Delta H(\Delta t)^2} = \frac{10 \cdot 1000}{10 + 5 \cdot 1} = 95.23889523.$$

With the same values $\alpha_{\max_0}$, n, P_i, x amplitude value α the current is greater with a factor overlap (multiplication of factors), and not with a factor chain (additivity of factors). Consequently, the factor overlap is more dangerous than the factor chain, since the factor phenomena manifest themselves more strongly when the factors acting on the crew are multiplied.

For example, let us consider the manifestation of this negative phenomenon in the aviation accident on August 22, 2006 with the Tu-154M aircraft (near Donetsk) and in a number of other accidents based on the transcripts of the crew members' conversations and the operation of the angle of attack and overload signaling machine (AUASP). In the summarized table. 3.3 shows the moments of AUASP actuation of the Tu-154M aircraft, (in minutes and seconds), as well as the actuation intervals Δt (in seconds) between the previous and the next triggering. From table. 3.3 it can be seen that during the critical part of the flight there are 3–6 AUASP operations in the supercritical angle of attack, which occur unevenly, with different time intervals Δt.

Table 3.1

AUASP signals and intervals Δt between them

№	1	2	3	4	5	6	7
t, c	11:33: 12,5	11:33: 55,5	11:35: 15,9	11:35: 20,9	11:35: 30,8	11:36: 07,2	11:38: 37,2
Δt, c	43	80,4	5	9,9	36,4	150	–

Uneven intervals Δt triggering of AUASP is caused by the fact that the pilots in this phase of the flight worked in conditions of manifestation of factorial resonance processes.

The resonance curve of factorial resonance is shown in Fig. 3.1 in coordinates:

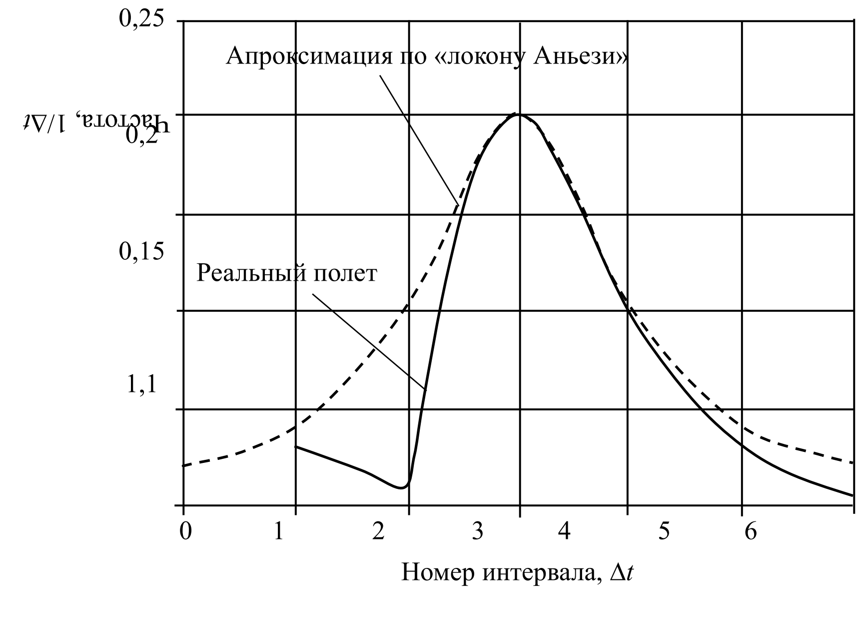

Fig. 3.1. Frequency response of FRP and its approximation by "curl Agnesi»

where, abscissa is a sequence of intervals Δt: from 1 to 6;

ordinate - frequency of AUASP operation: $\omega = \frac{1}{\Delta t} \left(\frac{1}{c}\right)$.

The peculiarity of the resonance curve in Fig. 3.8 is that it characterizes not only amplitude increases in the resonant process, but changes in response frequency. Tables 3.4 and 3.5 present the data for constructing the resonance curve and the points of approximation of the resonance curve.

Table 3.2

Resonance curve data

Interval number, Δt	1	2	3	4	5	6
AUASP response frequency	0,0232	0,0124	0,2	0,101	0,0271	0,006

Table 3.3

Resonance Curve Fitting Points

Δt, s	0	1	2	3	4	5	6
AUASP	0,02	0,04	0,1	0,2	0,1	0,04	0,02

From fig. 3.1 and tab. 3.1–3.3, it should be concluded that in this AM the tendency to change the angle of attack has the character of a resonance curve in terms of the frequency of operation of automatic machines for angles of attack and overload signaling (AUASP) when the aircraft reaches supercritical angles of attack.

3.2. Methodology for determining the first signs of factor resonance based on the analysis of operational flights

The problem of flight safety and the human factor as one of the main problems of the world aviation community requires fundamentally new approaches for its solution. At present, according to official data, the share of accidents in the Black Sea Fleet is 80–90%.

Despite good preparation for actions in flights without complicating situations, most pilots cannot cope with the negative phenomena that are identified based on the application of process analysis [9, 10, 11]. Such negative phenomena in flight processes should include a little-known phenomenon as the process of factorial resonance [12, 13, 14].

The method for assessing the first signs of factorial resonance refers not only to the field of aeronautics, aviation, but also to mechanical engineering and the operation of complex production machines in terms of methods for determining the operability of operators of complex automated complexes. It is an effective way to prevent aircraft accidents caused by the "human factor", to manage the flight activities of the crew and industrial accidents.

By the nature of the curves, the levels of interaction between operators in a group with an emphasis on informational interactions can be assessed.

Structurally, the method for assessing the first signs of factor resonance involves:

- collection of data for each workout or work cycle;
- compilation of a list of data for all work cycles and training;
- ranking of data by time intervals or selective ranking of data;
- grouping data with a large number of operators or comparing several groups;
- drawing up tables for building graphs;
- construction of coordinate graphs and performance curves;
- assessment of the initial level of performance and professional training;
- assessment of the stationary level of performance and professional training;
- comparative analysis of the success of an individual operator and the group as a whole.

The initial assessment of the curves is carried out by determining the arithmetic mean of the success indicator for five to six initial trainings or work cycles, the resulting value of the success indicator is plotted on the graph.

The described method, as the closest to the proposed method in terms of a set of features, is selected as a prototype. The prototype method, like other analogs, does not allow making forecasts for possible accidents and preventing aircraft accidents. The main purpose of determining the level of operator training is to increase the level of flight safety and improve the level of flight control in Ukrainian airlines while preventing and eliminating accidents and disasters caused by the human factor [15].

The technical result is achieved due to the fact that the flight crew is given a cycle of flights, during which the flight parameters are recorded, the readings of the recording devices are collected, the measured data are processed, the results are plotted on a graph, and the performance of the operator or a group of operators is judged by the nature of the curves. At the same time, the initial level of professional training is determined, for which the pilots are presented with a cycle of work carried out without the influence of negative environmental factors and factor overlaps, and the level of professional training is assessed according to the success schedule, the value of which is obtained as the arithmetic mean of the success indicator for five to six initial work cycles. According to the proposed approach, for data processing, the results of measurements of normal flights are selected, and the processing of the selected data is carried out in factor zones, highlighting the maximum amplitude and period of factor fluctuations (uncertainties). Then they are applied to a special cartogram for the analysis of factor uncertainties and the categories of normal flight are determined according to the control boundaries of factor-safe, relatively-factor-safe, limiting factor-uncertain flights. These data are used to judge the operability of the operator or groups of air transport operators, including the presence or absence of the first signs of FRP.

The proposed method is provided with a sufficient amount of statistical data and increased representativeness (representativeness) of these data. Usually, in flight practice, the total number of normal flights (flights without comments) (NF) is much greater than flights with comments, incidents, accidents, accidents, the share of which is one thousandth of a percent of the total number of flights. Therefore, the method based on the statistics of normal flights (the bulk of flights) has increased reliability, since all statistical patterns have sufficient samples close to the general population [16].

The division of normal flights (flights without comments) into three categories and the allocation of the category of undefined flights predicts and simulates the development of any emergency or catastrophic situation before it occurs. It should be noted that a plane crash is an extremely indefinite flight in terms of its stages, phases, moments, and usually it arises from a normal flight.

A flight without remarks may contain "in the bud" a catastrophe in the form of the first signs, i.e. factor uncertainties - uncertain changes in parameters, stages of flight. For example, the factorial uncertainties of the turns of a normal flight consist in the change in the shape of the turn when entering and exiting the turn, in the indefinite duration of the turn, etc.

Extremely factor-uncertain flights are a source of future catastrophes and accidents, it is they that, with an increase in the number of factors affecting the crews, turn into accidents and disasters. Statistics on them should be the main one in factor analysis.

Therefore, using this factor, pilots will be aware of potentially dangerous flights, and will be able to take them into account in a timely manner using the cartogram and take measures to prevent emergency and catastrophic situations.

For the first time, universal maps of flight directors have been developed and proposed from the PIC, squadron commanders, flight detachments to the command and control personnel of flight departments and aviation regions. Processing on a single form (from the crew to the aviation region) allows you to quickly and efficiently make factor forecasts and methods of organizing flight operations (according to the NPP methodology), to eliminate such an extremely dangerous phenomenon in flight processes as FRP and especially its polyparametric forms.

In fig. 3.2, 3.3, 3.4, maps of the analysis of factor uncertainties of the flight process and forecast by the level of factor overlaps are shown, respectively, illustrating three specific examples of the implementation of the method for determining the first signs at the level:

- the crew, for individual adjustments according to the handwriting of any pilot;

- flight detachment, squadron, for the removal of uncertain-factor flights and the prevention of catastrophic and emergency situations;

- aviation directorates, aviation concerns, aviation departments to optimize flight operations management methods.

The method for determining the operability of operators (pilots) or a group of air transport operators is carried out as follows. The initial level of professional training of pilots is preliminarily determined. Flights to determine the initial level of professional training of pilots are carried out on integrated aircraft simulators (CTS) in simple conditions, without the influence of negative environmental factors and factor overlays of the work cycle itself (failures, malfunctions, emergencies, catastrophic situations, etc.).

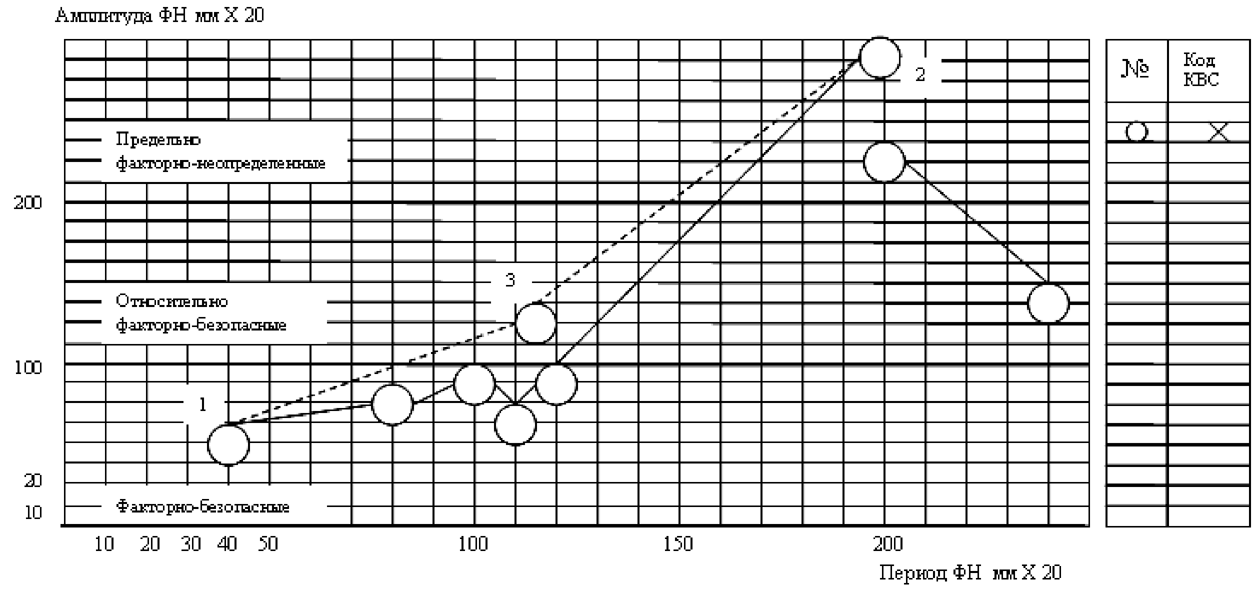

Fig. 3.2. Operational chart of the first signs of factor resonance

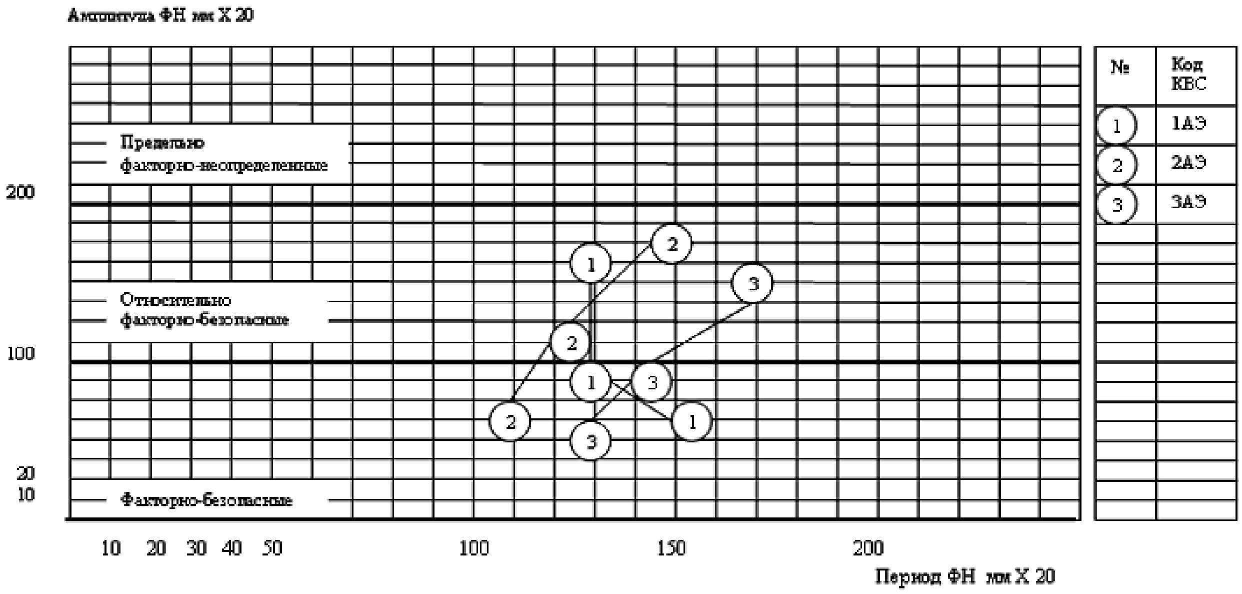

Fig. 3.3. Operational chart of the first signs of factor resonance

The pilot (operator) is assigned a cycle of work, for example, flight flights in one region or several regions, in the process of which they record flight parameters, for example, pitch, roll, heading. The readings of the recording devices (magnetic tapes, digital recordings, oscillograms) are collected, the data are processed by calculating the arithmetic mean value of the amplitude and period of the factor oscillations and applied to the preliminary form of the cartogram. Then an array of cartogram forms is prepared for analysis by types of aircraft of the squadron or airline, calibration and scaling. An initial level assessment is carried out to clarify the scale of the cartogram construction to prevent data going beyond the map.

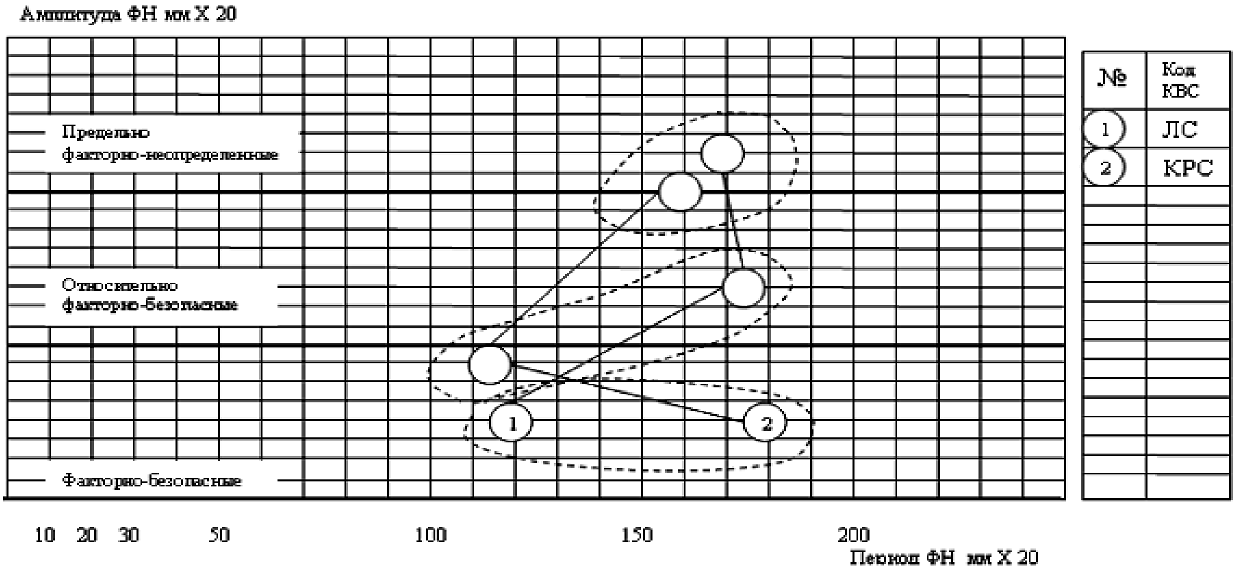

Fig. 3.4 Operational chart of the first signs of factor resonance

Next, they collect oscillograms of normal flights by crews. Normal flights include flights performed without comments from aviation specialists. The collection of oscillograms of normal flights by crew assumes:

- preliminary analysis, the stage of analyzing magnetic tapes, digital recording or computer data, for displaying an array of flight oscillograms without remarks;

- the formation of a general set of oscillograms of normal flights by sampling from the total set of all flights of the squadron;

- primary processing of oscillograms according to the principle of withdrawing flights without remarks on autopilot and other automatic modes;

- secondary selection of oscillograms, including scaling selected parameters on oscillograms for analysis, secondary display of oscillograms on flight data recorders.

At the same time, normal flights are grouped and divided into three categories.:

- factor-safe flights;
- relatively factor-safe flights;
- extremely factor-uncertain flights.

In Figures 3.2, 3.3, 3.4, these flights are separated by control boundaries, which are determined according to the rules of probability theory - "three sigma" (three root mean square).

Processing of normal flight oscillograms includes the determination of the factorial zones of flights with turns (4 zones) and flights without turns

(2 zones) and the choice of the zone of the factorial counteraction of the pilots. Selection of the pilot counteraction zone to factor overlays as the main one (from the 4th turn to touch or BPRM - a short-range beacon drive). In each zone, the type of factor uncertainty is determined by the maximum amplitude and period of any parameter (for example, roll, pitch, etc.). Determine the amplitude and period of factorial oscillations by the "sliding algorithm" method according to an automatic or manual program in accordance with the Pugachev method. The values of the amplitude of factorial fluctuations (ordinate of the cartogram) and the period of factorial uncertainties (abscissa of the cartogram) are plotted on the map in the form of points on a conventional scale (for example, amplitude in mm multiplied by 20; period - mm multiplied by 20).

Based on the location of the points, a conclusion is made about the category of the flight and a forecast of accident rate (factor-uncertain flights) or failure-free (factor-safety of flights - FSF) is given for the totality of flights without comments. The analysis map is built for any flight parameter, in any factorial flight zone. Thus, the procedure for preventing aircraft accidents when using the proposed method is as follows. Oscillations of the maximum factor-uncertain (MFU) flights (amplitude and period) are compared with the statistics (oscillograms) of the catastrophic flights of the analyzed squadron. Then a secondary analysis of the MFU is carried out, comparing the MFU with the statistics of negative flights, starting with flights with remarks to emergency flights according to the ICAO (International Civil Aviation

Organization) classification. The most complex MFU in terms of the level of uncertainty should be repeated on complex simulators in order to further define the types of factor uncertainties. Compare two current periods of MFU flights until the full effect of MFU removal is obtained for all pilots.

Let's consider three specific examples of the implementation of the method. The first example is illustrated in Fig. 3.2 and given at the crew level. The squadron commander analyzed the data of processing aircraft recorders of 9 flights of the PIC (aircraft commander) and gave a rating of "5" (or no comments), using a well-known analysis method. Then, according to the claimed method, flight oscillograms were selected with an estimate of "5", the data were processed, the level of the factorial uncertainty of the flight at the approach stage of each flight was determined with an estimate of "5" PAC No. X, and the values of the amplitude and period of the aircraft oscillations on the pre-landing straight line were determined.

The obtained values are summarized in table. 3.4. We multiply the obtained data by 20 (for scaling) and map the analysis of the factor uncertainties of the flight process and forecast by the level of factor overlaps.

Table 3.4

№ flight	A (amplitude)	T (period)
1	2	2
2	2	2
3	3	4
4	4	5
5	3	5,5
6	4	6
7	15	10
8	10	10
9	6	7
Average $\left(\frac{\sum}{9}\right)$	5,4	5,7

We determine the arithmetic mean and plot it on the map in three positions. We also apply all the other values.

We make an analysis and forecast. The map shows that the flight №7 (on the map it is indicated by the position 2) is the limiting factor-uncertain, i.e. performed to the grade "5" with great difficulty, which was confirmed by the pilot of this flight. Mapped flights №1, №2 were given to the commander easily, i.e. show the level of his ability (indicated on the map by the position 1).

The rest of the flights turned out to be of medium difficulty - relatively factor-safe - OFP (position 3).

The general level of difficulty in performing flights with the command staff was reported on the debriefing so that they would pay attention to the PIC №X and would reveal the reasons for the difficulty for PIC №X to perform flights 7, 8, 9 with a score of "5". However, the command did not react to the performance of the card analysis and after a month PIC №X grossly violated flight documents and brought an aviation accident.

The second example is illustrated in Fig. 3.3 (Table 3.5) and is given at the level of the flight squadron (3-rd air squadron).

Table 3.5

№	A_{min}	T_{min}	A^{cp}	T^{cp}	A_{max}	T_{max}
I	2,5	7,6	4,2	6,7	6,5	6,8
II	2,3	5,7	4,7	6,2	7,5	7,5
III	2,1	6,6	4,0	7,5	6,0	8,5

A similar analysis is carried out for each PIC in each air squadron (see Fig. 3.2). The arithmetic mean values of all KVS are calculated by three values:

- the best flights of each PIC (factor-uncertain);
- arithmetic mean flight data of all PICs;
- maximum factor-uncertain flights of all PICs.

We draw up a table for each aviation squadron and fill in the map. Flights are analyzed after filling in a special cartogram of each aviation squadron.

The third example is illustrated in Fig. 3.4 and given at the level of the Aviation Administration (industry).

The selection of oscillograms of "flights without remarks" is carried out in the accident, for example, in the aviation department. Oscillograms are grouped for flights of LS and KLS (linear flight personnel and separately command ones). An analysis of the flights of each crew headed by the CLS is carried out, as shown by the example of the flight crew.

For each analyzed group, calculations and analysis are carried out, as shown in Fig. 3.3, and are entered in table. 3.4.

Table 3.6

№	A_{min}	T_{min}	A^{cp}	T^{cp}	A_{max}	T_{max}
LS	2	6	6	7,5	11	8
KLS	2	8	4	6	9	8

From the table, the data multiplied by 20 is applied to a special cartogram of the aviation department's work cycle (see Fig. 3.4).

The cartogram is analyzed and the reason for the different levels of uncertainty in the flights of aircraft and CLS is found. Determination of the first signs of factor resonance is an effective way to prevent aircraft accidents due to the interaction of operational factors, in part:

- debriefing;
- flight control;
- flight methodical work;
- flights with inspectors.

3.3. Factor resonance analyzer as a technical tool for processing flight information by technical personnel

There are analyzers for measuring spectra, such as: S4-60, S4-77, SK4-58, SK4-59, etc., as well as harmonic coefficient meters, which own the functions of an analyzer, but do not take into account and do not implement resonance processes [17]. There are also meters of resonant processes as vibration parameters, such as: D11, D14, PDU-2, IS-313A, IS-312, TS-579, which measure the effects of mechanical resonance, but do not allow measuring the effects of factor resonance [18].

Existing automata and indicators for measuring angles of attack (AUASP, UAPK-1-PB) allow measuring: current, local, critical angles of attack, but when flying in difficult conditions, when they begin to work at supercritical angles of attack in the factor resonance mode, they do not have the function of a factor resonance analyzer and display on the pilot's dashboard of this most dangerous phenomenon.

It is necessary to create a special factor resonance analyzer to warn flight crews about the appearance of this dangerous mode in flight, which consists in the fact that the amplitudes of the flight parameters reach critical values, and the flight can go into the stage of an emergency or catastrophic situation.

The device is based on taking into account a little-known and too dangerous phenomenon in flight, factor resonance [19] [20], and also taking into account the maximum of the resonance curve for triggering AUASP when critical angles of attack appear.

The device contains a critical angle sensor, a setpoint (landing mode), a setpoint (takeoff mode), a mode switch, a current angle of attack sensor, an overload sensor, a switching unit, a number-to-code signal converter, a frequency discriminator, a resonance curve maximum limiter, an operating amplifier-limiter. resonance curve range, resonance curve steepness determinant, resonance alarm generator, voice informant, light board, computer indicator, resonance alarm index on the computer, autopilot (AP) command generator, AP signal.

The problem is solved in such a way that a number-to-code converter, a frequency discriminator, a maximum limiter of the resonance curve, an amplifier-limiter of the operating range of the resonance curve, a determinant of the slope of the resonance curve and an indicator of factorial resonance are used to analyze the factorial resonance.

The factorial resonance analyzer allows you to determine the moment when the resonance curve reaches the maximum according to the series of AUASP triggering at critical angles of attack, and by the same to warn the pilots about this dangerous phenomenon. In fig. 3.5 shows a block diagram of a factor resonance analyzer.

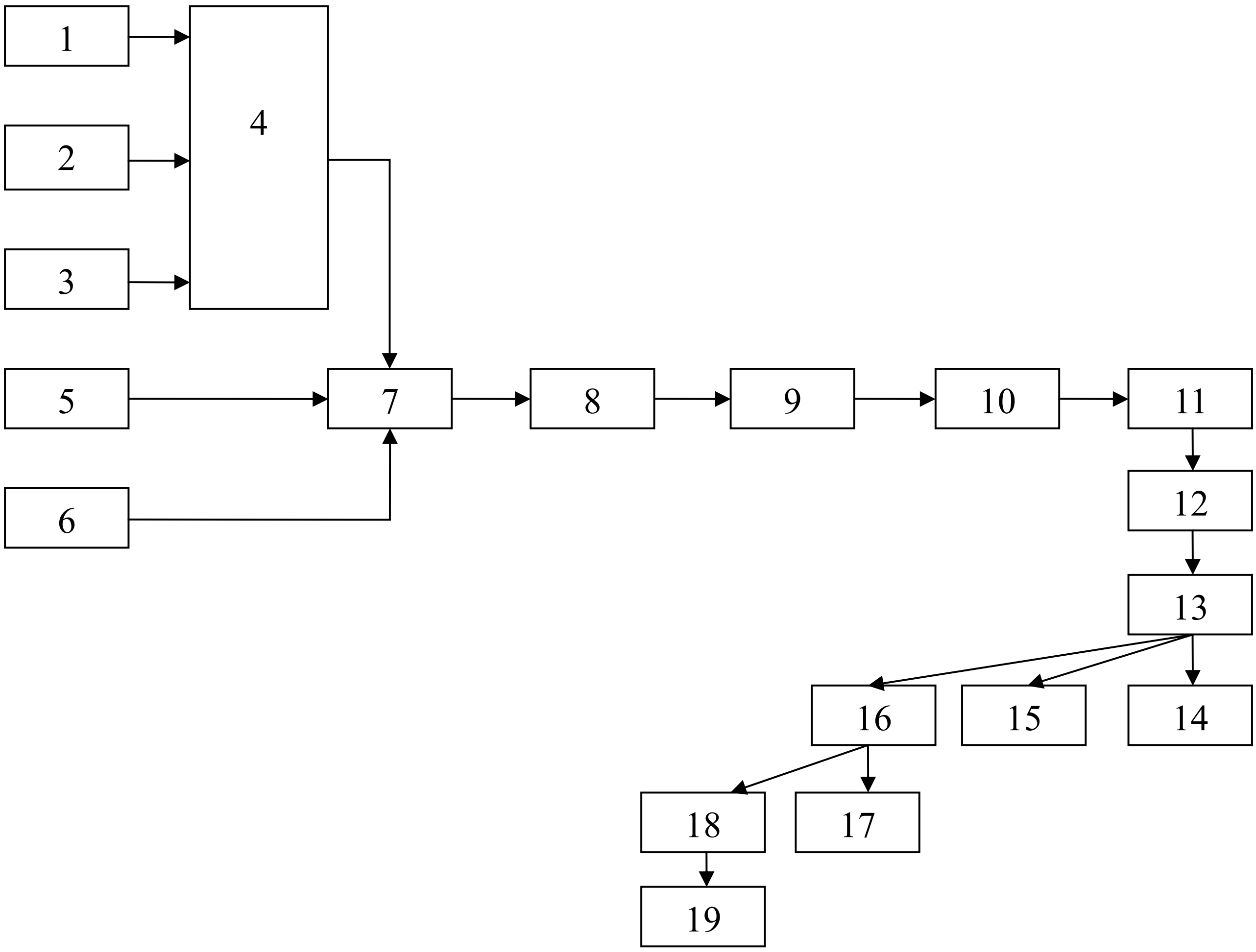

Fig. 3.5 Factor resonance analyzer block diagram

The factor resonance analyzer contains: critical angle of attack sensor 1, setpoint 2 (landing mode), setpoint 3 (takeoff mode), mode switch 4, current angle of attack sensor 5, overload sensor 6, switching unit 7, converter (number-code) 8 , frequency discriminator 9, limiter of the maximum of the resonance curve 10, amplifier-limiter of the operating range of the resonance curve 11, determinant of the steepness of the resonance curve 12, resonance alarm generator 13, voice informant 14, light display 15, computer indicator 16, resonance alarm index on the computer 17, autopilot (AP) command generator 18, AP 19.

The current voltages U, proportional to 1, 2, 3, come to the switching unit 7 through the mode switch 4.

The mode switch is controlled by the aircraft system depending on the flight mode. Mode switch 4, dial and, located in the switching unit 7.

At the same time, the switching unit receives voltages proportional to the current value of the overloads and the local current angles, which seem to be the overload sensor 6 and the current angle of attack sensor 5. The signals amplified in the switching unit 7 are converted from analog to digital, using the converter 8, after which they enter in the frequency discriminator 9, in which the values of the parameter (amplitude, duration, polarity, frequency, phase) of the input signal are equalized with the nominal value of this parameter of an individual signal.

As a result of the comparison, a differential voltage appears at the output of the discriminator. After that, the signal passes through the limiter of the maximum of the resonance curve 10, in which the limits on the maximum of the resonance pass. Further, the signal passes to the resonance curve steepness determinant 12, which determines the degree of the aircraft reaching critical angles, and if the aircraft is close to reaching these angles, then using the resonance alarm generator 13 signals are sent to the voice informant 14, the light display 15 and on the computer indicator 16. The resonance alarm index is displayed on the computer 17.

If the pilot does not respond to the signals and does not take the necessary measures, the signal from the computer comes to the autopilot command generator 18, and then to the autopilot 19.

The proposed device is used in the field of civil aviation to improve the efficiency of flight operation of aircraft of different generations, and to prevent events associated with the exit of the aircraft to supercritical angles of attack.

Conclusions to chapter 3:

1. The development of an aviation accident (AA) can occur either with a sequential (additive) effect of factors - a model of the "ICAO factor chain" type, or with a simultaneous impact on the crew of groups of factors (factor multiplications, the effect of interaction of factors). In this case, the properties and regularities of the FRP will be different.
2. Determination of the first signs of factor resonance is an effective way to prevent aircraft accidents due to the interaction of operational factors, in part: debriefing; flight control; flight methodical work; flights with inspectors.
3. Some of the factorial fluctuations contain the first signs of factorial resonance in the form of fuzzy actions, swinging in various parameters, poor work with the controls and, especially, in the range of disproportionate and uncoordinated actions. These signs are observed with variations and changes in both the amplitude and the frequency of the oscillations.
4. The development of a methodology for assessing the first signs of factor resonance allows solving the main problem in the global aviation process - reaching an absolute ("zero") accident rate for all aviation accidents, including aviation accidents [6].

CHAPTER 4

LABOUR PROTECTION

4.1. Introduction

Occupational health and safety is an organic part of the production process. She is obliged to provide the most favorable working conditions, as well as to protect the health of workers from industrial hazards.

Labor protection is a complex of legal, organizational, educational, fire-prevention measures and technical means that ensure the creation of healthy and safe working conditions.

4.2. Analysis of working conditions

The root cause of all injuries and diseases is the labor factors impact on the human organism. This influence depends on the presence of a factor, its potentially unfavorable properties for the human body, the possibility of direct or indirect action on the body, the nature of the response of the organism depending on the intensity and duration of action of tis factor.

Depending on the intensity and time of action, these factors can be dangerous or harmful. The former can lead to injuries, including death; others lead to diseases, including increasing existing ones.

4.2.1. Workplace organization

The office is designed to be a working place for 6 person. Its total area is equal to:

$$A = a \cdot b \; [m^2]$$

$$A = 10 \cdot 8 = 80 \; m^2,$$

Where a – length, b – width (Fig.4.1)

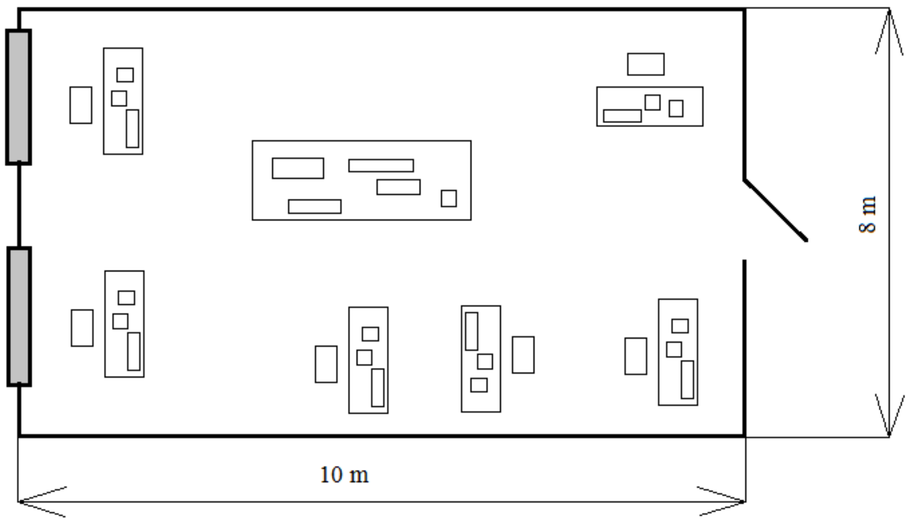

Figure 4.1. Laboratory facilities layout

The working area of one person is approximately equal to:

$$\boldsymbol{A_{op}} = \frac{\boldsymbol{A}}{\boldsymbol{n}}\ [m^2],$$

$$\boldsymbol{A_{op}} = \frac{\mathbf{80}}{\mathbf{6}} = 13{,}3\ m^2,$$

Where n – number of workers.

The volume of the room can be determined:

$$V = A \cdot h\ [m^3],$$

$$V = 80 \cdot 3 = 240\ m^3,$$

Where h – height of the room.

Office perimeter is equal to:

$$P = 2a + 2b\ [m],$$

$$P = 2 \cdot 10 + 2 \cdot 8 = 36\ m.$$

All dimensions listed are approved by building codes Ukraine ДБН В.2.2-28-2010 “Administrative buildings”.

Laboratory is equipped with 4 ceiling lights and 2 windows. Also, it has sockets for 220V users.

The most favorable microclimate at the workplace according to ДСН 3.3.6.042-99 are:

- Temperature within 20-23°;
- Relative humidity should be 40-60%
- Air velocity 0.1 m/s

To maintain optimal values of microclimate heater and air conditioner is used. The room is equipped with a first aid kit and a fire extinguisher.

4.2.2. The list of harmful and hazardous factors

From the hygienic standards ГН від 08.04.2014 №248 «Гігієнічна класифікація праці за показниками шкідливості та небезпечності факторів виробничого середовища, важкості та напруженості трудового процесу» we can distinguish a list of harmful and hazardous factors for our case. They all belong to physical factors group:

- Microlimate (temperature, humidity, air velocity)
- Illumination: natural (lack or insufficiency), artificial (insufficient illumination, direct and reflected dazzling glare, etc.).

4.2.3. Analysis of harmful and dangerous production factor

Depending on the destination, the following classes are distinguished:

- Means of normalization of the air environment of rooms and workplaces (ventilation, air conditioning, heating, etc.);
- Means of normalization of illumination of permises and workplaces (light sources, lightning devices, etc.).

Analysis of the listed harmful and dangerous factors is shown below.

4.2.3.1. Microclimate of the working place

Microclimate factors analysis lies in comparison of optimal air conditions with actual.

Table 4.1. Comparison of microclimate characteristics

	Optimal	Actual
Temperature, °	20-23	18
Humidity, %	40-60	45
Air velocity, m/sec	0.1	0.1

Table 4.1 shows that almost all parameters, except air temperature are in allowable range. It is obvious that for improving the working conditions it is necessary to increase the number of air heaters on the working place.

4.2.3.2. Illumination of the working place

The most favorable illumination at the workplace according to ДБН В.2.5-28:2018 is 400 lx.

Actual illumination at a workplace at the daytime is 400 lx, at nighttime – 370 lx.

Table 4.2. Comparison of illumination characteristics

Optimal	Actual	
	Daytime	Nighttime
400 lx	400 lx	370 lx

It is obvious that for improving the working conditions it is necessary to increase the number of ceiling lights on the working place.

4.3. Engineering, technical and organizational solutions to prevent the effect of hazardous and harmful production factors

Collective and individual protection measures are provided to prevent accidents and avoid injuries during the work.

Collective remedies are designed to prevent or reduce the impact on workers of hazardous production factors, as well as to protect against pollution.

In order to prevent the adverse effects of the microclimate, protective measures are used:

- protective earthing;
- introduction of modern technological processes that exclude the impact of an unfavorable microclimate on the human body;
- organization of forced air exchange in accordance with the requirements of regulatory documents (air conditioning, ventilation, etc.);
- compensation for the adverse impact of one parameter by changing another;
- use of overalls and personal protective equipment;
- organization of special rooms with dynamic microclimate parameters (rooms for heating, cooling, etc.);
- physically grounded regulation of work and rest regimes (shorter working hours, regulated time for heating, etc.);
- correct organization of heating and air exchange systems.

4.4. Fire safety of production facilities

The causes of fires in training laboratories are very diverse, and they are subject to constant changes due to the development of technologies. According to НАПБ А.01.001-14 Правила пожежної безпеки в Україні scientific laboratory refers to category Д, as it contains non - combustible substances and materials in cold state. Laboratory is equipped with a fire extinguisher and fire alarm system.

The length of the main escape route is around 70 m. For evacuation from the laboratory worker should leave the room from the door “EXIT” and follow the way on Figure 4.2. The same picture is located in the scientific laboratory.

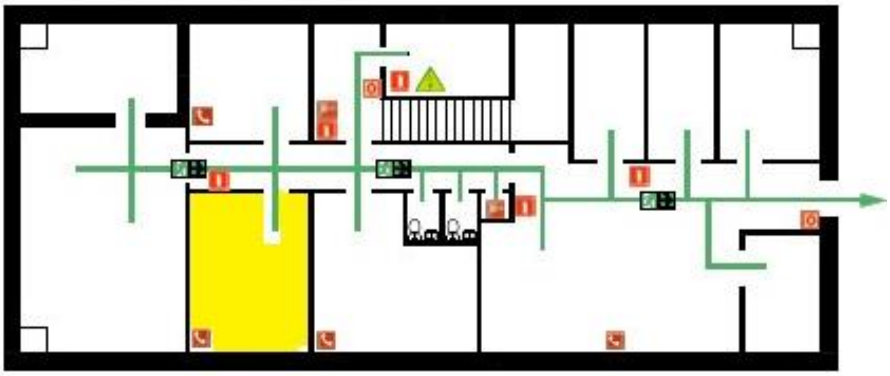

Figure 4.2. Emergency evacuation scheme

4.5. Occupational safety management system at the enterprise.

The State Enterprise "ANTONOV" by order №364 of 25.05.1999 "On the implementation of the enterprise standard (labor protection management system)" introduced a management system of labor protection and created a labor protection service, the head of this service is Kucher Sergei Nikolaevich according to Order 944k from August 6, 2001 "On appointment to the position of head of the department of labor protection and safety", who performs his duties in accordance with the "Regulations on the labor protection service", the Standard of the enterprise "Labor protection management system", the Regulations on the labor protection department »; labor protection service subordinated directly to the Vice-President of SE "ANTONOV" Sementsov Viktor Fedorovich.

A Collective Agreement was concluded between the administration of SE "ANTONOV" and the labor collective, registered on December 17, 2018.

Order №802 of 14.10.2005 “Implementation of the“ Standard Regulations on the Procedure for Conducting Training and Testing of Knowledge on Occupational Safety ”established a system for training and testing of knowledge on occupational safety. Order №399 of 07.02.2019 "On the implementation of the Regulations on the procedure for training and testing of knowledge on Occupational safety officials and other employees of SE "ANTONOV" organization of training, instruction and testing of knowledge on occupational safety is entrusted to the heads of structural units of SE "ANTONOV".

Orders №1971 of 08.08.2017 "On the appointment of the Central Commission for the examination of knowledge on labor protection" and №7209k of 13.12.2019 "On training and certification (testing of knowledge) on occupational safety of workers engaged in high-risk work "created appropriate commissions of officials of the enterprise; which have passed appropriate special training; also appointed responsible for conducting a test of knowledge on labor protection of the heads of divisions of SE "Antonov".

The company has an emergency department; Order №4000k of 24.07.2019 "On training and briefing on civil protection, fire safety and emergency response" control over training and briefing on civil protection, fire safety and emergency response assigned to the head of the emergency department Skvortsov S.V.; Order №468 of 13.02.2020 "On the appointment of the person responsible for the technical condition of fire safety systems" appointed responsible for the technical condition of fire safety systems, the head of the department of communication systems Sklyarova P.M.

The company has an energy service in the form of the Department of Chief Power Engineer; By Order №2560 of September 19, 2018 “On Assigning Responsibility for the Technical Condition and Safe Operation of the Electricity of the Enterprise”, the Chief Power Engineer has been appointed responsible for the safe operation of the electricity at site №1 − Klymenko Oleksiy Oleksiyovych, on the site №2 − chief power engineer Tupikov Roman Yuriyovych.

The company registered the Declaration of Conformity of material and technical base employer to the requirements of the legislation on labor protection during the performance of work at a height of more than 1.3 meters (registered in the State Labor Office on October 30, 2019 for №2930-19-32).

Order №172 of 06.03.2006 "On approval of the List of works with increased danger "approved the List of works with increased danger.

Order №2407 of 05.09.2019 "On approval of the list of instructions on protection labor ”approved and put into effect instructions on labor protection, which are guided by employees of the enterprise during the performance of high-risk work.

The Company properly maintains journals on labor protection, namely: registration workplace safety briefings; registration of introductory training on labor protection; registration of initial training on labor protection; registration repeated briefings on health and safety; accounting for high-risk equipment; accounting and storage of means of protection; accounting for the issuance of instructions on labor protection; registration workplace safety briefings; registration of work according to orders and instructions; registration of victims of industrial accidents; registration and accounting for the issuance of instructions on labor protection; registration of briefings on fire safety, civil protection, and emergency response; log of protocols testing of knowledge on labor protection.

The company is provided with technological, operational documentation and reference literature required for production activities.

The enterprise is provided with legislative and other normative-legal acts from labor protection, means of individual and collective protection, in accordance with the current legislation. Operational documentation for equipment, devices, mechanisms, devices used in the performance of works at the enterprise. For implementation of the quality of the declared works, the company has the necessary material technical base, which is constantly updated. As of today, the company is equipped office equipment, measuring instruments, copies of regulations with labor protection, current instructions on labor protection.

Conclusion to chapter 4:

1. In this section, the scientific laboratory has been examined to satisfy labor protection norms. According to temperature measuring and illumination measuring additional heaters and light sources should be installed.
2. The most effective solutions to prevent exposure to hazardous factors are to use safety instructions in the laboratory.

CHAPTER 5

ENVIRONMENTAL PROTECTION

5.1. Environmental impact of aircraft noise

Air transport has firmly entered human life thanks to the ability to cover long distances in hours, which is an irrefutable advantage in the intense pace of modern life. Despite the relative high cost, the demand for air transport is growing every year in all countries of the world. To meet the growing needs for air transport services, the aircraft fleet is expanding, new airlines are opening, additional runways, new airfields and airports are being built.

Along with the rapid development of air transport, its negative impact on the environment is increasing. The problem of the harmful influence of aircraft on the environment and, above all, noise, in aviation is very acute and ranks second among the problems of air traffic management after the problem of flight safety. The main causes of aircraft noise are disturbances in the air and gas flows generated by the operation of aircraft engines, among which, all other things being equal, jet engines have the worst noise performance. At the aerodrome, the noise of takeoff and landing, movement along the taxiways is accompanied by intense noise when preparing aircraft for takeoff, as well as noise arising on special sites during engine tests. All ecosystems are susceptible to the harmful effects of aircraft noise: humans, animals and plants.

The effect of noise exposure on the body depends on the totality of its characteristics: intensity, frequency, duration and time specificity. At the same time, the main role in the development of noise pathology belongs to the intensity. The louder the sound, the higher the risk of irreparable changes. Therefore, the hazard level of noise is usually assessed by its intensity, expressed in the number of dB. In this case, an important place is occupied by the duration of the noise exposure: the longer the influence, the faster the defeat occurs.

The noise level of 20-30 dB is harmless to humans, it is a natural background noise. The permissible level of noise intensity in the workplace is 80 dB. A sound of 130 dB already causes a painful sensation in a person, and 140 or more dB becomes unbearable. The noise volume of 180 dB is fatal for humans.

Noise is not addictive. The entire body is affected by noise. Even with a relatively low but constant noise level, a person may experience discomfort, irritability, and headaches. Especially dangerous is sudden noise that disrupts the psychological comfort of a person (takeoff and landing, areas of the routes of supersonic aircraft).

Distinguish between specific and non-specific effects of noise on the body. The specific effect of noise is reflected in the organs of hearing, the outcome of which is the occurrence of a disease - sensorineural hearing loss, manifested by persistent hearing loss. As a rule, the development of sensorineural hearing loss is associated with prolonged and regular exposure to noise, as is the case in industrial conditions. Thus, the noise levels affecting the pilot in the cockpits of the aircraft, depending on the type of engine, altitude and flight mode, fluctuates in the ranges of 90-109 dB, and in the cockpits of helicopters - in the ranges of 100-118 dB. Along with the operation of the engine, an additional source of noise in the cockpit are airborne radio headsets designed for continuous radio exchange during the entire flight.

Systematic long-term exposure of aircraft crew members that exceeds the permissible level to the body of aircraft crew members leads to the development of sensorineural (occupational) hearing loss from the pilots. A direct relationship was established between occupational hearing loss, age and work experience in the flight profession. So, after 15 years of flying work, young, healthy, physically prepared men who came to aviation have occupational hearing loss in 8% of cases, with more than 20 years of experience, half of the flight personnel have a hearing loss. The same pattern with age: by 40-50 years, every fourth suffers from hearing loss, at the age from 51 to 60 years, hearing loss is recorded in 60% of cases.

The non-specific effect of noise is manifested in the damage to the body as a whole and manifests itself in a wide range of serious symptoms and diseases, such as: neuroses, irritability, memory impairment, decreased concentration and reaction speed, increased blood pressure, heart rhythm disturbances, etc. Complex of symptoms, including disorders hearing that occurs when exposed to noise is referred to as noise sickness.

Noise pollution around airports and airways spans millions of square kilometers, including residential areas. When the airport is located close to the city, the social problem of aircraft noise arises, interfering with sleep and rest of the population and negatively affecting health.

Aircraft noise is highly irritating. It has been found that people react more sharply to the same intensity of noise at night than during the day. This is due to the different levels of permissible noise at night and during the day, provided for by the current regulatory documents.

At the same time, in a number of European cities, when the airport is located close to the city, night flights are prohibited. Thus, the decision of the Federal Administrative Court in Leipzig to ban night flights from 2012 at the largest airport in Germany in Frankfurt am Main was a successful result of many years of protests by residents against aircraft noise. Tegel and Tempelhof airports in the center of Berlin also have day and night noise quotas.

To reduce the noise level from airports / aerodromes along the way of its propagation in the aerodrome territories, a complex of architectural planning, construction and special noise protection measures is used. These include: the creation of sanitary protection zones and their functional zoning; a ban on residential development in an area of high noise levels; special planning options for buildings aimed at noise protection; the use of building noise protection structures, planting noise protection belts of green spaces, etc.

The systematic application of such measures made it possible in the period from 2005 to 2014 to stabilize the noise levels at the airports of European cities and to achieve a reduction in the size of the area of aircraft noise contours by 2%.

The original method succeeded in halving the noise level at the airport of Amsterdam, which is one of the 5 largest airports in Europe: rows of artificial 2-meter-high hills were arranged in such a way that they dampen the noise from the runways.

Noise pollution disrupts the natural balance in ecosystems. Under the influence of noise, disorders of the nervous and cardiovascular systems of the animal body occur, and hearing impairment occurs. Unlike humans, many animals have more developed hearing organs, respectively, the defeat occurs at lower levels of sound intensity.

Noise can lead to disturbance in animals of orientation in space, communication and search for food. The effects of noise cause some wildlife to leave their familiar habitat and migrate to other areas, sometimes less conducive to life. Under the influence of noises of considerable intensity, the death of the queen bee occurred, and egg shells cracked in the nests of birds. American ecologists have recorded the facts of "inexplicable" aggression of the musk ox grazing not far from the airfield. In noisy areas, the singing of birds changes, bats catch prey worse, frogs find it difficult to find partners. At the same time, it was revealed that some representatives of the animal world, on the contrary, move to noisy places, free from predators frightened by the noise.

For farm animals, noise levels are set at 65-70 dB. With a higher noise intensity, there is a decrease in milk yield of cows, weight gain in animals, and egg production of chickens. The aircraft noise of the airfield constantly affects the natural background of the forest. Alien sounds distort the familiar and natural sounds of wildlife, which, in particular, help animals recognize the sense of danger. As a result of these processes, there is a violation of the natural ecosystems that have developed in nature.

The effect of noise pollution on plants is not so obvious and manifests itself indirectly with the participation of certain types of animal organisms.

For example, shrub jays, avoiding noisy areas, play an important role in the emergence of young pines, as they carry their seeds. One bird can collect thousands of seeds and hide them. In winter, jays feed on these reserves, and new pines grow from unused seeds. It was experimentally found that from the same number of seeds scattered in noisy places where there were no jays, 4 times fewer pine trees grew than in noise-free areas where jays lived.

In another experiment, it was found that flowers planted in a noisy area are five times more likely to receive the attention of pollinators than flowers planted in an area with a natural background noise. The pollinators in this experiment were hummingbirds, which preferred noisy places. Based on the results obtained, a conclusion was made about the effect of noise on plants through pollinators.

A striking conclusion about the influence of anthropogenic noise on the environment is the statement of the famous American ecologist Francis Clinton that, although most literary sources speak of the stressful effect of noise on one species of animals, it should be understood that stress is experienced by the entire ecosystem, since the reaction one or two important species can cause major changes in the entire ecosystem in the future. Noise reduction technologies

5.2. Noise reduction technologies

Significant progress in efforts to reduce aircraft noise occurred in the sixties and seventies with the advent of engines with a high bypass ratio. They were created, first of all, as part of the struggle for fuel economy, and noise reduction was a concomitant factor. Turbofan engines consumed much more air than classic turbojets, but threw it away at a much lower speed. Thus, it was possible to increase the overall efficiency and at the same time improve the acoustic performance.

The development potential of turbofan engines turned out to be quite high, which was very useful against the background of repeated tightening of environmental standards. Due to the decrease in the rate of exhaust of gases from the engine, their influence on the generated noise was significantly reduced, but the loud sound from the fan came to the fore. In the take-off thrust mode, its maximum peripheral speed was significantly higher than the sound one.

Sound-absorbing structures placed in the engine nacelle help to suppress noise. As a rule, these are acoustic panels of a resonant type, consisting of several layers and tuned to damp sound waves of a certain frequency.

Another relatively new solution for noise reduction is the so-called "chevrons": special sawtooth edges at the nozzle exit of one or both of the engine circuits. Thanks to them, there is a smoother mixing of the flow of gases from the engine with the ambient air - less turbulence, less noise.

However, it arises not only as a result of the operation of the engines. The airframe itself makes a significant contribution to its creation. Especially in takeoff and landing modes, when the wing and landing gear is released. Turbulent vortices resulting from ambient air flow around the aircraft structural elements are an additional source of noise.

In this regard, in order to initiate manufacturers of new aircraft to introduce the latest technologies to reduce noise, the 38th ICAO Assembly in October 2013 decided to gradually tighten the noise requirements for new aircraft. New standards for aggregate aircraft noise levels are lower than the previously established 7 EPNdB (Effective Perceived Noise Level in decibels). The expected result of stricter noise standards for new aircraft is to achieve compliance with new

the requirements of the main categories of aircraft operating international flights. This will entail a reduction in the area of noise pollution of the environment and, as a consequence, a decrease in the number of population exposed to the harmful effects of aircraft noise.

Conclusion

The problem of noise pollution in aviation is analyzed, as a result of which:

- We determined exactly how noise negatively affects the human body (nervousness, hearing loss, etc.) and the environment (forced relocation of animals, disruption of natural ecosystems that have developed in nature, etc.).
- Summarized the ways to solve this problem.

As mentioned above, in order to reduce the noise level from airports / aerodromes along the way of its propagation in the aerodrome territories, it is proposed to build a complex of architectural planning, construction and special noise protection measures.

Structural methods include: the development of new low-noise aircraft engines and aircraft, as well as the modernization of existing aircraft engines and aircraft.

CONCLUSION

1. An urgent scientific and applied problem has been solved, which consists in the development and experimental study of the processes of interaction of factors (factor multiplication), and reveals a polyfactor resonance. When studying the influence of operational factors on flight safety, it was revealed that in an accident the "inevitable area" arises when at least 20 factors.
2. The methodology of the first signs of the factor resonance phenomenon has been developed as methodological recommendations for modeling the actions of flight crews and flight managers.
3. Almost any process with continuous time can be reduced to the scheme of a finite Markov chain, for which it is sufficient to divide the simulation interval into intervals Δt and put $p = \mu \Delta t$ and $q = \nu \Delta t$.
4. Depending on the informative value of the instruments and the alarm system, the psychophysiological properties of the pilot, the intervention time can vary over a fairly wide range - from several tenths to tens of seconds. If a failure leads to a rapid change in the motion parameters, the pilot detects the fact of the failure by acceleration sensations and reflexively intervenes in the control.
5. Probabilistic models make it possible to find the probability distribution of the system being in individual states of the systems, and from them to determine the necessary characteristics: mathematical expectations, variances, etc. When compiling the equations for the dynamics of averages, a more general assumption is used, including those indicated as a special case.

LIST OF REFERENCE

1. Joseph Gerver. The Differentiability of the Riemann Function at Certain Rational Multiples / American Journal of Mathematics. — 1970. — Т. 92, вып. 1. — С. 33—55

2. Сушков Ю.А. АНАЛИТИЧЕСКИЕ МОДЕЛИ СИСТЕМ / Ю.А. Сушков – СПб.: С.-Петерб. ун-т. 2016.

3. Выгодский М.Я. Справочник по высшей математике / М.Я. Выгодский. – М.: АСТ: Астрель, 2006.

4. Банных Н.С. Вопросы проектирования процесса подготовки операторов и деятельности в аварийных ситуациях // Психологические проблемы деятельности в особых условиях / Н.С. Банных. – М.: Наука, 1985. – С. 196–206.

5. Обухова Л.Е. Автоматизированное производство и человек / Л.Е. Обухова. – М.: Наука, 1984. – 144 с.

6. Новожилов В.Г. Безопасность полета самолета. Концепция и технология / В.Г. Новожилов, М.С. Неймарк, Л.Г. Цесарский. – М.: Машиностроение, 2003. – 144 с.

7. Немчин Т.А. Состояние нервно-психологического напряжения / Т.А. Немчин. – Л.: изд-во Ленингр. ун-та,1983. – 156 с.

8. Шеридан Т.Б. Системы человек-машина. Модели обработки информации, управления и принятия решений человеком-оператором: под ред. чл.-кор. АН СССР К.В. Фролова / Т.Б. Шеридан, У.Р. Феррелл. – М. :Машиностроение, 1980. – 400 с.

9. Яцков Н.А. Основы построения автоматизированных систем контроля полетов воздушных судов / Н.А. Яцков. – К.: КИИГА, 1989.

10. Грищенко Ю.В. Парные полеты как способ анализа явления усиления динамического стереотипа у пилотов // Кибернетика и вычислительная техника / Ю.В. Грищенко. – К.: НАН Украины, 2003. – Вып. 140. – С. 31–34.

11. Хохлов Е.М. Процессная концепция безопасных полетов как формула мирового научного приоритета и методология защиты летного эксплуатанта // Проблемы безопасности полетов №12/1994, РАН, ВНИИТИ / Е.М. Хохлов. – М., 1994. – С. 3–12.

12. Системы менеджмента качества. Требования (ISO 9001:2008, IDT) : ДСТУ ISO 9001:2009. – [действующий с 2008-11-15]. – К.: Держспоживстандарт України, 2009. – IV, 39 с. – (Национальный стандарт Украины).

13. Малая Советская энциклопедия, 1958 – 1960 / [упоряд. Б. А. Вве-денский и др.] – М.: 3-е изд. – В 10-ти том. – Т. 7. – 1959. – С. 1010–1011.

14. Положевець Г. А. Полипараметрический факторный резонанс: особенности учета взаимодействия факторов в реальных и тренировочных полетах при снятии аварийности по человеческому фактору (ЧФ)/Наука и молодь // Прикладна серія: зб. наук. пр. / Г. А. Положевець. – К.: НАУ, 2006. –188 с., с. 137–141.

15. Ищенко С.А. Разработка методов контроля и диагностики аэродинамического состояния воздушных судов ГА / С.А. Ищенко, А.Р. Давидов: под ред. О.И. Гоменюка. – К. : Знание, 1990. – 43 с.

16. А. с. ВНТИЦ РАН № 70990000130. Приоритетные научно-мето-дологические программы выхода на нулевой уровень аварийности по человеческому фактору (экипажу) в глобальном авиатранспортном процессе / Е.М. Хохлов; опубл. 04.10.99.

17. Чистяков М. М. Довідник молодого робочого по радіовимірюючим приладам / М. М. Чистяков. – М.: Вища шк., 1990. – 191 с., с. 116 – 121.

18. Колчан А.В. Датчики засобів діагностування машин: навч. посіб. / А.В. Колчан. – М.: Машинобудування, 1984. – 120 с. ил., с. 71 – 74.

19. Пат. 39943, Україна, МПК G09B 9/00. Спосіб визначення перших ознак факторного резонансу авіаційного оператора / Г. А. Положевець, Є. М. Хохлов, А. О. Ткаченко; заявник і патентовласник Національний авіаційний університет. – № 200808986; заявл. 09.07.2008; опубл. 25.03.2009, Бюл. № 6.

20. Хохлов Е.М., Ударцева Т.Е. Приоритетные подходы в решении проблемы безопасности полетов и человеческого фактора при использовании вертолетов. Материалы научно-технической конференции «Перспективы использования вертолетов в Украине», Харьков, 2–4 декабря 2003 г., с. 8–11.