APPROVED

Head of department

S.V. Pavlova

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GRADUATION WORK

(EXPLANATORY NOTES)

FOR THE DEGREE OF MASTER

SPECIALITY 173 “AVIONICS”

Theme: Flight data analysis based on flight data recording results

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Kyiv 2021

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
ФАКУЛЬТЕТ АЕРОНАВІГАЦІЇ, ЕЛЕКТРОНІКИ ТА ТЕЛЕКОМУНІКАЦІЙ
КАФЕДРА АВІОНІКИ

ДОПУСТИТИ ДО ЗАХИСТУ
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ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

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

Тема: Обробка польотної інформації по результатам систем об'єктивного контролю

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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

I.O. Ponomarenko

1. Theme of graduation work is the ’Flight data analysis based on flight data recording results’, 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: an operational chart of the analysis of the first signs of the factor resonance phenomenon has been developed for the development of optimal decisions in the production of flights.

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: Graphical presentation of the results of the study of the methodological framework for the analysis of the "area of inevitability" based on the operational map in the form of a presentation.

6. Planned schedule

№	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 and sixth chapter of diploma	19.11.2021 – 11.12.2021	
7.	Tested for anti-plagiarism and obtaining a review of the diploma	12.12.2021	

7. 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 ‘Flight data analysis based on flight data recording results’ contained 127 pages, 37 figures, 18 tables, 20 references.

The object of the research – phenomenon of factor resonance.

The purpose of the work – A method for determining the first signs of the factor resonance phenomenon

Research Method – theoretical studies are based on the ICAO concept of flight safety and the human factor, on the general concept of the process approach, the psychological engineering concept of the task of accounting for a large number of factors (TALNF), the general classification of resonant processes.

The scientific novelty of the research:

- ***For the first time***: a method of index processing of flight parameters is proposed as realizations of a non-stationary and weakly formalized process in the “inevitability area” of an accident.

- ***Improved***: methodological foundations for the analysis of the "area of inevitability" based on the operational map have been developed.

Keywords: PHENOMENON OF FACTOR RESONANCE, FACTOR OVERLAYS, POLYPARAMETRIC FACTOR RESONANCE, FLIGHT SAFETY.

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LIST OF CONDITIONAL TERMS AND ABBREVIATIONS

AA	Aircraft Accident
FR	Factor Resonance
PFR	Phenomenon of Factor Resonance
RP	Resonant Process
PPFR	Polyparametric Factor Resonance
RC	Resonance Curve
ICAO	International Civil Aviation Organization
NTD	Normative Technical Documentation
FI	Flight Information
SC	Single Command
AFM	Aircraft Flight Manual
ACS	Automatic Control System
FS	Flight Safety

INTRODUCTION

Flight safety is the most important operational and technical characteristic of the aviation system, which largely determines the combat readiness and combat effectiveness of the aviation of the Armed Forces. The problem of ensuring flight safety is one of the most pressing, most complex and least studied problems of modern aviation.

The urgency of the problem is determined by the fact that people die as a result of accidents and disasters, significant material and moral damage to the state is inflicted, combat training plans are violated, the commissioning of new aviation equipment is delayed, and damage is caused to the combat readiness and combat effectiveness of aviation units.

The complexity of the problem of ensuring flight safety lies in the fact that flight safety depends on numerous factors that randomly manifest themselves at all stages of the existence of aviation technology, starting from the development of tactical and technical specifications, design, creation of a prototype, testing, serial production and, finally, mass operation. and the use of aviation technology. A large number of specialists from the aviation industry and aviation of the Armed Forces are involved in ensuring flight safety. The shortcomings and miscalculations made at all stages of the existence of aircraft are explicitly revealed only at the final stage - in the process of their mass operation and application.

At the same time, an increase in flight speeds, an expansion of the range of used angles of attack and overloads increased the potential for an accident, and its danger to crews, despite the equipment of aircraft with modern rescue equipment, increased. So, for example, if in 1940. out of 13 aviation accidents, on average, only one ended in a catastrophic outcome; in recent years, a catastrophe occurs in every second or third aviation accident.

Statistics show that the development of aviation technology is accompanied by an uneven but natural increase in the level of flight safety. However, this increase lags behind the requirements for modern aviation technology. The noted lag is explained by a number of reasons. The main ones are the insufficient correspondence of the properties of equipment and personnel training to the increasingly complex tasks performed by military aviation, and the insufficient development of the theory of flight safety.

Unfortunately, the theory of flight safety is only in its infancy and has not really become a "productive force" yet. Therefore, the most important tasks are to expand the front of scientific research in the field of flight safety and radically improve the training of flight and engineering personnel who are able not only to maintain the level of flight safety inherent in the new aviation technology, but also to increase it by improving the methods of maintenance and the use of aviation technology.

CHAPTER 1. FLIGHT SAFETY INDICATORS. METHODS FOR THEIR DETERMINATION

1.1. FACTORS AFFECTING ON FLIGHT SAFETY

Flight safety is determined by the reliable functioning of all elements of the aviation system (AS), their correct interaction, as well as the conditions of the external environment in which flights are carried out.

The technical complexity of modern AS, the large number of personnel, services involved in the organization, preparation, performance and maintenance of flights, aircraft operation in a wide range of weather, climatic and physical-geographical conditions give rise to a variety of factors affecting the final outcome of the flight.

An unfavorable outcome of a flight as an accident is caused by dangerous (unfavorable) factors, which, as a rule, are interconnected with each other, by their nature, unstable and random. Therefore, in most cases, an accident as an unfavorable outcome of a flight is a consequence of the influence of not one, but a combination of factors, that is, such an accident has multi-factor causes.

The integral influence of all factors on the level of flight safety is determined based on the results of mass aircraft operation. To assess the impact of individual factors or their combinations on FS, it is necessary to consider the nature of the factors both by the sources of their occurrence and by the nature of their negative manifestations. According to the sources of the occurrence of factors, it seems advisable to give such a classification so that it reveals them as the root causes of potential danger for flights, that is, as the main ones in the chain of cause-and-effect relationships that ultimately lead to accident.

Taking into account that the AS is a complex polyergic system, each subsystem of which includes technical devices and people, according to the sources of occurrence, all factors potentially affecting BZP can be divided into three groups: technical, personal and environmental factors. The first two categories of factors are generated by the internal properties of the AS, therefore they are sometimes also called systemic, in contrast to environmental factors that are non-systemic. It should be noted that the boundaries between the AS and the environment are generally conditional and should be assigned in each specific case, depending on the task of the study.

For each of the AS subsystems, the ratio of technical and personal factors and their specification will be different. Integrally for such an important subsystem as the "crew-aircraft", technical factors can be represented by the reliability of the aircraft systems, its power plant, equipment and weapons and the ergonomic perfection of the aircraft.

The reliability of these aircraft components has a direct impact on the FS through possible in-flight failures. The ergonomic perfection of an aircraft is determined by the correspondence between the properties of the aircraft and those of the specialists who service and operate the aircraft. An aircraft imperfection in ergonomics can lead to errors in the engineering and technical staff (ETS) when servicing aircraft, performing routine maintenance and repairs, as well as to flight crew errors in piloting techniques and in operating equipment during flights.

On a modern aircraft, ergonomic disadvantages that complicate the work of the engineering and technical staff are distributed on average by groups as follows: disadvantages leading to non-compliance with safety measures - 11 ... 17%; shortcomings of ETS jobs - 22 ... 32%; insufficient operational manufacturability - 13 ... 16%; constructive and production shortcomings leading to erroneous actions - 28 ... 31%. More than 30% of ergonomic shortcomings significantly reduce flight safety.

The degree of aircraft ergonomic compliance with the capabilities of the flight crew is determined primarily by the characteristics of aircraft stability and controllability, the characteristics of the information display system, the degree of automation of control processes, the layout of workstations of flight crew members, that is, those characteristics that determine the quality of contact between the crew and the aircraft.

The second group of factors - personal factors - can be determined by a set of indicators related to the individual characteristics of people, such as moral and professional qualities, physiological characteristics and physical development, psychological characteristics. Deficiencies in the category of personal factors are manifested as violations of the established rules, erroneous actions or inaction of persons associated with the organization, provision and performance of flights.

The goal of preventing errors caused by personal factors should be to identify specific shortcomings of a particular specialist and to eliminate them by working with this specialist (group of specialists).

Not all the mistakes of specialists can be explained only by personal factors. Some of the errors, as noted above, are due to insufficient ergonomic perfection of aviation technology. To explain the causal nature of such errors, the concept of "human factor" is introduced.

The human factor is understood as the psychophysiological capabilities of a person inherent in all people with the training necessary for professional activity, and manifested in the interaction of specialists with equipment, for example, a pilot and an aircraft.

Erroneous actions caused by the human factor are characterized by the following features: the stability of their repetition in the same conditions, regardless of the specific personality of the specialist and his level of training, the independence of errors from the type of aircraft. The elimination of erroneous actions caused by the human factor should be resolved through the ergonomic improvement of technology to the level of compliance with the psychophysiological capabilities of a person.

Strictly speaking, as a rule, every erroneous action of a specialist is the result of a number of reasons related to both personal and human factors. In many cases, it is not possible to strictly single out where the technology is to blame, provoking human errors, and where - the person himself as a person - is not possible. Therefore, accidental accident and other unfavorable events that occurred due to the mistakes of specialists are very often classified according to the category of a personal factor, that is, in fact, a person takes on part of the blame of technology. This is due to the fact that aviation ergonomics and the human factor are difficult to measure and are largely subjective.

The third group of factors - environmental factors - can be defined as factors of the natural and man-made artificial environment, in which all sub-systems and elements of the AS function. Certain natural phenomena or factors of the built environment can directly affect FS, others can cause equipment failures, and still others can cause crew errors.

Socio-economic factors constitute a special group of factors that potentially indirectly affect the FS and are currently the least studied and recorded in the practice of operation. In the hierarchy of factors leading along the chain of cause-and-effect relationships ultimately to AA, such factors in some cases are primary in relation to other factors. There is no doubt that socio-economic factors to some extent determine both technical and personal factors, because technology is created and exploited by very specific people living in specific socio-economic conditions.

Methodologically, it is expedient to divide them into three groups according to the nature of negative manifestations of hazardous factors: aircraft equipment failures, personnel errors, unfavorable external flight conditions. The relationship of these groups of factors with the sources of their occurrence is illustrated by the diagram shown in Fig. 1.1.

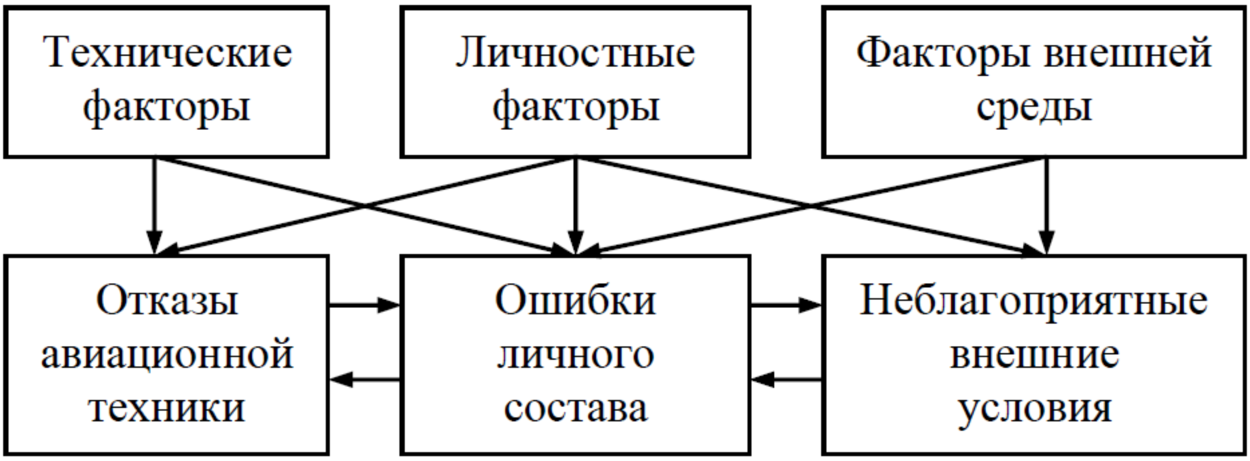


Figure 1.1.

Failures of aviation technology include failures of the functional systems of the aircraft, its power plant, equipment. Flight safety is adversely affected by failures of ground-based technical devices for flight support and control.

Errors of personnel include errors of flight and engineering personnel, persons of the flight management group, as well as personnel of flight support services in organizing, preparing and performing flights.

Adverse conditions should be understood as such external conditions that do not correspond to the established minima for flight crews, aircraft and aerodromes.

A significant number of factors affecting flight safety require a scientific analysis of the causes of their occurrence, an assessment of the degree of their danger for the development of preventive measures to increase the safety of flights.

1.2. FLIGHT SAFETY STATISTICS

To quantitatively assess the level of flight safety and identify its dependence on the properties of the aviation system, special indicators (criteria) are used. Currently, in aviation practice and research (analysis) of flight safety, two types of indicators are used - statistical and probabilistic.

Statistical indicators are usually expressed as physical quantities or the ratio of these quantities obtained as a result of processing statistical data of operation. Probability indicators are calculated using the methods of probability theory in an analytical way. Strictly speaking, statistical and probabilistic indicators are functionally related to each other, therefore, both types of indicators, in principle, can be calculated both according to accident statistics and analytically based on the use of probabilistic methods. As a rule, their direct calculation is performed as indicated above.

Statistical indicators can be divided into general and private, absolute and relative. General indicators characterize the level of flight safety, taking into account the integral influence of all factors on it, and private indicators - the influence of only individual factors or groups of homogeneous factors.

General absolute statistics. These include: the absolute number of accidents $n_{АП}$, catastrophes n_K, incidents $n_И$, the number of crew members and passengers killed in an accident m, material damage from the accident.

Absolute indicators can be used in the long-term planning of orders for aviation equipment, to clarify the corresponding items of expenditure on the development of aviation, to identify general trends in the dynamics of accidents and other cases.

The losses of aviation equipment from the accident are quite large. More than a dozen aircraft are lost annually as a result of accidents and disasters. The ever-increasing cost of modern combat aircraft leads to an increase in material damage from the accident.

During the conduct of hostilities, aviation, along with combat losses, suffers significant losses from AP (non-combat losses). This is confirmed by the experience of the Second World War and subsequent local wars and conflicts. During the Second World War, the United States lost more aircraft from AP than as a result of enemy actions. In 1983. during the conflicts in Grenada and Lebanon, in which the US Navy was involved, the accident rate in them more than doubled. The sharp increase in the accident rate during the period of warfare is explained by the specific conditions for the use of aviation: a significant increase in the workload on flight and ground crews, the use of limiting flight modes, flights in adverse weather conditions, etc. very relevant.

Direct absolute indicators do not quantitatively characterize the level of flight safety, since they depend on the quantitative and qualitative composition of the aircraft fleet, total flight time, etc. In absolute terms, it is impossible to compare the BZP levels of various types of aircraft, types of aviation. To a certain extent, relative statistical indicators are free of the considered shortcomings.

General relative statistics. Two types of indicators are used as relative indicators:

- average flight time per one event of the considered severity T_i, per one $T_{АП}$ accident, per one T_K accident, per one $T_И$ incident;

- the average number of events of the considered severity M_i per 10^5 flight hours.

The calculation of these indicators is carried out according to obvious ratios, for example:

$$T_{A\Pi} = \frac{t_\Sigma}{n_{\text{АП}}}; M_{\text{АП}} = \frac{n_{\text{АП}}}{t_\Sigma} \cdot 10^5 = \frac{10^5}{T_{\text{АП}}}, \qquad (1.1)$$

Where $t_\Sigma$is the total flight hours in hours for the analyzed period.

Indicators can be calculated as annual (the analyzed period is one calendar year) or as cumulative (total). In the latter case, the analyzed period is several calendar years. Cumulative indicators are more reliable in a statistical sense and less prone to random fluctuations compared to annual indicators.

The validity of this provision can be confirmed by the graphs shown in Fig. 1.2 and 1.3. In fig. 1.2 shows the dependences on the total flight time of the cumulative T_{AA} index for the F-15 and F-16 aircraft from the beginning of their operation, and in Fig. 1.3 - the dependence of the annual TAP indicator on the calendar time in general for the US Air Force and tactical aviation of the US Air Force.

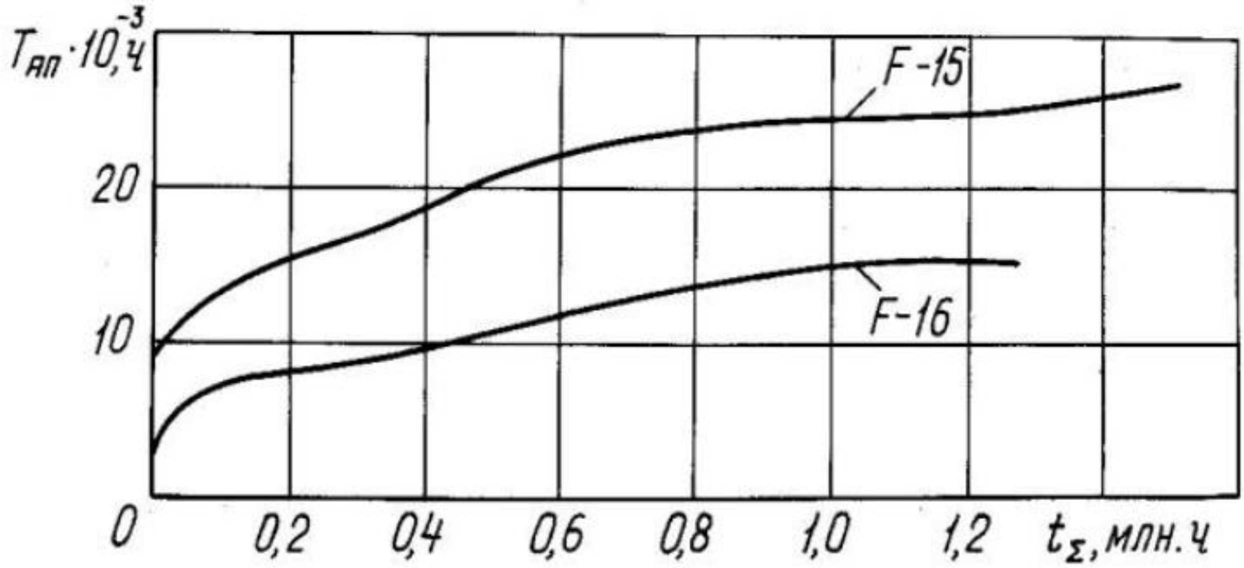


Figure 1.2.

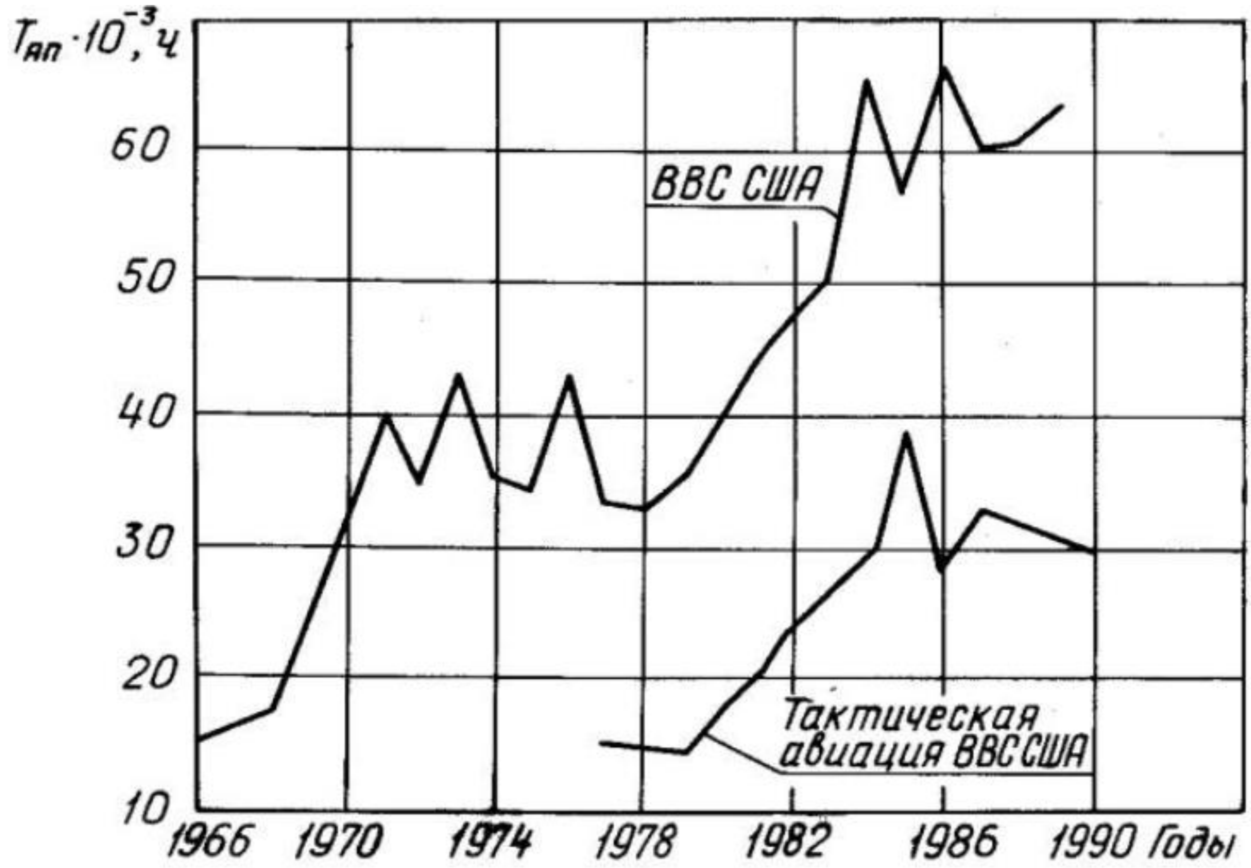


Figure 1.3.

Let us consider the general trends in the change in the annual average flight time per TAP aircraft accident as the most general characteristics of the level of flight safety using the example of accident data from the US Air Force (see Fig. 1.3). The analysis of the graphs allows us to formulate conclusions reflecting the general patterns in the change in the level of FS of military aircraft:

1. The development of aviation is accompanied by an increase in the average flight time per aircraft, although this trend is extremely uneven. Periods of growth in the FS level alternate with periods of its practical stabilization.
2. For tactical aircraft (attack aircraft, fighters, fighter-bombers), the average flight time per aircraft is significantly less than the average for the aircraft fleet. This is due to the fact that a certain part of the aircraft fleet is made up of heavy aircraft (bombers, military transport aircraft), for which the average flight time per aircraft is much higher than for light aircraft.

In civil aviation, indicators regulated by ICAO (the international civil aviation organization at the UN) are used to assess the achieved level of flight safety. The most important of them are the following: M_{K_1}, M_{K_2}, M_{K_3} - the number of accidents per 100 million flying kilometers, per 100 thousand flying hours, per 100 thousand flights (landings); m¯is the number of passengers killed in accidents per 100 million passenger-kilometers. Figure 1.4 shows the dynamics of these indicators according to ICAO data.

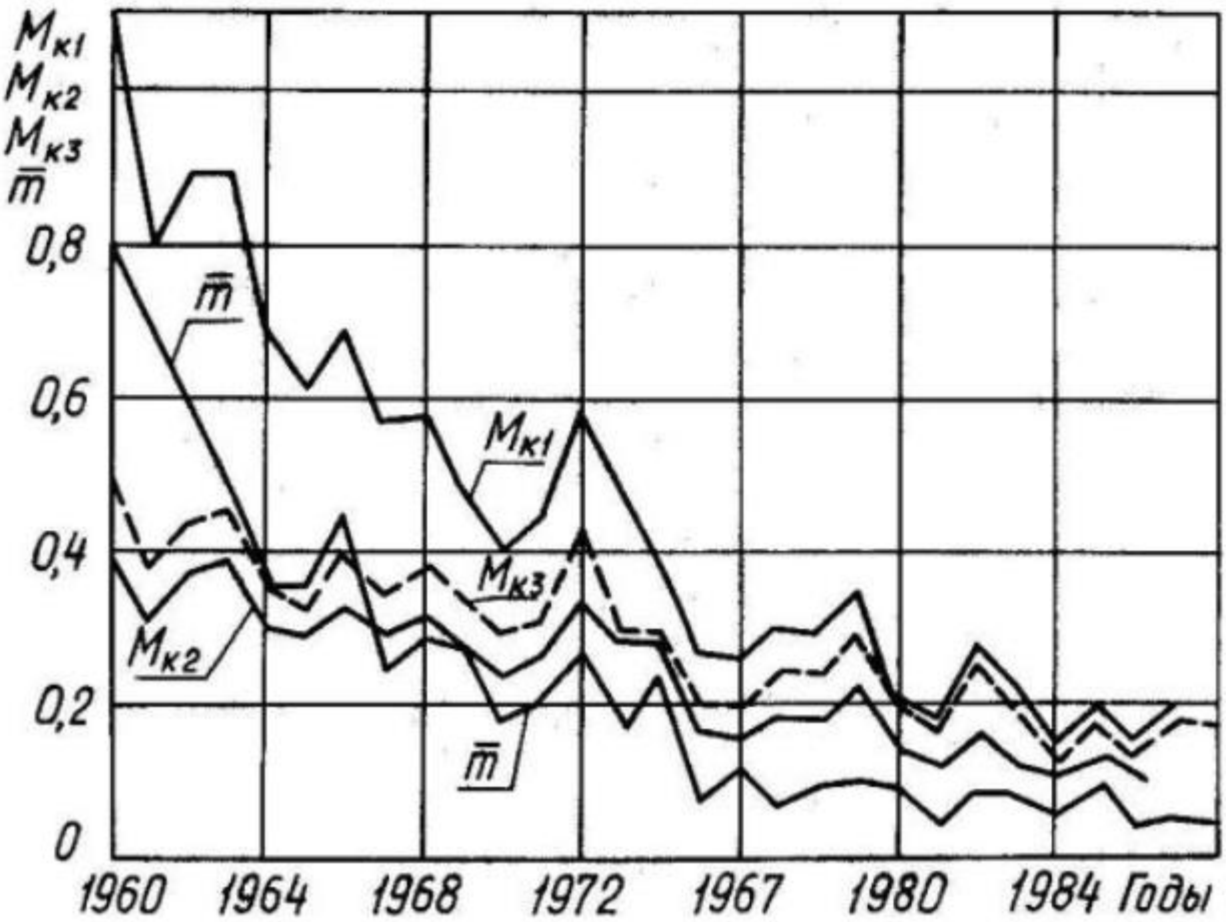


Figure 1.4.

Private statistics. General statistical indicators are integral in nature and, therefore, do not allow to reveal the influence of individual factors on the FS level. This task is to a certain extent solved by using private indicators. Like general indicators, they can be absolute and relative.

The absolute partial indicators include n_i, n_j, n_v - the number of events (accidents, catastrophes, accident in general), respectively, caused by the i-th cause (factor), the j-th group of reasons (factors) that occurred at the v-th stage of flight ...

Relative partial indicators include the relative numbers of events that occurred for the above reasons:

$$\bar{n}_i = \frac{n_i}{n};\ \bar{n}_j = \frac{n_j}{n};\ \bar{n}_v = \frac{n_v}{n},$$

Where n is the total number of events for all reasons (flight stages); T_j is the average flight time per event occurring for the j-th group of reasons (factors),

$$T_j = \frac{t_\Sigma}{n_j}.$$

Table 1.1 shows the distribution in percentage of AP by main groups of reasons and by stages of flight for military and civil aviation.

Table 1.1.

Groups of causes of AA				Flight stages			
Personnel errors	Aviation equipment failures	Unfavourable conditions	The causes of AA have not been established	Takeoff and climb	Flight along the route	Zone, combat use	Approach and landing
Military aviation							
60...70	20...30	2...5	2...4	15...20	10...20	30...50	20...40
Civil aviation							
60...80	10...25	5...10	5...7	30...35	15...20	-	50...55

From the data table. 1.1 follows:

1. Personnel errors as causes of accident are prevalent among other causes in both military and civil aviation. This confirms the importance of the problem of identifying the causes of erroneous actions of personnel from the standpoint of personal and human factors.

2. For military aviation, the most emergency phases of flight: approach and landing, flight into the zone and combat use. The first stage is associated with the

transience of control processes in the approach mode, the lack of time to correct the error, the need to strictly adhere to the specified flight parameters and flight profile; the second - flight into the zone and combat use - is due to the use of flight modes close to the limit at these flight stages, with an increased load on flight crews and their some distraction from piloting tasks when performing a combat mission.

3. For civil aviation, the most emergency phase of the flight is the approach and landing, since of all the phases of the flight, this phase is the most difficult to perform.

Statistical indicators are calculated on the basis of real data of mass exploitation, their main advantage is objectivity. However, statistical indicators also have a number of disadvantages that narrow the area of their practical use. These include:

• the assessment of the FS level according to statistical indicators is carried out when the accident occurred, that is, they register the past facts;

• statistical indicators cannot be applied to predict the FS level when operating and application conditions change;

• according to statistical indicators, it is impossible to assess the effectiveness of various organizational and technical measures aimed at increasing the labor market, even before their practical implementation;

• according to statistical indicators, it is impossible to reveal the influence of any design or aerodynamic parameter of the aircraft on the FS level, to optimize the FS level, taking into account cost and efficiency.

The listed disadvantages of statistical indicators are fundamentally removable or can be compensated for by using the second type of indicators - probabilistic.

1.3. PROBABILISTIC FLIGHT SAFETY INDICATORS

Probabilistic flight safety indicators objectively reflect the regularity that an aviation accident, as a potential outcome of a particular flight, is by its nature a random event due to the randomness of the occurrence of dangerous factors in time and space of flight that cause it.

Let us take the probability P of its successful completion as the safety level of an individual flight. The probability of an unfavorable end of the flight, that is, the ending accident, will be denoted by Q. This probability characterizes the level of risk in an individual flight. It is clear from physical considerations that

$$P + Q = 1 \qquad (1.2)$$

Probabilities P and Q are flight safety indicators. Based on (1.2), to assess the flight safety, it is sufficient to know one of the indicated probabilities, for example, Q.

It is quite obvious that the safety of many flights is determined by the safety of individual flights. Let us formalize the connection between the concepts of "flight safety" and "flight safety". If Q is the risk level in an individual flight, then for a set, in particular N, flights, the probability n Q can be taken as the same semantic criterion, that is, the probability that exactly n APs will occur in N flights, where $n = \overline{0, N}$.

We will assume that all flights are identical in terms of their safety, that is, Q1 = Q2 =… = Qn = Q. Under this assumption, to calculate the probabilities n of AP in N flights, one can use a particular theorem of the theory of probability of repetition of experiments, according to which the relationship between n Q and Q will be determined by the binomial distribution:

$$Q_n = C_N^n Q^n (1 - Q)^{N-n}, \qquad (1.3)$$

where $C_N^n = \frac{N!}{n!(N-n)!}$.

In fact, in the general case, flights can be carried out under different conditions, and the probabilities of a successful completion of each flight vary from flight to flight. To calculate the probabilities of occurrence of a certain number of AP in these cases, it is necessary to use a technique based on the general theorem of the theory of probability about the repetition of experiments.

Difficulties in calculating by formula (1.3) increase with an increase in the number of flights N. When assessing flight safety, the following conditions are actually met: Q<<1; the number of flights N is quite large. In accordance with this, with a sufficient degree of accuracy to simplify computational procedures, the binomial distribution (1.3) can be replaced by the Poisson probability distribution:

$$Q_n = \frac{(NQ)^n}{n!} e^{-NQ}. \qquad (1.4)$$

For the probability of successful completion of all N flights, assuming n=0 in formula (1.4), we obtain

$$P_{FS} = Q_{n=0} = e^{-NQ} = e^{-N(1-P)}. \qquad (1.5)$$

In terms of its meaning, the probability PPS is an indicator of flight safety, and, therefore, formula (1.5) is a mathematical expression of the flight safety indicator PPS through the safety indicator of one flight P, that is, it is a formalized connection between the concepts of flight safety and flight safety.

The number of flights N considered in distribution (1.4) is realized for the total flight time t_Σ, so $N = \frac{t_\Sigma}{t_n}$, where t_n is the duration of one flight. Taking into account that more than one accident cannot occur in one flight, the mathematical expectation of the number of accident in the time interval n t can formally be written in the form $\Lambda t_n = Q$, where Λ is the intensity of the accident, that is, the average number of accident per unit of flight time. For all N flights, the mathematical expectation of the number of aircraft will be determined by $m_n = NQ = \Lambda t_n N = \Lambda t_\Sigma$and, accordingly, distribution (1.4) can be written in the form

$$Q_n = \frac{(m_n)^n}{n!} e^{-m_n} = \frac{(\Lambda t_\Sigma)^n}{n!} e^{-\Lambda t_\Sigma}. \qquad (1.6)$$

The AA flow described by distribution (1.6) is the simplest, that is, it possesses the properties of stationarity, ordinariness, and absence of aftereffect. For such a flow, the time t between neighboring events (AA), as is known from the theory of probability, is distributed according to the exponential law with the probability density

$$f(t) = \Lambda e^{-\Lambda t}. \qquad (1.7)$$

Applying the operation of determining the mathematical expectation to expression (1.7), we calculate the average flight time per one AA

$$T_{AA} = m_t = \Lambda \int_0^{\infty} te^{-\Lambda t} = \frac{1}{\Lambda}. \qquad (1.8)$$

Using result (1.8), we write distribution (1.6) in the form

$$Q_n = \frac{\left(\frac{t_\Sigma}{T_{AA}}\right)^n}{n!} e^{\frac{t_\Sigma}{T_{AA}}}. \qquad (1.9)$$

For n = 0, we obtain an expression for the flight safety indicator

$$P_{FS} = e^{\frac{t_\Sigma}{T_{AA}}}. \qquad (1.10)$$

Formula (1.10) determines the relationship between the probability indicator of flight safety and the statistical indicator - the average flight time per accident.

Comparing formulas (1.5) and (1.10), we determine that

$$Q = \frac{t_\Sigma}{NT_{AA}} = \frac{t_n}{T_{AA}}. \qquad (1.11)$$

With a flight duration t_n one hour, the risk level

$$Q = \frac{1}{T_{AA}} = \Lambda,$$

that is, it is numerically equal to the intensity of the AA flux.

Formulas (1.4), (1.9), (1.11) indicate that when calculating safety indicators for certain values of $t_\Sigma(N)$, it is enough to know one of the three indicators Q, Q_n , T_{AA}, and the other two are determined by the above ratios ...

Having adopted the designations $\Lambda_{\text{т}}$, $\Lambda_{\text{лс}}$, $\Lambda_{\text{ну}}$ - the intensity of accident flows, respectively, due to aircraft failures, errors of personnel and unfavorable flight conditions and assuming the accident for these factors to be independent events from each other, the general indicator of flight safety PBS can be represented through private indicators:

$$P_{FS} = e^{-\Lambda t_\Sigma} = e^{-\Lambda_{\text{т}} t_\Sigma} e^{-\Lambda_{\text{лс}} t_\Sigma} e^{-\Lambda_{\text{ну}} t_\Sigma} = \text{Р}_{\text{т}}\text{Р}_{\text{лс}}\text{Р}_{\text{ну}}\,, \qquad (1.12)$$

where $\text{Р}_{\text{т}}, \text{Р}_{\text{лс}}, \text{Р}_{\text{ну}}$ are the probabilities of the absence of an accident for the total flight time, respectively, due to equipment failures, personnel errors, and unfavorable conditions.

It should be noted that relations (1.5) and (1.10) are applicable not only to assessing the probability of the absence of an accident, but also the probability of the absence of incidents, failures in the air, if the flows of these events are the simplest (obey the Poisson distribution). In this case, Q (or P) in formula (1.5) should be understood as the probability of occurrence (or non-occurrence) of the corresponding event, and TAP in formula (1.10) is the average flight time for one such event.

The relationship between probabilistic and statistical indicators of flight safety makes it possible to solve a number of practical problems, in particular, to set in probabilistic form the requirements for the FS level for the aircraft being designed based on the operating experience of the same type of aircraft; evaluate the effectiveness of various measures aimed at improving the health and safety benefits; determine the compliance of the actual FS level with the given one, etc.

1.4. GENERAL APPROACH TO ASSESSMENT OF FLIGHT SAFETY USING PROBABILITY INDICATORS

An aircraft accident is a random event. It can occur provided that a dangerous factor (group of factors) appears in flight and its consequences are not countered by the crew (pilot). Dangerous factors, as a consequence of very specific reasons, arise at arbitrary times, and this is their accident.

For a parrying event, we take the event of failure of the defining parameters x_j as our limit values $x_j < x_{j_{пр}}; j = \overline{1, l}$. Strictly speaking, the event $x_j > x_{j_{пр}}$ does not always necessarily lead to an accident. In some cases, after exceeding $x_{j_{пр}}$, the pilot, by his actions, can return the aircraft to the area $x_j < x_{j_{пр}}$, for example, fend off the stall mode of the aircraft and return it to normal angles of attack. In what follows, for the unambiguity of judgments, the exit of one or several defining parameters beyond their limiting values will be assumed to be an unfavorable outcome of the flight (AA).

Let's designate: p_i, q_i - probabilities of non-appearance and appearance of the i -th hazardous factor; r_i, s_i - conditional probabilities of parrying and non-parrying of its consequences. In the accepted notation, taking into account that $p_i + q_i = 1$, $r_i + s_i = 1$, the probabilistic indicators of the FS will have the obvious expressions

$$P_i = p_i + q_i r_i = 1 - Q_i; \qquad (1.13)$$

$$Q_i = q_i s_i. \qquad (1.14)$$

Formula (1.13) has a simple physical meaning, which can be interpreted as follows: with respect to the i-th hazardous factor, flight with probability P_i will be safe, if the i-th factor does not manifest itself with probability pi, and if it does manifest itself with probability qi, then its consequences with the conditional probability r_i will be parried by the crew (pilot). By analogy, one can reveal the meaning of formula (1.14).

The problem of obtaining detailed expressions for P and Q is more complicated, taking into account the possible impact on the aircraft in flight of a combination of hazardous factors.

The problem of determining the analytical dependence of the risk level Q (or probability P) during the flight time t, taking into account all the properties of the aviation system and the external environment, potentially affecting the FS, is key in the theory of flight safety and has not yet been ultimately solved. The complexity of solving this problem lies in the fact that, firstly, the properties of the aviation system and the external environment are represented by an extensive set of physically dissimilar parameters, which leads to a large dimension of the problem being solved; secondly, not all the properties of the aviation system that negatively affect the FS have been identified quite clearly; thirdly, individual properties of the aviation system and the external environment cannot be formally represented by a set of certain parameters that are statistically controlled. With regard to the latter, an example can be given: it is known that the possibility of an aircraft collision with birds affects the level of risk, however, it is not possible to calculate the probability of this event in the general case. One can only indicate the periods of time or modes of flight where a collision is most likely.

For the above reasons, the problem of determining the analytical dependence of the risk level Q on the flight time is solved only in special cases for individual sets of hazardous factors. The method for calculating P and Q in this case depends on the specifics of hazardous factors and their consequences. This specificity can be displayed by a set of features shown in Fig. 1.5.

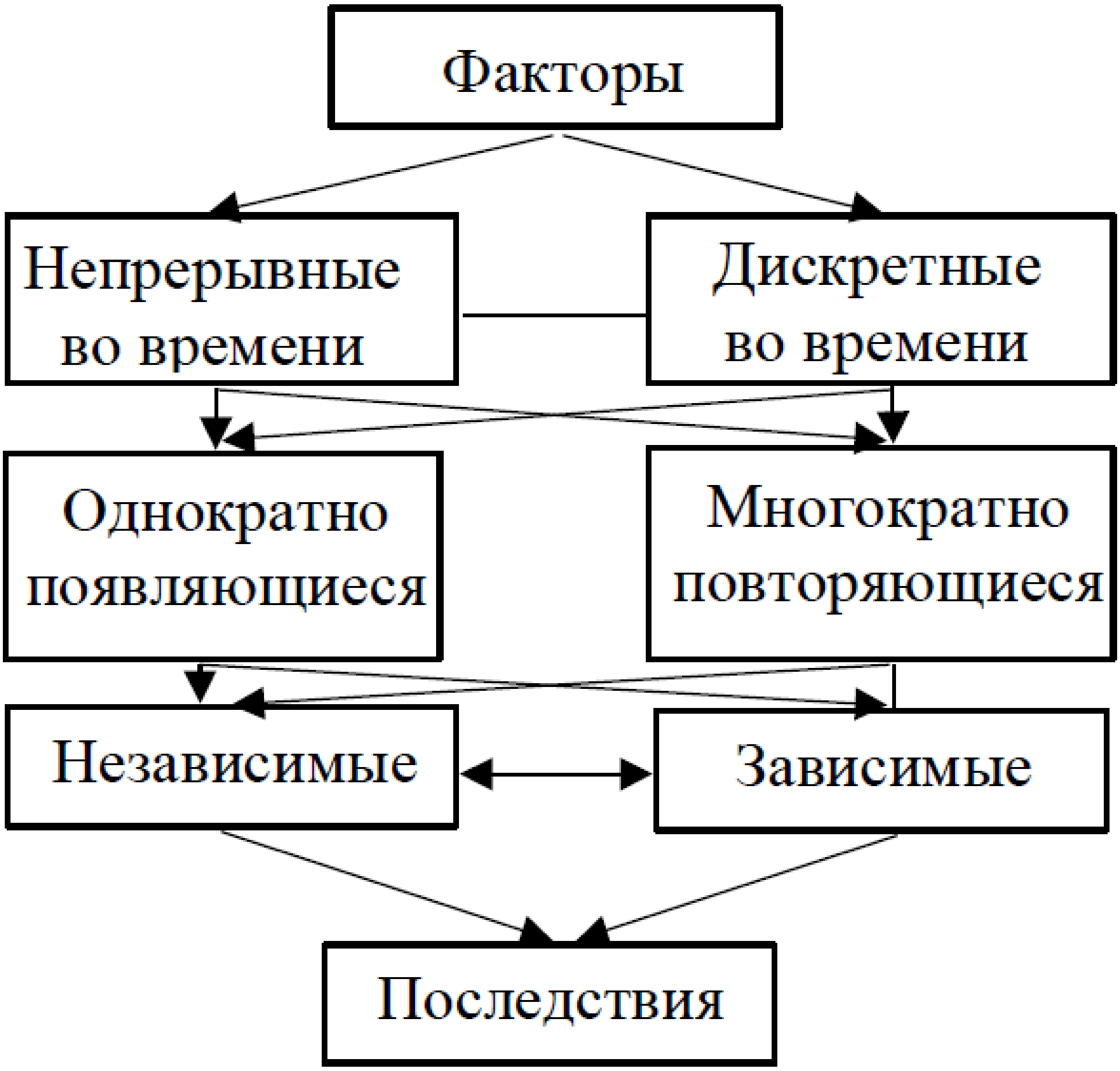


Figure 1.5.

The probability of occurrence of discrete in time factors does not depend on the flight time, but is mainly determined by the nature of the flight stage being performed, the level of the pilot's training. Such factors include, for example, failures of discretely functioning aircraft systems, errors in piloting techniques when performing a complex maneuver. The probability of occurrence of time-continuous factors is a function of flight time. Such factors include failures of continuously functioning aircraft systems, pilot errors in piloting technique when performing stationary flight modes, overload surges due to turbulence, etc. Factors that appear once can occur only once in flight, and factors that appear repeatedly in flight can be repeated. several times, provided that the previous appearance of the factor was parried by the crew.

Independent factors can appear in flight in any sequence, dependent - in such a sequence, which is determined by the dependence of the factors on each other. The consequences of factors can be considered independent if they do not depend on the sequence in which the factors appear in flight, and dependent - otherwise. An example of the latter can be failures in the ACS – control unit. If the ACS fails while the control unit is running, then its failures are usually not dangerous; if the ACS fails when the control unit has already failed, then its failures can be dangerous.

The mathematical formulations of the methods for calculating the indicators P and Q, set out in paragraphs 1.5 and 1.6, we prescribe the following initial provisions:

1. For the investigated case of calculating the P and Q indices, the occurrence of n hazardous factors in flight is possible.

2. A flight of duration t consists of z successively (in accordance with the assignment) stages (1, 2, ..., s, ..., z).

3. The value of the conditional probability of parrying the consequences of factors depends on the stage of the flight and changes from stage to stage in steps.

4. The values p_i, s, q_i, s, r_i, s, s_i, s are considered known for each s -th stage - respectively, the probability of non-occurrence and occurrence of the i -th factor and the conditional probabilities of its parry and non-parity.\

1.5. DETERMINING THE PROBABILITY OF A SAFE FLIGHT BY EXAMINING HYPOTHESES

The mathematical formulation of the method can be based on the formula of total probability, which provides for the consideration of all physically possible hypotheses associated with individual hazardous factors and their combinations.

The probability of a successful flight outcome for n possible hazardous factors in any combination of them can be written as

$$P = P(A_0) + \sum_{i=1}^{n} P_i(A_1) + \sum_{\substack{k=1 \\ k\in i,j \\ i\neq j}}^{C_n^2} P_{i,j}(A_2) + \cdots + P_{i,j,\ldots,n}(A_n), \qquad (1.15)$$

where $P(A_0)$ is the probability that no hazardous factor arises; $P_i(A_1), P_{i,j}(A_2)$ - the probability that only one hazardous factor occurs and the outcome of the flight will be successful, two hazardous factors, etc.

The terms in (1.15), provided that the factors are independent, are determined by the following expressions:

$$\begin{cases} P(A_0) = p_1 p_2 \ldots p_n; \\ P_i(A_1) = p_1 p_2 \ldots p_{i-1} p_{i+1} \ldots p_n q_i r_i; \\ P_{i,j}(A_2) = p_1 p_2 \ldots p_{i-1} p_{i+1} \ldots p_{j-1} p_{j+1} \ldots p_n q_i q_j r_i r_j; \\ \ldots\ldots\ldots\ldots\ldots \\ P_{i,j,\ldots,n}(A_n) = q_1 q_2 \ldots q_n r_1 r_2 \ldots r_n. \end{cases} \qquad (1.16)$$

The probability of an accident Q is determined from the obvious condition that each subsequent hazardous factor during the flight is physically possible if the hazardous factors did not arise before, and if they did arise, they were countered. In accordance with this condition, we obtain

$$Q = q_1 s_1 + (p_1 + q_1 r_1) q_2 s_2 + \cdots$$
$$+ (p_1 + q_1 r_1)(p_2 + q_2 r_2)(p_{n-1} + q_{n-1} r_{n-1}) q_n s_n$$
$$= q_1 s_1 + \sum_{i=2}^{n} \left\{ q_i s_i \prod_{k=1}^{i-1} (p_k + q_k r_k) \right\}. \qquad (1.17)$$

Generally speaking, the risk level Q can be calculated in a simpler way - as the probability of an opposite event, that is

$$Q = 1 - P. \qquad (1.18)$$

Let's consider an elementary example. Determine the expression for P under the influence of two independent factors. In accordance with (1.15) and (1.16), we have

$$P = p_1p_2 + p_1q_2r_2 + p_2q_1r_1 + q_1q_2r_1r_2. \qquad (1.19)$$

It is easy to see that expression (1.19) can be represented by the product

$$P = (p_1 + q_1r_1)(p_2 + q_2r_2).$$

Generalizing this result for n independent factors, we obtain

$$P = \prod_{i=1}^{n}(p_i + q_ir_i). \qquad (1.20)$$

Formula (1.20) is a compact record of expanded expressions presented by (1.15) and (1.16).

Taking into account the effect on the aircraft of only one factor, which can occur repeatedly in flight, for example, m times, on the basis of (1.20) we have

$$P = (p + qr)^m. \qquad (1.21)$$

Taking into account that p + q = 1, r = 1-s, from (1.21) it follows

$$P = (1 - Q)^m, \qquad (1.22)$$

where Q = qs is the risk level for a single occurrence of the factor.

Expanding function (1.22) in a series and restricting ourselves to the first two terms of the expansion, we obtain

$$P = 1 - Qm.$$

Note that this corresponds to the expansion of the function e-Qm limited to the first two terms of the expansion. Therefore, approximately one can represent

$$P = e^{-Qm} = e^{-qsm}. \qquad (1.23)$$

Example. When performing a maneuver, the probability of a pilot's error is $q=10^{-3}$, the conditional probability of its non-pairing is $s=10^{-1}$. Assess the safety of 100 such maneuvers.

Calculations are carried out in accordance with the formula (1.22):

$$P = (1 - 10^{-3} \cdot 10^{-1})^{100} = 0.990049834.$$

and formula (1.23):

$$P = e^{-10^{-3} \cdot 10^{-1} \cdot 10^{2}} = 0.990049834.$$

As you can see, the error from replacing the exact formula with an approximate one affects only starting from the seventh decimal place.

Until now, all the reasoning and calculations regarding the methodology for calculating the P and Q indicators were carried out without taking into account the stages of the flight. The solution to this problem can be approached by considering the probabilities of a favorable Pi and unfavorable Qi outcomes for each ith factor, taking into account the stages of the flight.

For a factor of the i-th type, the sequence of events by stages of flight, associated with the possibility of its occurrence at one of the stages, can be represented by a graph (tree of states) shown in Fig. 1.6. The graph characterizes the multistep process (1, ..., s-1, s, ..., z) of the system transition from one state (event) to another, taking into account the possibility of the appearance of the ith factor at the considered stage, starting from the first and ending last. The probabilities of transition from one state to another are put on the arrows of the graph, while the condition must be met: the sum of the probabilities on all arrows leaving one state must be equal to one.

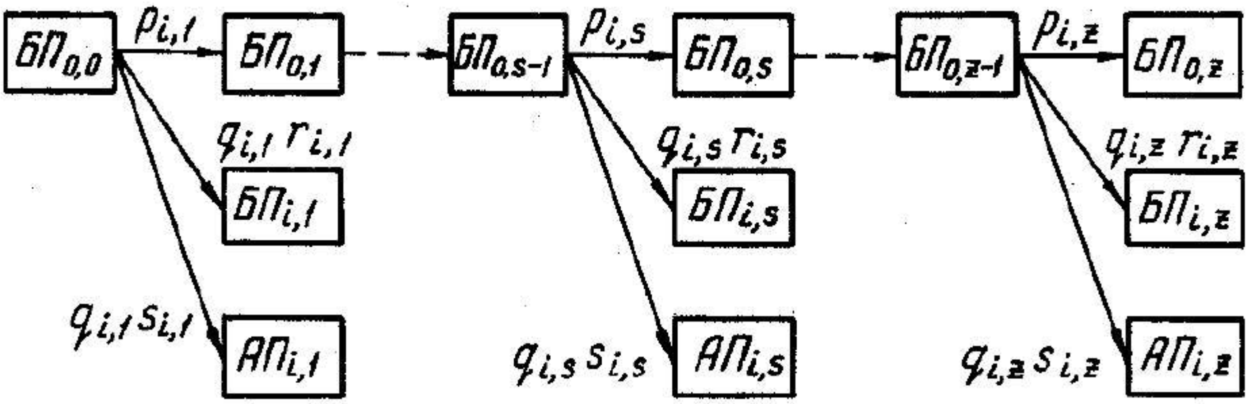


Figure 1.6. $BP_{0,s}$ - event of non-appearance of the i-th factor at the s-th stage; $B\Pi_{i,s}$, $A\Pi_{i,s}$ - events of successful and unfavorable outcomes when the i-th factor appears at the s-th stage.

The probabilities of these events are defined as the product of all the probabilities indicated on the arrows, starting from the event under consideration and ending with the initial BP0.0. Note that the probability $P(\text{БП}_{0,0}) = p_{i,0} = 1$, that is, at the beginning of the flight, the i-th factor is absent.

In accordance with the above

$$P(FS_{0,s}) = \prod_{k=1}^{s} p_{i,k}\ ; \qquad (1.24)$$

$$P(FS_{i,s}) = q_{i,s} r_{i,s} \prod_{k=1}^{s-1} p_{i,k}\ ; \qquad (1.25)$$

$$Q(AA_{i,s}) = q_{i,s} s_{i,s} \prod_{k=1}^{s-1} p_{i,k}\ . \qquad (1.26)$$

For all z stages of the flight, the indicators P_i and Q_i, taking into account the effect of only one i-th factor, on the basis of formulas (1.24) - (1.26) take the form:

$$P_i = \prod_{s=1}^{z} p_{i,s} + \sum_{s=1}^{z} \left(q_{i,s} r_{i,s} \prod_{k=1}^{s-1} p_{i,k} \right); \qquad (1.27)$$

$$Q_i = \sum_{s=1}^{z} \left(q_{i,s} s_{i,s} \prod_{k=1}^{s-1} p_{i,k} \right); \qquad (1.28)$$

For all n factors, taking into account their independence, we have

$$P_i = \prod_{i=1}^{n} P_i = \prod_{i=1}^{n} \left[\prod_{k=1}^{z} p_{i,s} + \sum_{s=1}^{z} \left(q_{i,s} r_{i,s} \prod_{k=1}^{s-1} p_{i,k} \right) \right]. \qquad (1.29)$$

The risk level Q per flight, taking into account the possible impact of all n factors, is defined as

$$Q = 1 - P = 1 - \prod_{i=1}^{n} (1 - Q_i). \qquad (1.30)$$

Expanding the term-by-term product $\prod_{i=1}^{n}(1 - Q_i)$, on the basis of formula (1.30) we determine

$$Q = \sum_{i=1}^{n} Q_i - \sum_{\substack{I=1 \\ I \in i,j \\ i \neq j}}^{C_n^2} Q_i Q_j + \cdots + (-1)^{n-1} \prod_{i=1}^{n} Q_i\ . \qquad (1.31)$$

The normalization condition P + Q = 1 is satisfied. Taking into account that Qi<<1, in a number of cases formula (1.31) can be restricted to only the first term, that is

$$Q = \sum_{i=1}^{n} Q_i .$$

In conclusion, we point out that the method of enumerating hypotheses when calculating the indicators P and Q can be used for both discrete and continuous factors, both dependent and independent.

When calculating the indicators P and Q for dependent factors, it is advisable to use a graphical interpretation of the transition of the system from one state (event) to another, since speculative enumeration of all hypotheses associated with the appearance of individual factors and their combinations is difficult. The graph (state tree) should be built according to the rules implemented when constructing the graph shown in Fig. 1.6.

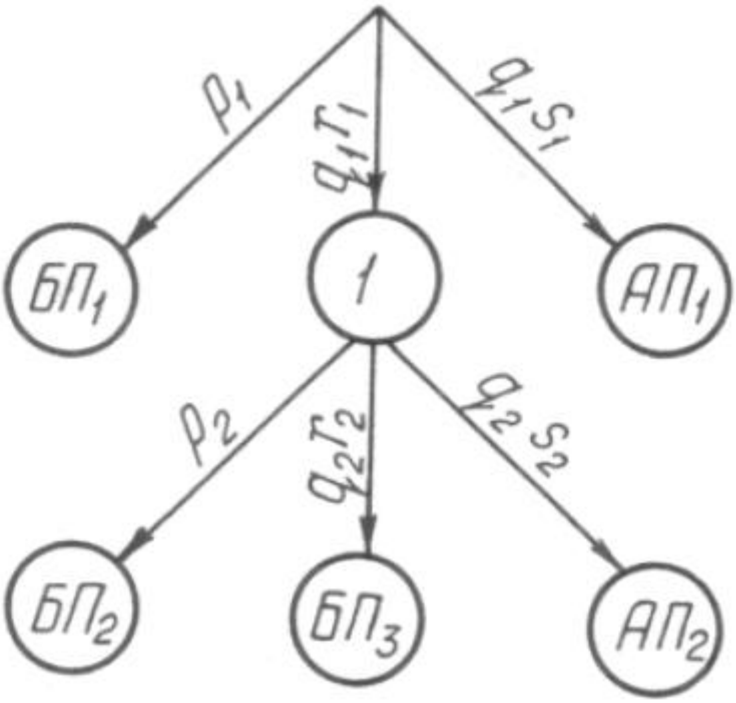


Figure 1.7

As an example, consider the case of the influence of two dependent factors: the second factor can appear provided that the first has already appeared. The graph for this case is shown in Fig. 1.7. As you can see from it, complex events BP and AP are represented by the sums of events: $B\Pi = B\Pi_1 + B\Pi_2 + B\Pi_3$; $A\Pi = A\Pi_1 + A\Pi_2$.

The probabilities of elementary events are equal:

$$P(FS_1) = p_1;\ P(FS_2) = q_1p_2r_1;\ P(FS_3) = q_1q_2r_1r_2;$$

$$Q(AA_1) = q_1s_1;\ Q(AA_2) = q_1q_2r_1s_2;$$

Hence $P = p_1 + q_1p_2r_1 + q_1q_2r_1r_2$; $Q = q_1s_1 + q_1q_2r_1s_2$.

The correctness of the calculations can be verified by the condition

P+Q=1.

CONCLUSIONS TO CHAPTER 1

1. A significant number of factors affecting flight safety require a scientific analysis of the causes of their occurrence, an assessment of the degree of their danger for the development of preventive measures to increase the safety of flights.
2. The listed disadvantages of statistical indicators are fundamentally removable or can be compensated for by using the second type of indicators - probabilistic.
3. The relationship between probabilistic and statistical indicators of flight safety makes it possible to solve a number of practical problems, in particular, to set in probabilistic form the requirements for the FS level for the aircraft being designed based on the operating experience of the same type of aircraft; evaluate the effectiveness of various measures aimed at improving the health and safety benefits; determine the compliance of the actual FS level with the given one, etc.
4. In conclusion of this section, we note that it considered the methodology for calculating flight safety indicators based on the representation of the system state change in flight as a homogeneous Markov process, that is, when λ_i = const. If the intensity of transitions λ is a function of time, that is, $\lambda_i=\lambda_i(t)$, then the Markov process is inhomogeneous and described by a system of differential equations with variable coefficients. As for the rest, the methodology for calculating flight safety indicators remains the same.

CHAPTER 2. FLIGHT INFORMATION PROCESSING METHODS AND ALGORITHMS

2.1. METHOD OF COMPOSITION AND EVALUATION OF ALGORITHMS

The part of the flight control algorithm that prescribes the system to perform simple logical operations with the registered parameters to achieve the control goal is called the analysis and tolerance control logic algorithm. To increase the reliability of the control results, generalization algorithms, statistical estimation, statistical hypothesis testing, etc. can be used. When describing logical algorithms, the rules of logic algebra are used.

Algorithms are developed on the basis of diagnostic models using NTD on aircraft.

When compiling a computer program, the information characteristics of onboard registration systems and the capabilities of ground-based FI processing facilities are taken into account. The developed algorithms are presented in the form of message catalogs. After drawing up logical algorithms, the potential reliability of the control results is assessed taking into account the characteristics of the accuracy and reliability of the control system. The complication of algorithms and the use of unregistered parameters by them reduces the reliability.

Based on the results of assessing the potential reliability, a decision is made on the use of methods and algorithms for statistical processing of FI and other means that ensure its increase, for example, changes in the tolerance field.

Logical algorithms for analysis and tolerance control are used to process the parameters accumulated by the МСРП.

The control algorithm is called the exact prescription for the execution in a certain order of a certain system of operations to obtain estimates of the quality of the functioning of the control object in accordance with its diagnostic model. The algorithms are used to generate messages about the state of the controlled object and during expert analysis of the generated computer messages from the graphs of flight parameters.

Flight recorders installed on aircraft to obtain information about the causes of accidents and prerequisites have been effectively used for many years as the main means of objective post-flight control over the quality of the ATC functioning, its elements and connections in regular scheduled flights. The increase in the information content of on-board recorders and the use of ground-based systems for automated processing of FI allow to increase the depth and reliability of control over the actions of the crew to control the aircraft and its systems during piloting and air navigation, to improve the quality of the operation of the power plant, flight control systems, takeoff and landing devices, air conditioning systems, power supply and others. elements of ATC. To increase the reliability of the results of automated control, various methods of processing the observed values of the parameters are used with a preliminary logical analysis of the FI, in the process of which the flight is divided into separate stages and signs of the moments of control of the determining parameters are distinguished within the stages.

In automated control, the following stages of flight are usually distinguished:

- starting engines;
- taxiing onto the runway;
- take off;
- climb;
- flight along the route,
- decrease;
- approach and landing;
- after landing taxiing (until the engine is switched off).

The moments of control are formed in accordance with diagnostic models containing signs of control of regular messages and permissible deviations of the defining parameters. The deviations are calculated by tolerance control. The limiting values of the defining parameters are specified in the form of constants or functionals.

Logical algorithms for automated analysis and tolerance control reflect the relationship between the values of the monitored parameters and features that characterize the quality of the ATC functioning, and constitute the central part of the complete flight control algorithm. All other algorithms only supplement and develop logical algorithms in order to clarify the results obtained and identify patterns by communicating these results.

Logical algorithms for automated analysis and tolerance control must correspond to the diagnostic models of the objects of control and the information characteristics of the on-board registration systems (lists of recorded parameters, registration accuracy), and when the diagnostic models change, they must be easily corrected. Programs corresponding to these algorithms should economically use computer resources.

Algorithms that use simple logical operations - comparison, addition, multiplication, etc., satisfy the listed requirements in the best way. These algorithms are written in the form of logical functionals that establish the relationship between the current values of the registered parameters, AC and restrictions determined at a given interval of their change.

Parameters mean coordinates that are continuous functions of time and limited to a certain range of their measurement. For example, altitude, flight speed, and roll angle refer to the parameters characterizing the aircraft movement. SC (binary signals) are parameters that characterize the possible states of coordinates by their discrete values (most often two). These commands include parameters characterizing the position of the chassis (retracted - released), turning on and off the aircraft systems, etc. When formalizing the algorithms, the notation, operations, properties of transformations of logical expressions and terminology established by the algebra of logic are used.

The main elements that the algebra of logic operates with are events. Events characterize the fulfillment of the conditions set by the diagnostic model, and are usually indicated by capital letters of the Latin or Russian alphabet. In flight control algorithms, events are designated S_i, where i is the sequence number of the event in the message catalog. In the process of automated control, the formed event may turn out to be unreliable due to the influence on the result obtained by various factors: measurement errors, registration and processing of FI, etc. e. The reliability of the event is confirmed by an expert. An unacknowledged event is commonly referred to as a message (potential event). The state of the controlled object is characterized by the presence or absence of an event. The probability of a complete group of events is equal to one, therefore, when compiling the algorithms, the opposite event S is used, which complements the event S to a complete group.

Events are divided into simple and complex. Examples of simple events are the execution of the command "landing gear down" $S=i_{шв}$, flight with admissible roll angles $S=(\gamma<\gamma_{доп})$, increased vibration of the engine $S=i_{дв}$, and others. Complex events characterize not only the value of the controlled parameter, but also the conditions (moment) of control. To record a complex event, use the operations of logical multiplication or conjunction S1 · S2 or S1∧S2 (read "S1 and S2") and logical addition or disjunction S1 + S2 or S1∨S2 (read "S1 or S2"), as well as relation operations (more, no less, less, no more). Thus, a complex event algorithm usually consists of two parts:

$$S = (S_1 \vee S_2) \wedge S_3,$$

where S_3 - the results of the control of the determining parameter; S_1 and S_2 - conditions under which the control is carried out.

When transforming complex events, the basic laws of associativity are fulfilled:

$$(S_1 \wedge S_2) \wedge S_3 = S_1 \wedge (S_2 \wedge S_3),$$

commutability:

$$S_1 \wedge S_2 = S_2 \wedge S_1,$$

distribution:

$$(S_1 \vee S_2) \wedge S_3 = (S_1 \wedge S_3) \vee (S_2 \wedge S_3).$$

By applying these laws, complex events are transformed into a form convenient for further use.

The methodology for drawing up flight control algorithms for aircraft provides for the implementation of four sequential stages: preparatory, analysis of diagnostic models, compilation of descriptions of algorithms and documentation.

At the preparatory stage, a preliminary analysis of the diagnostic model is carried out, the documentation necessary for the compilation of algorithms is selected and analyzed.

Diagnostic models in a formalized form are usually compiled by the developer of the control (operation) object. This makes it easier to prepare for the compilation of algorithms, since there is no need to select diagnostic features, calculate their nominal and limiting values. If the diagnostic models are specified in the form of technical parameters of AE products, recommendations and restrictions set out in the flight manual of a specific aircraft type and in another NTD, then at the preparatory stage it is necessary to formalize the verbal description of the diagnostic model in accordance with the purpose of control.

The global purpose of control is to assess the impact of the quality of ATC functioning on safety and other indicators of flight efficiency. Specific goals are to identify dangerous deviations in the operation of functional systems and in the actions of the crew to control the aircraft, to monitor the quality of the functioning of the crew and aircraft systems during the performance of the flight mission and its individual elements, etc. Dangerous deviations are characterized by exceeding the operational and limiting limits of diagnostic signs and the quality of functioning - by deviations of these features from their nominal and most advantageous values. Signs can be characterized by parameter values (for example, speed, altitude, roll, pitch, etc.), their combinations (specific fuel consumption depending on the engine operating mode, speed depending on the aircraft flight mass and flight level, etc.) .), as well as complex analytical dependencies (consumption of the engine resource depending on the operating time, modes and conditions of its operation).

To determine the list and description of diagnostic signs, their nominal, operational and limit values, the normative and technical and reference documentation is used, including ЕНЛГС, technical descriptions of the aircraft and its systems, flight manual, technical parameters standards, etc.

To check the possibility of realizing the control goal by processing FI, it is necessary to analyze the information characteristics of the on-board registration system. The preliminary analysis provides for an assessment of the compliance of the list of registered parameters and SC from aircraft systems and their distribution over the registration channels. The need for such a preliminary analysis will be illustrated by the following example.

One of the important parameters for aircraft piloting is the roll angle. To ensure the reliability of the indication of this parameter, the aircraft are equipped with three measuring systems and a device for monitoring their operation - the tilt control unit. Failures of any of the systems are indicated to the crew. Since tilt control unit can also fail, FI is used to monitor their performance. This method of monitoring the tilt control unit is successfully used on the Ty-134 aircraft. It was not possible to use it on the Ty-154: instead of the roll angles from three gyrohorizons, the list of recorded parameters included two roll angles from different points of the gyrohorizon of the left pilot and the roll angle of the gyrohorizon of the right pilot.

When analyzing diagnostic models, it is necessary to describe the functional dependences of diagnostic signs and the moments of their control on the recorded parameters, SC, to determine the composition of the necessary unrecorded information, as well as the nominal and limiting values of diagnostic signs.

Non-registered information necessary for the formation of diagnostic signs (for example, atmospheric pressure at the airport of landing) is entered by the crew in the passport of the magnetic tape (Fig. 2.1), and in case of automated processing - by the operator in the computer.

ПАСПОРТ

магнитной ленты самописца МСРП________№ _______ самолет №.____________

Ленту установил «   » ___________ 19 .... г. техник цеха №______________ (подпись)

ЛПМ (МЛП) снял «   » ___________ 19 .... г. техник цеха №______________ (подпись)

после выполнения рейса __________________ число _______ месяц______________

Дата полета	Номер рейса	Этап полета	Время, ч	Аэропорт	МК, град	$X_ц$, %	Масса ВС, т	Высота, м						$p_{аэр}$, мбар	Метеоусловия			Код КВС
								1	2	3	4	5	6		ветер, град	ветер, м/с	ВПР, м	
		Взлет																
		Посадка																
		Взлет																
		Посадка																
		Взлет																
		Посадка																

Figure 2.1. Magnetic tape passport: ЛПМ (МЛП) - magnetic-tape handler mechanism; МК - magnetic course of landing (takeoff); $X_ц$ - centering, percentage of the average aerodynamic chord (САХ); altitude: 1 - transition, 2 - echelon, 3 - transition echelon, 4 - circle, 5 - glide slope over the ДПРМ, glide slope over the БПРМ; $P_{аэр}$ - atmospheric pressure at the landing airport; КВС - commander of the aircraft.

Lists of the registered parameters and SC with indication of the registration channel number and their designations in the algorithm and program are drawn up in the form of a table. 2.1.

Table 2.1. List of parameters (SC) for quality control of aircraft approach

Parameter name (SC)	Channel number	Designation	
		In the algorithm	**In a programme**
Barometric altitude	02	$H_б$	HB
Geometric altitude	03	$H_г$	HG
Indicated speed	04	$V_п$	V
Vertical overload	09	n_y	NY
Roll angle according to КПП-75 left	06	$\gamma_л$	KR
Gyromagnetic course	12	ψ	KS
Thrust lever	19	$\alpha_{руд1}$	RA

position 1			
Engine low pressure rotor speed 1	21	$n_{нд1}$	NA
Thrust lever position 2	23	$\alpha_{руд2}$	RB
Thrust lever position 3	31	$\alpha_{руд3}$	RC
Thrust lever position 4	35	$\alpha_{руд4}$	RD
Engine low pressure rotor speed 4	37	$n_{нд4}$	ND
ACS activation signal by channel «Высота»	8-1	$i_{сп}$	СП
ACS activation signal by channel «Крен»	8-2	$i_{сб}$	СБ
Signal of readiness of radio technical means of landing on the glide path channel	56-1	$i_{гл}$	ГЛ
Signal of readiness of radio technical means of landing on the course channel	56-2	$i_{зх}$	ЗХ
Service signal of the left radio altimeter	56-3	$i_{рв}$	р
Signal of maximum deviation from the equal-signal glide path zone	56-5	$i_{пг}$	ПГ
Signal of maximum deviation from the equal-signal course zone	56-6	$i_{пк}$	ПК

If the algorithms use information that is not recorded in flight and is not entered in the magnetic tape passport, then the crew fills in a special report card on the performance of training flights controlled with the use of FI.

The descriptions of the algorithms include descriptions of the features of the moments of control, the values of diagnostic features and the logical connections between them. Let us consider this using an example of an algorithm for assessing the quality of the aircraft automatic control system during landing approach. The quality of the system's functioning meets the established requirements if the following conditions are met during the flight:

- there were no failures of ground-airborne radio-technical means of approach (glide-scope beacon – glide-scope receiver, on-course beacon – on-course receiver), the ACS channels did not turn off prematurely due to unsatisfactory operation of the course-glide path system;
- radio altimeters did not fail;
- the increment of the vertical overload during automatic descent along the glide path did not exceed 0.3, and the values of the roll angles - ± 8 °;
- deviations from the heading and glide path zones, as well as the flight speed did not exceed the established values.

The fulfillment of these conditions can be described by the algorithm

$$S = S_1 \wedge S_2 = [\bar{M}_1 \wedge \bar{M}_2 \wedge \bar{M}_3 \wedge \bar{M}_4 \wedge \bar{M}_5 \wedge \bar{M}_6 \wedge \bar{M}_7 \wedge \bar{M}_8] \wedge [\Pi_{\text{кас}} \wedge V < 200]V,$$

where S_1 is a message characterizing the quality of ACS functioning during autoapproach, S_2 is the moment of control (the approach must end with a landing).

Let us analyze the content of the message algorithms S_1 and S_2. The names and designations of parameters and SC are given in Table 2.1.

Sign M_1 characterizes the increment of vertical overload on the glide path, the absolute value of which should not exceed 0.3:

$$M_1 = \Pi_{\text{зах}} \wedge H_{\text{г}} < 60 \wedge i_{\text{рн}} \wedge \left(n_y > 1.3 \wedge n_y < 0.7\right).$$

The algorithm of this sign contains a number of conditions formed on the basis of the RK and the specified value of the parameter $H_{\text{г}}$, as well as the sign of approaching in automatic mode:

$$\Pi_{зах} = i_{гл} \wedge i_{сп}.$$

The absence of the M_1 feature (the $\bar{M}_1$ feature) characterizes the normal operation of the ACS in terms of overload.

All other signs are formed in a similar way:

- sign of failure of the glide-scope beacon – glide-scope receiver:

$$M_2 = \Gamma T_{A_{зп}} \wedge i_{гл} \wedge H_г > 30,$$

where

$$\Gamma T_{A_{зп}} = \Pi_{зах} \wedge i_{сб} \wedge i_{зх}$$

- a sign of a violation of the requirements for the accuracy of maintaining the roll angles on the glide path:

$$M_3 = \Pi_{зах} \wedge i_{сб} \wedge i_{зх} \wedge [(\gamma > 9) \vee (\gamma < -9)] \wedge \tau > 3,$$

in which the condition for duration ($\tau > 3$) is imposed to protect the algorithm from recorder failures;

- sign of failure of the on-course beacon – on-course receiver path:

$$M_4 = \Gamma T_{A_{зп}} \wedge \bar{i}_{зх} \wedge H_г > 30;$$

- sign of failure of the altimeter on the glide path:

$$M_5 = \Pi_{зах} \wedge i_{рв} \wedge H_г > 30;$$

- sign of unsatisfactory operation of the autothrottle:

$$M_6 = \Pi_{зах} \wedge i_{аг} \wedge H_г > 30 \wedge i_{рв} \wedge \left[\left|V - V_{зад}\right| > 20\right] \wedge \tau > 3;$$

- sign of alarm actuation "Limit deviations from heading and glide path zones" with automatic control:

$$M_7 = \Pi_{зах} \wedge (H_г > 25 \wedge H_г < 100) \wedge i_{рв} \wedge [(\Pi_{зах} \wedge i_{пг}) \vee (i_{сб} \wedge i_{зх} \wedge i_{пк})] \wedge \tau > 3;$$

- sign of disconnection of the ACS channels before reaching the decision-making height due to the unstable operation of the on-course beacon – on-course receiver or glide-scope beacon – glide-scope receiver path:

$$M_8 = \Pi_{зах} \wedge H_г < 33 \wedge i_{рв} \wedge [(M_2 \geq 1 \wedge i_{сп}) \vee (M_4 \geq 1 \wedge i_{сб})] \wedge 3M \geq 1 \wedge \tau > 3,$$

where the component 3M≥1 characterizes the crew's claims to the quality of operation of radio-technical landing equipment included in the report card;

- sign of the plane touching the landing strip:

$$П_{кас} = П_{зах} \wedge Н_{г} < 5 \wedge i_{рв} \wedge \left(n_y > 1.1 \vee k_{n_y} > 6\right),$$

where k_{n_y} is the number of vertical overload changes within 1 s.

The content of signs can be corrected when changing the list of registered parameters, receiving the results of operational tests.

Similar algorithms are drawn up to achieve all the control objectives provided for by the diagnostic model or technical assignment for the development of special mathematical support for automated flight control.

The developed algorithms are the basis for compiling automated control programs and for confirming messages, so they should be drawn up in the form of an output document, convenient for further use. Such a document is a message catalog (Table 2.2), which reflects the tasks to be solved, message numbers, their content, a list of parameters and SC displayed on the graph in order to confirm the reliability.

Table 2.2

Каталог сообщений

Задача контроля в соответствии с диагностической моделью	Номер и текст сообщения	Содержание	
		алгоритм	графика

Reliability is a measure of the objectivity of the reflection of the actual vehicle of the object by the diagnostic results. The methodological component of reliability characterizes the diagnostic model, and the instrumental component characterizes the technical means of the ASC. The required level of methodological and instrumental reliability is ensured by the choice of the optimal list of diagnostic features, tolerances for diagnostic parameters, features and quality indicators, and the accuracy of technical means for measuring, converting and processing diagnostic information. The maximum achievable confidence provided by a particular ACS is called potential confidence. During operation, the characteristics of technical equipment may change, which leads to a decrease in the accuracy of the ACS and the reliability of the diagnosis. Therefore, the real reliability is lower than the potential and, moreover, methodical. The task of specialists in the field of AE diagnostics is to ensure such a level of reliability of the diagnostic results at the stages of development and operation of the automated control system, which creates the necessary conditions for increasing the efficiency of aircraft operation.

There are several methods for determining credibility.

From the standpoint of the general theory of testing statistical hypotheses, the diagnostic result may contain type I and type II errors, sometimes called the supplier's and the customer's risk, respectively (Fig. 2.2). When determining the assessments of the type of vehicle, there is a possibility of obtaining erroneous results. For example, a workable object can be recognized as inoperative (type I error) and vice versa (type II error). The conditional probabilities of the appearance of errors of the first kind $P(C_{12})=\alpha$ and the second kind $P(C_{21})=\beta$ serve as a measure of the unreliability of the ACS operation.

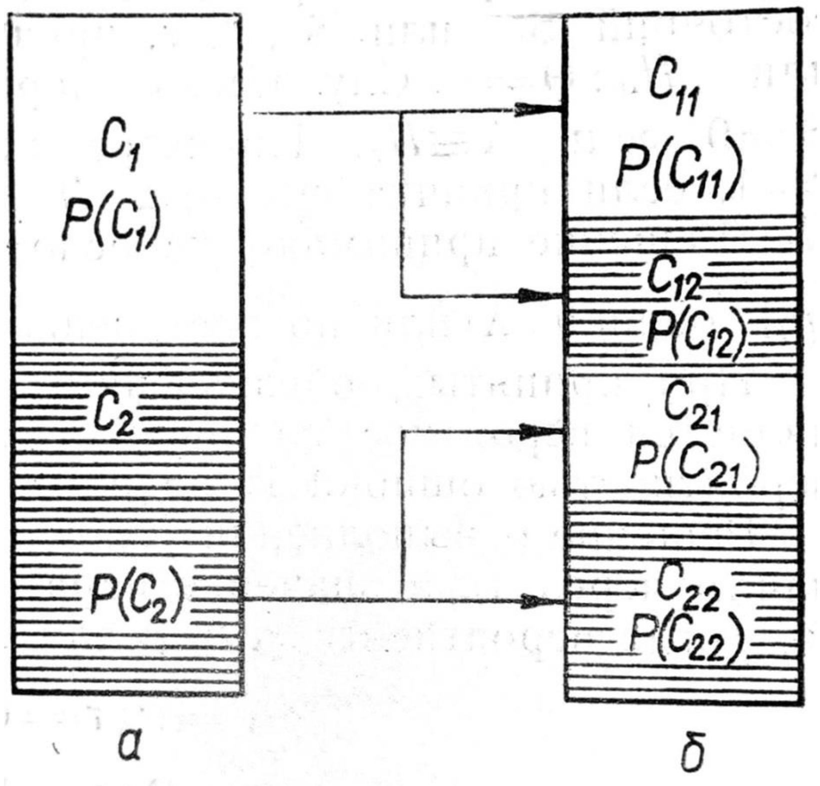


Figure. 2.2. Determination of errors of the I and II kind: a - the actual states of the object; b - assessments of states; C1 - no refusal; C2 - the presence of a refusal; C11, C22 - correct assessments of states; C12 - type I error; C21 - type II error

Errors of the first kind lead to an increase in the cost of the operation process due to the repair and restoration of serviceable equipment, errors of the second kind can lead to a decrease in flight safety and even to the occurrence of emergency situations. Therefore, the ACS must ensure high reliability of the control of dangerous deviations.

The assessment of the reliability of the control results by the magnitudes of errors of the I and II kind is used in solving problems of statistical estimation of controlled parameters and testing statistical hypotheses about the belonging of these parameters to specified intervals. Consider a formalized formulation of the control problem.

Let the state of the system be determined by the n-dimensional vector of parameters $X=(x_1, x_2,...,x_n)$ with random values, two possible states of the system are expressed by the relations:

$$X \in \Pi_x \Rightarrow S_1;$$

$$X \overline{\in} \Pi_x \Rightarrow S_2,$$

where $\Pi_x = \sum_{i=1}^{n} \left[d_{i(\text{н})}, d_{i(\text{в})}\right]$, $d_{i(\text{н})}$, $d_{i(\text{в})}$ - lower and upper the limits of the tolerance for the change in xi,

$$x_i \in \left[d_{i(\text{н})}, d_{i(\text{в})}\right], i = \overline{1, n}. \qquad (2.1)$$

As a result of observation, you can get the values

$$Y = X + \eta,$$

where η is a random noise.

According to the totality of the obtained observations

$$\{y_j\}_1^m, m \geq 1$$

it is necessary to decide whether the system is in one of the states S1 or S2, i.e., to accept one of the hypotheses H_1:θ=1 or H_0:θ=0. Random parameter θ = 1, if $X \in \Pi_x$and θ=0, if $X \overline{\in} \Pi_x$. The adopted solution will be denoted by r (η). Then r = 1 if hypothesis H1 is accepted, and r = 0 if hypothesis H0 is accepted. The decision is made on the basis of the estimate $\hat{X}$ calculated from the observations $\{y_j\}$ or according to the constructed statistical rule.

With the accepted notation, the probability α = P (r = 0 / θ = 1) is the probability of a type I error, and β = P (r = 1 / θ = 0) is the probability of a type II error.

The decision on the fulfillment of condition (2.1) for the component xi will be denoted by ri, and the value of the parameter θ for this component is denoted by θ_i. Then the probabilities α and β for xi are determined by the relations:

$$\alpha_i = P(r_i = 0/\theta_i = 1),$$

$$\beta_i = P(r_i = 1/\theta_i = 0).$$

The solution for the vector X by the solutions r_i for the components x_i is determined by the rule:

$$r = \begin{cases} 1, \ if \ \prod_{i=1}^{n} r_i = 1; \\ 0, \ if \ \prod_{i=1}^{n} r_i = 0. \end{cases} \qquad (2.2)$$

The values of the probabilities α or β for the vector X by the values of α_i, β_i $(i = \overline{1,n})$ in accordance with rule (2.2) are calculated by the formula

$$P\left(\sum_{k=1}^{n} A_k\right) = \sum_{k=1}^{n} P(A_k) - \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} P\left(A_k A_j\right) - \sum_{k=1}^{n-2} \sum_{j=k+1}^{n-1} \sum_{i=j+1}^{n} P\left(A_k A_j A_i\right) - \cdots$$
$$+ (-1)^{n-1} P\left(\prod_{k=1}^{n} A_k\right),$$

for a two-dimensional vector of parameters:

$$P(A_1 + A_2) = P(A_1) + P(A_2) - P(A_1 A_2),$$

for three-dimensional:

$$P(A_1 + A_2 + A_3)$$
$$= P(A_1) + P(A_2) + P(A_3) - [P(A_1 A_2) + P(A_2 A_3) + P(A_1 A_3)]$$
$$+ P(A_1 A_2 A_3)$$

etc.

If the components of the state vector are statistically independent, then

$$P\left(\sum_{k=1}^{n} A_k\right) = \sum_{k=1}^{n} P(A_k).$$

ГОСТ 23564-79 provides for an assessment of the diagnostic error by the value of the probability of the joint occurrence of two events: the controlled object is in the condition i, and as a result of the control - in the condition j. Consider the methodology for determining the joint probability when monitoring continuous parameters. The actual states of a one-dimensional object will be denoted by A_i, when the i-th parameter is good, and $\bar{A}_i$, when it is invalid, estimates of the state values by the control means are B_i and $\bar{B}_i$, respectively. Then the probabilities of joint events for the ith parameter can be written as $P(A_i B_i)$, $P(\bar{A}_i \bar{B}_i)$, $P(\bar{A}_i \bar{B}_i)$ и $P(\bar{A}_i \bar{B}_i)$. These messages make up a complete group of events, so the sum of their probabilities is equal to one:

$$P(A_i B_i) + P(A_i \bar{B}_i) + P(\bar{A}_i B_i) + P(\bar{A}_i \bar{B}_i) = 1.$$

Values $P(\bar{A}_i\bar{B}_i)$ and $P(A_iB_i)$ characterize correct, and $P(A_i\bar{B}_i)$ and $P(\bar{A}_iB_i)$ - incorrect control results. To calculate any of the joint probabilities, it is necessary to know the analytical expressions for the probability densities of the distribution of the parameter x_i and the measurement error η_i. Then, as can be seen from Fig. 2.3:

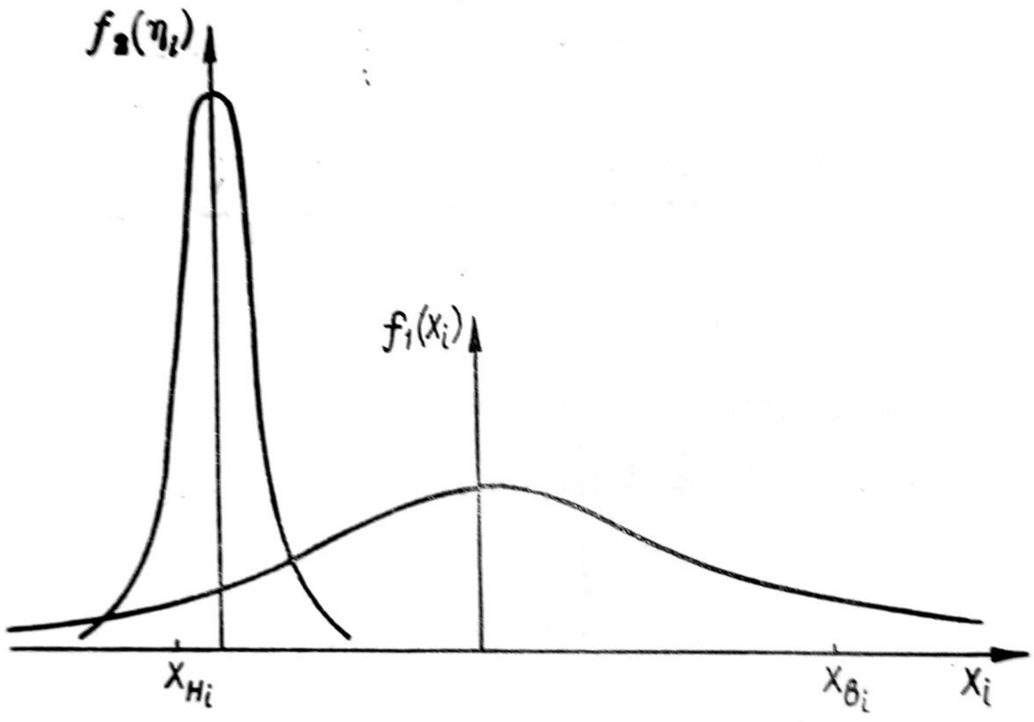


Figure 2.3. Evaluation of the reliability of flight control results

$$(A_iB_i) = \int_{x_i(\text{н})}^{x_i(\text{в})} f_1(x_i)\left[\int_{x_i(\text{н})-x}^{x_i(\text{в})-x} f_2(\eta_i)d\eta_i\right]dx_i;$$

$$(A_i\bar{B}_i) = \int_{x_i(\text{н})}^{x_i(\text{в})} f_1(x_i)\left[\int_{-\infty}^{x_i(\text{н})} f_2(\eta_i)d\eta_i + \int_{x_i(\text{в})}^{\infty} f_2(\eta_i)d\eta_i\right]dx_i;$$

$$P(\bar{A}_iB_i) = \int_{x_i(\text{н})}^{x_i(\text{в})} f_1(x_i)\left[\int_{x_i(\text{н})-x}^{x_i(\text{в})-x} f_2(\eta_i)d\eta_i\right]dx_i$$

$$+ \int_{x_i(\text{в})}^{\infty} f_1(x_i)\left[\int_{x_i(\text{н})}^{x_i(\text{в})} f_2(\eta_i)d\eta_i\right]dx_i; \qquad (2.3)$$

$$P(\bar{A}_i\bar{B}_i) = \int_{x_i(\text{н})}^{x_i(\text{в})} f_1(x_i)\left[\int_{-\infty}^{x_i(\text{н})-x} f_2(\eta_i)d\eta_i + \int_{x_i(\text{в})-x}^{\infty} f_2(\eta_i)d\eta_i\right]dx_i$$
$$+ \int_{x_i(\text{в})}^{-\infty} f_1(x_i)\left[\int_{-\infty}^{x_i(\text{н})} f_2(\eta_i)d\eta_i + \int_{x_i(\text{в})-x}^{\infty} f_2(\eta_i)d\eta_i\right]dx_i;$$

Formulas (2.3) are valid only for symmetric distribution laws of control errors.

From the analysis of formulas (2.3) and Fig. 2.3 it follows that a change in the tolerance band significantly affects the result of the control. Expanding it increases type II errors, but decreases type I errors and vice versa. Therefore, when controlling parameters that significantly affect flight safety, it is advisable to choose stricter tolerances in control algorithms than those established by the NTD. Since errors of the first kind increase due to narrowing of the tolerances, a radical way to increase the reliability is the use of algorithms for testing statistical hypotheses in automated FI processing.

For the normal laws of distribution of parameters and errors of their change, nomograms have been developed that allow calculating the joint probabilities and choosing the tolerance field for the parameter at which the probabilities of an incorrect assessment by the monitoring system of the state of the controlled object are within the specified limits.

In some cases, it is advisable to evaluate the reliability of control results using information theory methods. The reliability of diagnostics from the standpoint of information theory is a measure of the certainty of the state of an object:

$$D = I/H_x,$$

where $I = H_x - H_y$ - the amount of information about the vehicle of the object, obtained as a result of diagnostics; H_x, H_y are the entropy of the condition of the object before and after diagnosis.

Assessment of the state of an object can be carried out according to the value of the quality indicator, which is a continuous function of the parameters. This must be taken into account when determining credibility. A priori and a posteriori entropy of quality indicators before and after control is the mathematical expectation of the function $log[f_x(x)\eta_1]$; $log[f_y(y)\eta_2]$, where η_1, η_2 characterize the degree of accuracy in determining the state of the system and in real systems is greater than zero, and $\eta_1 = \eta_2$ if the a priori and a posteriori estimates of the quality indicator are obtained using the same diagnostic equipment.

For the normal distribution law of the probability density of the quality indicator

$$H(x) = log\left(\frac{\sqrt{2\pi e}}{\eta}\sigma_x\right), H(y) = log\left(\frac{\sqrt{2\pi e}}{\eta}\sigma_y\right).$$

With small deviations σ_x and σ_y and a finite value of η, given that the logarithm is a smooth function, we can assume that $D \approx 1 - \frac{\sigma_x}{\sigma_y}$. For a uniform law

$$H(x) = log\left(\frac{2\sqrt{3}}{\eta}\sigma_x\right), H(y) = log\left(\frac{2\sqrt{3}}{\eta}\sigma_y\right), D \approx 1 - \frac{\sigma_x}{\sigma_y}.$$

Thus, for the most common distribution laws of deviations of the quality indicator, the reliability of diagnosis depends on the ratio of the a posteriori and a priori values of its standard deviations.

2.2. GROUND FLIGHT INFORMATION PROCESSING SYSTEMS

FI processing is carried out in a non-start-stop or start-stop mode.

The non-start-stop principle is based on frame-by-frame processing of information at the rate of its input into a computer. It is used to control the ATC, its elements and connections and control them in flight, since it allows processing information in real and accelerated time and saves computing resources. This principle is also used in the «Луч-74» system. However, the non-start-stop mode imposes significant restrictions on the complexity of FI processing algorithms. The use of the non-start-stop mode in the «Луч-74» system is due to the very limited computational capabilities of the computer.

In the start-stop mode, the FI is preliminarily rewritten from the magnetic medium of the МРСП to the magnetic medium of the computer, which allows in the process of processing to realize prompt access to the entire array of information.

The start-stop mode does not provide control results at the FI input rate. But it allows an unlimited increase in the depth of its processing and the complexity of control algorithms for an individual and a set of flights.

Information processing software can be built on a modular basis with the ability to increase the number of processing modules. It is advisable to develop software modules for individual functional subsystems of the information processing system. The composition of these subsystems is determined as a result of the analysis of formalized tasks solved by those automated control systems that are supposed to be implemented on the selected technical means.

In the «Луч-84» system, the start-stop mode of FI processing is used. Unusual improvement of the СМ-4 type computer («Луч-84» computer) and work on the creation of applied software packages allow us to hope that this system will become the basic one in solving problems of automation of technological processes of aircraft operation.

2.2.1. THE LOGICAL LAYOUT OF THE «ЛУЧ-84» SYSTEM

The experience of using FI accumulated by aviation specialists, the widespread use of various methods of creating redundancy and the principle of "safe failures" in aircraft design, the development of on-board control facilities contributed to the formation of a new concept of aircraft operation, which provides for the widespread use of automated instrumental control for assessing and predicting the quality of ATC functioning, its elements and connections.

Since the end of the 70s, aviation specialists in various fields have been creating and developing diagnostic models of functional control using FI, expanding and streamlining the lists of registered parameters. The technical characteristics of the «Луч-74» system do not allow the implementation of such models, therefore, ASK AT, fuel consumption and other systems using FI are created on the basis of universal computers. The operation and further improvement of such systems are usually associated with the solution of complex technical, organizational and economic issues: the need for priority allocation of computer time on a shared computer, the organization of interaction between aviation specialists and specialists of computer centers, the high cost of computer time for computers, etc. etc.

The need to develop work on automated flight control, the inexpediency of using universal technical means and specialists of information-computing centers for this purpose served as the basis for the development, creation and implementation of the ground-based system for processing parametric information «Луч-84», built on the basis of modern high-performance computer technology.

The Luch-84 ground-based parametric data processing system is based on the UVKS CM 1420 and includes the equipment shown in Fig. 2.10. The main structural elements of the system are racks in which stand-alone complete units (batteries) are placed, which are functionally complete devices with individual power supplies, a forced ventilation system, etc.

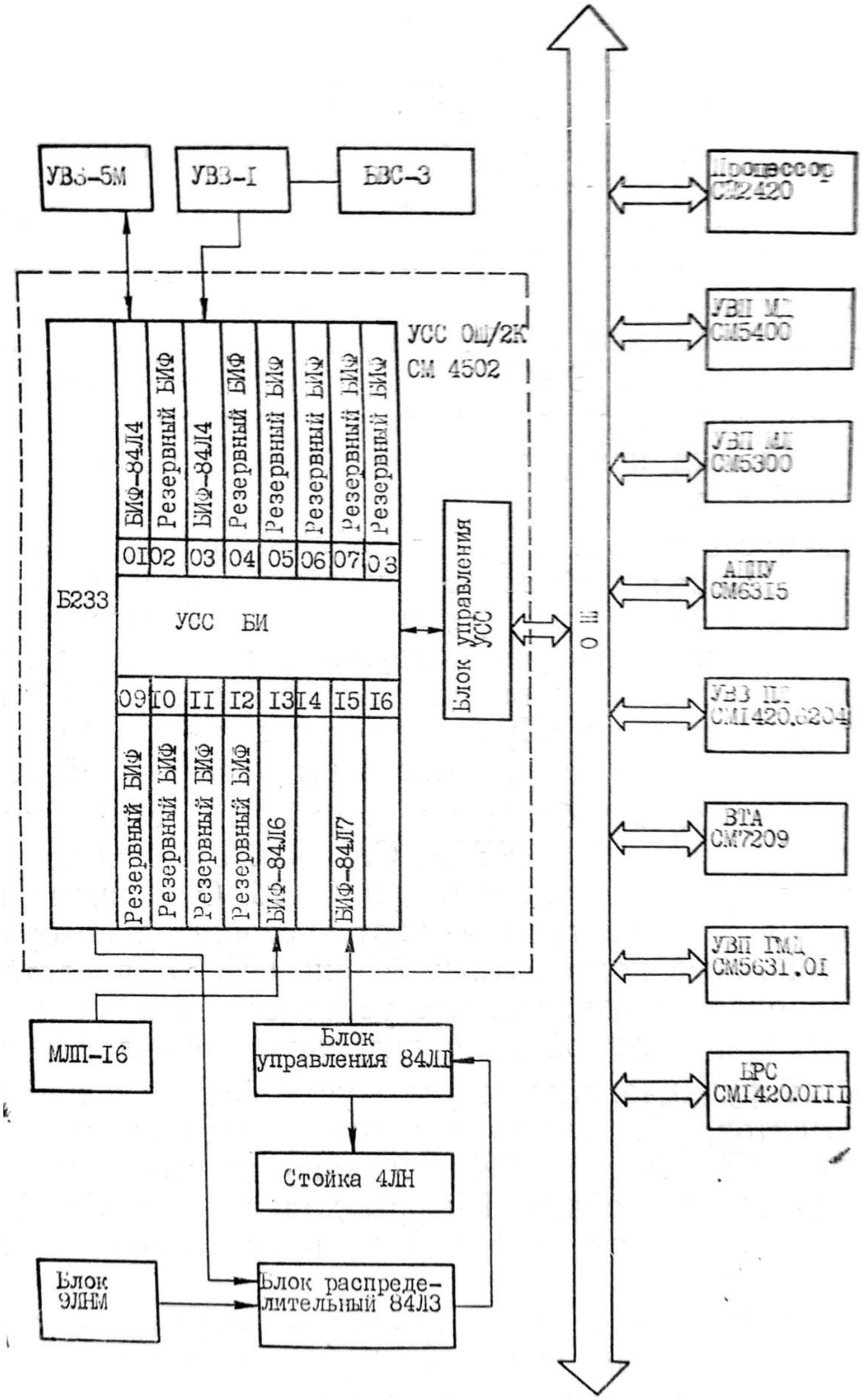


Figure 2.10. Structural diagram of the «Луч-84» system

Separate functional units of devices are made in the form of blocks of elements, combined into assembly blocks within a specific battery. In fig. 2.11

shows the arrangement of devices of the «Луч-84» system in racks. The codes for computer products are indicated in accordance with the classification given in the technical documentation.

<table>
<tr><th>Стойка 1</th><th>Стойка 2</th><th>Стойка 3</th><th>Стойка 4</th><th>Стойка 5</th></tr>
<tr><td rowspan="2">БВС-3</td><td rowspan="2">УВП ГМД СМ5631.01</td><td>Механизм СМ5300.01 НМЛ №1</td><td>Механизм СМ5300.01 НМЛ №2</td><td rowspan="5">Устройство графической регистрации 4ЛН</td></tr>
<tr><td>Контроллер СМ5002.04 НМЛ</td><td>УВВ ПЛ СМ1420.6204</td></tr>
<tr><td rowspan="2">УВЗ-5М</td><td rowspan="3">Процессор СМ2420</td><td>Механизм СМ5400 НМД №1</td><td>Механизм СМ5400 НМД №2</td></tr>
<tr><td>Контроллер СМ1420.5410 НМД</td><td>БУ СМ4502 УСС ОШ/2К</td></tr>
<tr><td>МЛП-16</td><td>БРС СМ1420.0111</td><td>БИ СМ4502 УСС ОШ/24</td></tr>
</table>

Figure 2.11. Layout of the «Луч-84»system

The CM1420 computer has a backbone organization that uses the asynchronous principle of the system functioning using a single backbone. This backbone is called a common bus and ensures the operation of the complex devices at the highest possible speed. Addresses, data and control information are transmitted over 56 OH lines, most of which are bidirectional. The protocol for the exchange of data between devices on the OS is the same for the processor, random access memory with a capacity of 128 K 22-bit words, and system peripherals. Each device (VP cells, processor registers or peripheral devices) is assigned addresses on the OR, which makes it possible to combine the input-output of information with its processing using address instructions of the processor.

The УВКС processor has the CM2420 code and includes: a central processing unit (CPU), a floating point processor (FPP) and a VP. The processor architecture allows for data processing to use the ability to refer to bytes and words, to interpret a 16-bit machine word as an instruction, or as an address, or as an operand.

The CPU executes all the basic instructions of a CMA-type computer, contains virtual addressing controls (memory manager), data paths and a control device.

The information flow control device has a microprogram structure. Circuit control prevails in the communication equipment with the OS and in the memory manager, and microprogram control prevails in the data paths of the CPU and PZ. The principle of microprogram control is to generate signals for processor equipment during sequential reading and decoding from microinstructions written in memory. To combine the microprograms of some instructions, indirect control by the instruction operation code is used by an arithmetic-logical unit, the basis of which is a 16-bit arithmetic-logic device built on the basis of a 4-bit microprocessor section K1804BC1, containing an adder, 16 local memory cells (general-purpose registers) , registers, shifters, data transmission multiplexers and control circuits.

The memory manager performs 18-bit virtual-to-physical address translation and protects the VI from unauthorized access.

The hardware timer allows to implement the time-sharing system operation mode. The use of a special diagnostic instruction in the CPU command system makes it possible to increase its testability and makes the work with software tests of the system more efficient. Special equipment for console emulation allows you to work with a remote console.

The reliability parameters of the CM2420 processor have been increased due to a decrease in the number of means for its implementation and the use of microinstruction control when reading it from memory.

The OSH interface provides direct access to the IOD RAM and exchange under the control of the program with or without the use of an interrupt system. The interrupt system is multi-line, multi-level. Interrupt requests are received at four priority levels 3P7 — ZP4. The request on the ZP7 line has the highest priority. All devices of the «Луч-84» system, including the processor connected to the common bus, have their own priority. The processor has a variable priority (7-0), which is programmatically set in its status word. When more than one device is connected to the same line, the higher priority belongs to the one that is connected closer to the arbiter.

The priority system is two-dimensional and provides each device with an individual priority and software interrupt resolution. Connection of devices of the «Луч-84» system to common bus, taking into account their priorities, is shown in Fig. 2.12.

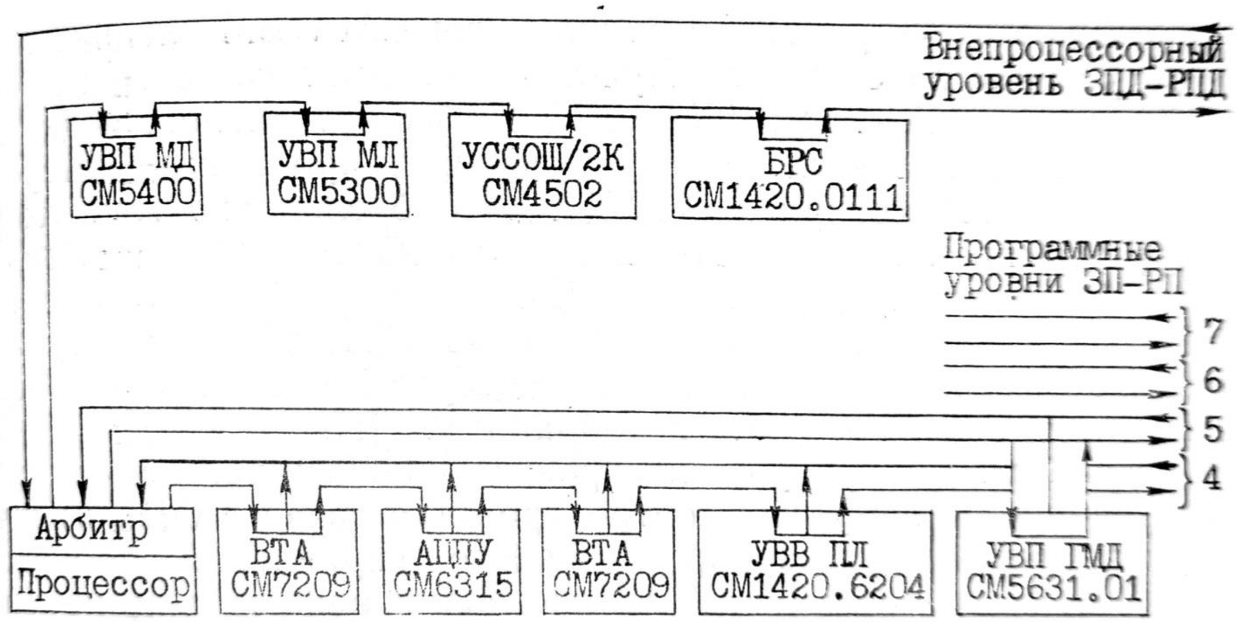


Figure 2.12. Diagram of connecting devices «Луч-84» to common bus

The analysis of requests and the granting of permissions to interrupt the program executed by the processor is carried out by the arbiter. This sets the processor to its lowest priority level, equal to zero. In this case, any device on the OSH can interrupt the program execution. The transition to the interrupt service routine is performed by the processor automatically according to the corresponding interrupt vector, after which the processor priority is set to seven. In this case, none of the devices, except for direct access devices, can interrupt the execution of the program.

Non-processor communication cannot be interrupted by the processor. Queries on this level, in turn, do not interrupt the processor's work, but only suspend it for the duration of data transfer via direct access. In this case, the exchange of data goes without the participation of the processor and the device is provided with quick access to the common bus. Having received permission to exchange, the device can transmit data at a rate equal to the VP cycle time.

The «Луч-84» system provides for the ability to reproduce and enter into the computer complex the FI accumulated by onboard recorders of various types: МСРП-12-96, МСРП-64-2, МСРП-256, МСРП-А, etc. Information recorded on the magnetic tape of flight recorders, has various data presentation formats, which differ from each other in the number of words in the frame, bit width, additional information about the flight, timing signals, etc.

However, the absence in the system of a device capable of reading information from any recorder complicates the PI input equipment. For example, the standard set of playback equipment for the Luch-84 system includes the following specialized devices: БВС-3, УВВ-1, БИФ-84Л4 for МСРП-64-2, МСРП-256, УВЗ-5М, БИФ-84Л4 for МСРП-64М, МСРП-256, МЛП-16, БИФ-84Л6 for МСРП-12-96. The playback units are located in the 84ST1 rack, and the BIF - in the information unit (BI) of the pairing matching device (УСС) ОШ / 2К. The PI playback equipment is connected to the common bus by means of BIFs installed in the USS BI both via the direct access channel and via the program channel (see Fig. 2.10).

In contrast to the devices of the CM computer nomenclature, specialized devices of the «Луч-84» system carry out data exchange via the УСС ОШ/2К and БИФ, which ensure the connection and coordination of these devices with the unified interface of the АСВТ М6000 “coupling 2K”. This is due to the fact that the hardware for reproducing the PI and outputting to the plotter is not adapted for the "common bus" interface.

When creating a file-copy of the flight on the УВПМД, the equipment does not allow efficient use of the system resources when solving a whole range of tasks for processing FI.

The unification of the flight data reproduction equipment, the use of standard controllers for communication with the OR, the presence of a buffer memory and microprocessor control of the process of reading and entering the FI into the УВКС will solve a number of problems in organizing the FI processing procedures in the multiuser modes of operation of the «Луч-84» system.

Table 2.3 shows the comparative characteristics of the «Луч-74» and «Луч-84» systems.

Table 2.3. The main characteristics of automated means of processing FI of the «Луч» type

Specifications	**Express processing device «Луч-74»**	**Ground processing system «Луч-84»**
Type of control computer complex	М6000	СМ1420
Bit width of information words entered for processing	16 binary bits	16 binary bits
Frequency of input information, kHz	3,2/6,4	3,2/6,4
High-speed performance, thousands of operations per 1s	200	700
RAM capacity, kilowords	8	256
Availability of external memory on magnetic tapes and disks	-	Yes
Variety of execution	«Луч-74», «Луч-74» серии 2	«Луч-84-03», «Луч-84-04», «Луч-84-05»
Flight recorder type	МСРП-12-96, МСРП-64-2, МСРП-256 When retrofitted with a block УВОП-2 МСРП-	МСРП-12-96, МСРП-64-2, МСРП-256, МСРП-МВЛ When retrofitted with a block:

	МВЛ	МСРП-А-01, МСРП-А-02, МСРП-64М-5
Processing mode	Automated (primary), express analysis	Automated (primary), express analysis, statistical processing of registered observations of parameters, data of express analysis and results of logical analysis
Using processing results	An objective analysis of the causes of accidents and prerequisites, Objective control and assessment of the piloting technique and the performance of the flight mission Monitoring of failures of monitored aircraft systems	Objective analysis of the causes of accidents and prerequisites, deepening the scientific level of analysis of the causes of accidents and prerequisites and development of measures to prevent them Objective control and techniques of piloting and performance of a flight task, development of methods for objective control of crew actions, improvement of piloting techniques and development of measures to timely prevent violations of piloting techniques Monitoring of failures of monitored aircraft systems, objective monitoring and assessment of vehicles of individual aircraft systems, monitoring compliance with optimal aircraft flight modes and operating modes of aircraft aggregates and systems

Operating system availability	No	ДЕМОС, РАФОС
Possibility of simultaneous processing of FI of several flights	No	Yes
Express analysis performance	Up to 5 flights per hour	1.5-3 times higher than that of «Луч-74»

As part of the «Луч-84»system, you can use computers that are information and software compatible with the CM1420, but have a much larger storage capacity, for example, CM1425 and CM1700. This will significantly expand the range of use of the system for solving problems of information support for aircraft operation.

2.2.2. FUNCTIONAL SUBSYSTEMS FOR PROCESSING FLIGHT INFORMATION IN THE «ЛУЧ-84» SYSTEM

The technical characteristics of the «Луч-84» complex make it possible to use it to solve a wide range of flight control tasks and control the operation of ATC using PI. It can be used to implement ACS "Control of crew actions", "Control of aircraft vehicles", "Fuel consumption control", "Flight reliability", etc. The users, operators, and often the designers of these ACS are specialists from aviation technical bases of enterprises. Therefore, the technical means, information, mathematics and software of the «Луч-84» system must have a high level of operational adaptability.

One of the main indicators of the operational adaptability of the system is the unification of the mathematical and software used by the automated control systems implemented on it. Analysis of information processing processes allows us to single out a number of functional subsystems common to all these ACS (Fig. 2.13).

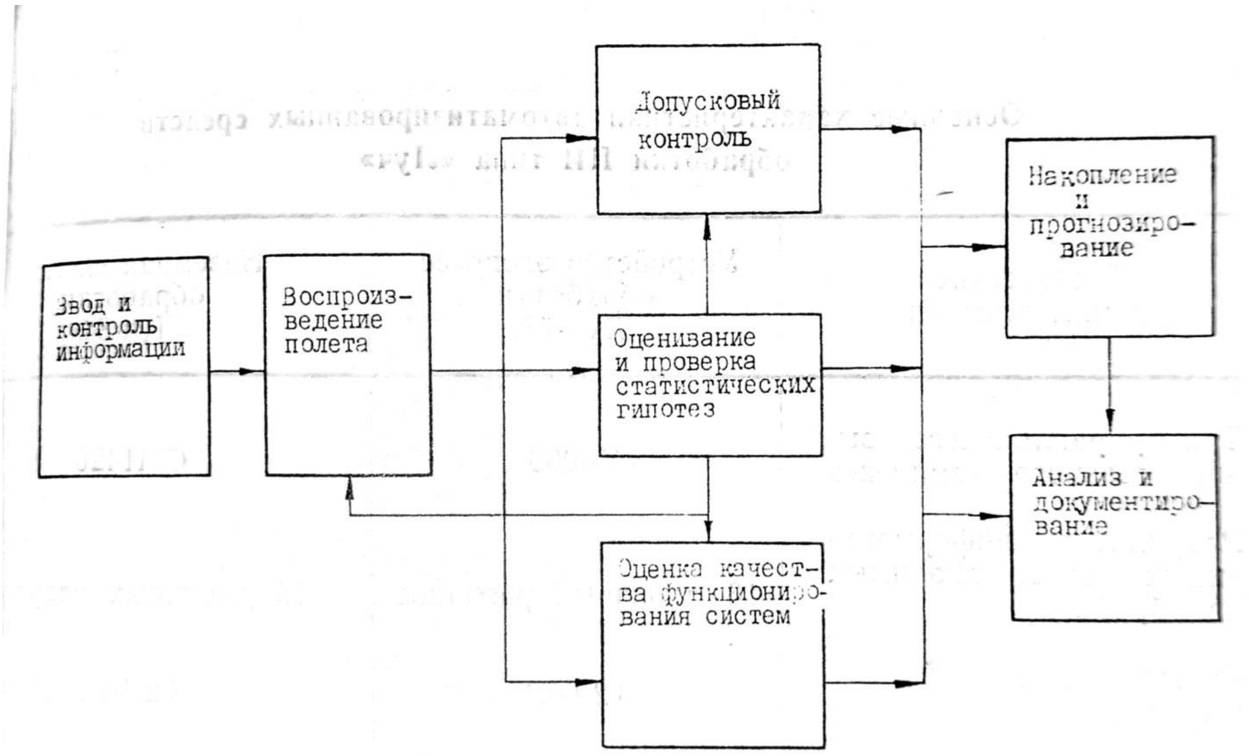


Figure 2.13. Functional subsystems for FI processing

In the functional subsystem "Input and control of information", FI is entered from the on-board recorder carrier and recorded on the machine carrier. In the process of entering the information is filtered, bad frames and parameters are restored. In addition, when overwriting on a machine medium, the information is compressed and formatted. Compaction consists mainly in the compression of flight sections that are uninformative for the tasks being solved. In the process of formatting, the structuring of data is carried out, which provides and accelerates access to information during its processing.

The "Flight replay" subsystem determines the flight stages, controlled states and various situations arising in flight. In this subsystem, the code values of the parameters are converted into physical ones, the signs of the stages and controlled situations, the values of diagnostic signs at the controlled points are determined.

Algorithms of tolerance control, implemented in the functional subsystem of tolerance control, are widely used to solve problems of operational assessment of the crew's activities and the quality of systems functioning in a single flight. In this case, both the measured values of the monitored parameters and their estimates can be used. The calculation of the parameter estimates is necessary if the tolerance control by the measured values does not provide the specified level of confidence.

The estimation of parameters is carried out in the subsystem “Estimation of parameters and testing of statistical hypotheses” by methods of approximation and interpolation, methods of situation analysis, as well as using mathematical statistics associated with control. To implement the algorithms for tolerance control and flight reproduction in the subsystem, an optimal estimation of the parameters is performed based on the values recorded during the flight. The problems of determining the state of controlled systems are often formulated as problems of testing various statistical hypotheses, which are solved in a subsystem. In the same subsystem, the type is determined and the parameters of the distributions of the controlled quantities are calculated. The input information of the subsystem is the values and samples of values obtained from the "Flight replay" subsystem. The normative base is made up of reference samples and a set of decision rules.

The subsystem "Assessment of the quality of the functioning of systems" is designed to solve quality control problems based on the calculation of generalized quality indicators and statistical rules, the implementation of algorithms for assessing resource development and operating time.

Information from the "Playback" subsystem in the form of parameter values and from the "Estimation and testing of statistical hypotheses" subsystem in the form of parameter estimates and other statistical characteristics goes to the "Accumulation and forecasting" and "Analysis and documentation" subsystems.

The subsystem "Accumulation and forecasting" is designed to solve long-term control problems associated with planning operation processes, problems of accumulating observation results, control and decision-making for the formation and storage of samples of parameter values used as an information base when solving forecasting problems, to determine trends in parameters , moments of parameters going beyond tolerances, predicting the quality of systems functioning, etc.

Subsystem "Analysis and Documentation" is designed to obtain the necessary forms of output documents with the results of processing. It ensures the receipt of processing results in the required form, the creation and maintenance of a catalog of layouts of output documents, the generation and delivery of output documents of various structures to БГР, АЦПУ, magnetic tapes and disks.

The list of the main functional subsystems of automated processing of FI, methods and algorithms used in their implementation is given in table. 2.4. Their implementation in the general and special software «Луч-84» facilitates the design, revision and operation of the automated control system.

Table 2.4. Functional subsystems, methods and algorithms for processing FI

Functional subsystems	**Methods and algorithms used**
Input and control of information	Digital filtering, structuring
Flight replay	Interpolation and approximation, situational analysis
Acceptance control	Interval and point estimation, logical algorithms
Estimating and testing statistical hypotheses	Bayesian method, modified method of maximum posterior probability, methods of stochastic approximation
Assessment of the quality of systems functioning	Functional analysis, optimization algorithms
Accumulation and forecasting	Regression Models, Moving Basis Methods, Stochastic Approximation Methods
Analysis and documentation	Factorial, regression and cluster analysis

Information processing in such a system is carried out both by system software and application programs. Of the system software, programs are used that are part of operating systems (OS), as well as database management systems (DBMS).

OS is a common (system) part of the computer software. It is intended for planning and organizing the processing process in accordance with applied programs, for managing input, output, distribution of information flows and computer resources, as well as for solving service problems. The main indicators of the OS efficiency in solving flight control problems are the level of automation of control of computational processes, its maintenance of a time-sharing computation mode, multi-user mode, and real-time mode. The structural elements of the operating system are the control system, system programs and programming systems.

A number of operating systems have been developed for the CM4 computer and its family, the greatest distribution of which was received by the OC PB (RSX), РАФОС (RT) and ДЕМОС (UNIX).

The RT OS family of real-time operating systems provides multi-user work with the terminal simultaneously with the execution of programs in real time. It has tools for protecting programs and data in multi-user mode, and allows you to organize the solution of tasks in batch mode. RT OS has a developed file system and can be used in conjunction with various DBMS. This OS has received the greatest application in solving problems of technological process control. Its further development is a multifunctional OS with virtual memory (MOS VP) of a 32-bit family of minicomputers (for example, CM1700), compatible with CM1420 in terms of information.

The set of CMO «Луч-84» can function in the environment of the OS РАФОС-2, the core of which is a monitor that provides the organization of input-output, maintaining the file system on external devices, dialogue with the operator, diagnosing errors and solving a number of other tasks. The structure of РАФОС-2 includes single-task (SJ) and multi-user (TS) monitors, as well as sets of drivers for external devices in single-task and multi-user modes, general-purpose system programs, text editors. All information (programs, data, texts) is placed in files. Files can be organized on direct access devices (tape drives) and sequential access devices (tape drives and punched tape drives). Information is allocated and transmitted in logical blocks of 512 bytes.

OS with separation of functions РАФОС has fewer capabilities in comparison with OS RT, however, it implements them at the expense of minimal resource consumption. It provides a multi-user mode of operation with authorization of access to devices and files.

The advantages of the РАФОС system are its simplicity, the ability to use it on a computer with little computing power, the fastest response to interrupts for input-output operations in single-user mode. The latter advantage is very significant for the "Input and control of information" and "Output and documentation" subsystems.

The most promising and rapidly progressing at present is the interactive unified mobile OS ДЕМОС, which is based on the following principles:

- portability to computers of many types without changing the language of user interaction with the system;
- the possibility of using in user programs a single set of system calls that ensure the creation of programs invariant to the type of computer;
- unified file structure;
- the presence of powerful programming tools, such as pipelines, program channels, interpreter language, that increase the productivity of the programmer.

Under the control of ДЕМОС, programming systems in the languages C, FORTRAN, PASKAL, BASIC, etc. operate. The hierarchical tree structure of processes and file system ensures high efficiency of the ДЕМОС OS while simultaneously serving a large number of users.

The use of non-start-stop specialized air-blast devices used for the implementation of the "Information Input and Control" and "Analysis and Documentation" subsystems and having a low information transfer rate significantly reduces the performance of the AECS when using any OS, and especially ДЕМОС, which has a slow response to interruptions compared to РАФОС and OS RV. Therefore, it is advisable to enter PI into a computer from the onboard carrier and output the test results to paper in an asynchronous mode, using microprocessors as buffers.

Thus, OS RV, РАФОС and ДЕМОС systems can be used for automated processing of FI. The advantage of ДЕМОС over other operating systems is its orientation towards use in many modern and promising mini-computers and ES computers of the «Ряд-2» series. This advantage of OS ДЕМОС is manifested in the continuity of special flight control software when replacing the computer type in «Луч» systems and in the information compatibility of databases when creating computer networks for solving a wide range of ACS tasks for aircraft operation.

CONCLUSIONS TO CHAPTER 2

1. The developed algorithms are the basis for compiling automated control programs and for confirming messages
2. For the most frequent distribution laws of deviations of the quality indicator, the reliability of diagnosis depends on the ratio of the a posteriori and a priori values of its standard deviations.
3. The most common way to organize control programs based on frame-by-frame data processing is to build them in the form of sequential checking of conditions
4. Unification of the flight data reproduction equipment, the use of standard controllers for communication with the OS, the presence of a buffer memory and microprocessor control of the process of reading and entering FI into the UVKS will solve a number of problems in organizing FI processing procedures in multi-user modes of the «Луч-84» system.

CHAPTER 3. AGNESI FUNCTION AND ITS APPLICATION FOR THE STUDY OF RESONANCE PROCESSES IN AVIATION

3.1. CHECKING THE ADEQUACY OF THE STRUCTURAL AND ANALYTICAL MODEL BASED ON THE ANALYSIS OF FLIGHT INFORMATION

Typical aviation accidents, in which the phenomenon of factor resonance in the phases of development of emergency or catastrophic situations in flight, manifests itself especially clearly and clearly, are associated with such a development of catastrophic situations when an aircraft finds itself in a flight or non-flight position at angles of attack [8,9].

Using the analytical database of the Interstate Aviation Committee (IAC), we chose for the analysis of the Tu-154M accident, with access to supercritical angles of attack α, which occurred near the Irkutsk airport on 07/03/2001. The IAC data on this accident were published in special literature, including decoding of flight recorders, voice recorders and operational analysis of the actions of crew members [10,11].

When checking the adequacy of the proposed structural-analytical model, the stages of analysis of the AP 03.07.2001 were developed, including 9 stages of research (Fig. 3.1):

- grouping of IAC data, their generalization and analysis;
- compilation of a list of operating factors according to the operational analysis of the IAC of an aviation accident;
- determination of the duration of the normal phase of the flight, the moment of transition to the catastrophic phase and the duration of the catastrophic phase of the flight (qualitative assessment of the flight in phases);
- determination of the initial moments of the emergence of an emergency (catastrophic) situation and presentation of the development phase of such a situation as a zone (region) of factor resonance;

- construction of a cyclogram of the action of factors (Fig. 3.2);
- analysis of the zone of development of a catastrophic situation as a zone of factor resonance by methods of processing non-stationary random processes (in terms of a set of realizations);
- determination of the type of resonance curve in the phase of development of a catastrophic situation;
- approximation of the obtained resonance curve by generalized Agnesi functions;
- Evaluation of the properties and regularities of the manifestation of PFR in a given AA according to a mathematical model (by the Agnesi functions);
- Creation of a list of recommendations for combating nuclear magnetic resonance in flights and in the organization of flight operations.

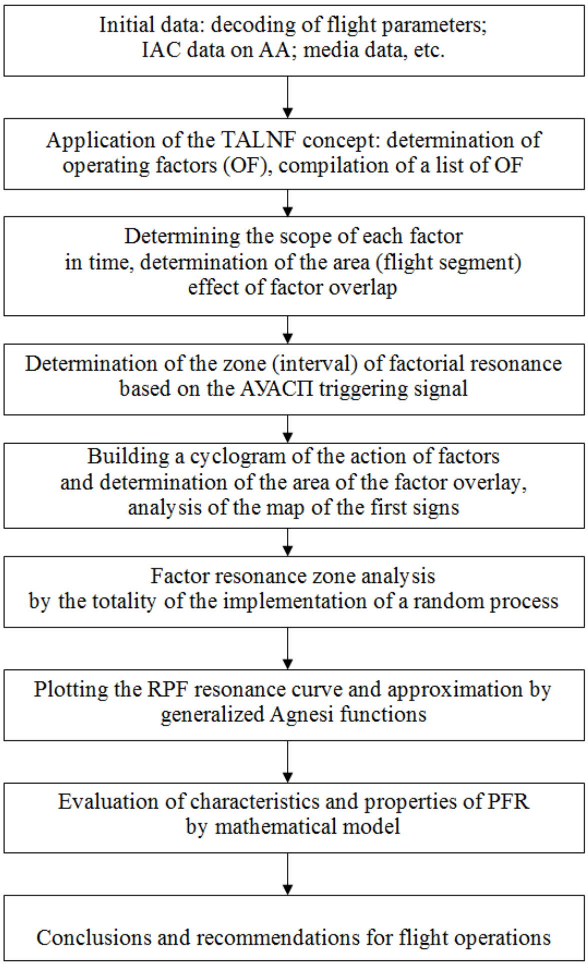


Figure 3.1. Stages of AA analysis of the Ty-154M 03.07.2001 in the area of Irkutsk airport according to the structural and analytical model

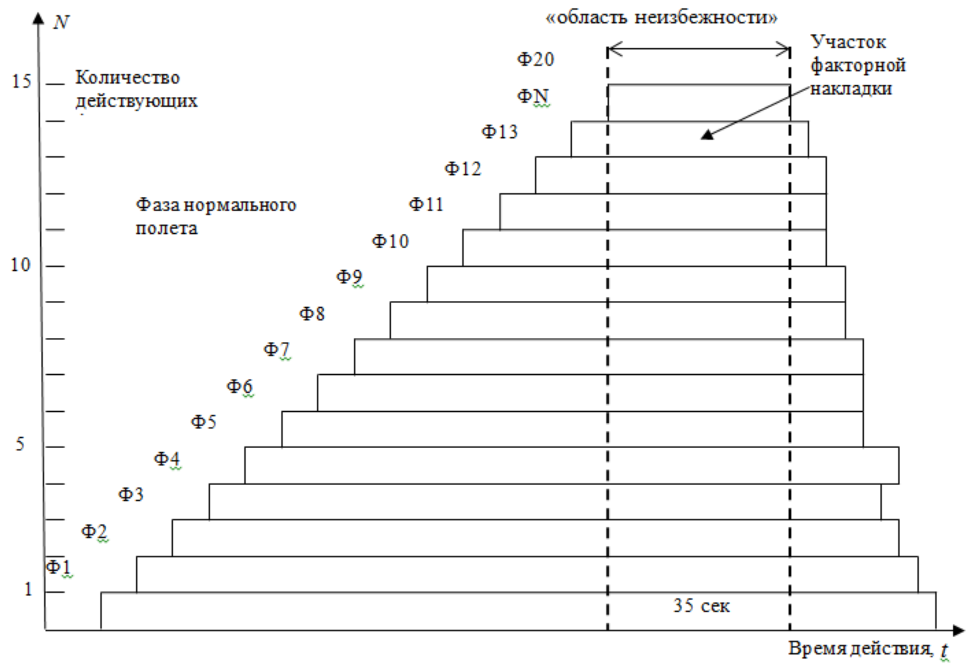


Figure 3.2. Cyclogram of the action of factors and determination of the site of the factor overlays ("factorial cyclogram of AA") - AA 03.07.2001

Based on the grouping of IAC data, a list of factors affecting the crew of Ty-154M 03.07.2001 was compiled (Table 3.1).

Table 3.1. Determination of the acting factors in the AA 03.07.2001 according to the operational analysis of the IAC

#	Factors	Manifestation factor
1	Rush	The factor of haste and intense in-cab negotiations
2	Psycho-emotional stress	Monotonous increases in psychoemotional (PE) stress
3	Damping speed	«Полностью вываливай и гаси скорость, гаси скорость»
4	Failure to inform the crew	Navigator's work without informing the crew
5	The reversal factor	Information complexities, technological elements
6	Engine mode	Delayed and insufficient increase in engine operating mode
7	АУАСП factor	Unexpected alarms
8	A sharp increase in psycho-	After АУАСП is triggered by the aircraft

	emotional stress	commander
9	Optimal AP and roll increase	Roll angle from –20 to –30 °, –44 and to –48 °
10	Intensive roll factor	2nd pilot: «Стоп, стоп! Куда, куда!»
11	Enhanced Reflex Factor	Energetic deviations of the steering wheel to the left-right to the maximum value
12	Aircraft attitude loss factor	Difficulty in determining large roll and pitch angles according to ПКП-1 ТУ-154
13	Cloud factor	«Вот вошли в облачность, Юра»
14	Repetition of enhanced reflexes	Captain: with left roll, deviating to the left
15	Aileron Shift Factor	Two aileron shifts with large deflection amplitudes
16	Stall factor	With a left roll of -45 °, the 2nd pilot abruptly deflected the control wheel "towards himself", the elevator deviated by an angle of - 24 ° for carbing (all the way)
17	Disruption Factor in Carriage	The emergence and development of an emergency due to emotional stress of the crew members with a rapid development of events
18	Factors contributing to	Decrease in indicated speed, delayed and insufficient increase in engine operating mode
19	General stress factor	Over-the-limit level of PE voltage
20	The factor of surprise and transience of a catastrophic situation	The duration of the normal flight phase is 21 minutes, the duration of the catastrophic flight phase is 35 seconds. The transience of the catastrophic phase is 36 times greater than the normal phase.

Let us consider the features of processing the phase of development of a catastrophic situation as an area of inevitability of factorial resonance.

The main signs of the phenomenon of factorial resonance:

1) according to the classical definition of the resonance process, there must be a qualitative or quantitative increase in the amplitude of oscillations;

2) an increase in the frequency of oscillations of parameters in the region of inevitability in comparison with the region of normal flight;

3) interaction of factors (at least 20 according to ICAO).

From the standpoint of the theory of probability and the theory of random processes, the inevitability area, as a flight segment during an accident, is an extremely complex random process, i.e. non-stationary and non-ergodic process.

When processing flight information using onboard means of objective control, methods are usually used that, in one way or another, are based on the recognition of the fact that the processes under investigation are stationary. Therefore, for example, in express analysis, processing is carried out according to the analytics of individual, functionally important time moments (the moment of entering the glide path, the moment of passing the DPRM, BPRM, the moment of touching the runway, etc.).

It should be noted that from the standpoint of the classical control theory, especially automation, the flight processes in the aircraft should be called unstable. However, the theory of control in automation does not study the nature of such processes, studying the indicators and criteria of stable processes.

With a polyfactorial polyparametric analysis of the area of inevitability of accidents, such an analysis is no longer enough, since the nature of the ongoing processes changes qualitatively when an AP occurs - from stationary (even sometimes ergodic) they become purely random, i.e. non-stationary processes.

Data processing for such processes is fundamentally different in comparison with stationary processes - they are evaluated by a set of realizations, i.e. along the sections of a random process.

In aviation practice, the processing of objective flight control data, we do such processing for the first time. The implementation of a random process is a change in one parameter. Therefore, for the first time, not the processing of each parameter separately (as, for example, in express analysis) is used, but along the sections of a random process at once of all its implementations [12]. The processing results are shown in table. 3.2.

*Table 2.3 Index processing of a nonstationary stochastic process in the "area of inevitability" for the AA **АП Ту-154М RA-85845 03.07.2001***

t Parameter number	Resonance zone (35 sec)						
	7:45	7:50	7:55	08:00	08:05	08:10	08:15
1	10	9	7	20	1	27	5
2	7	6	9	30	30	20	15
3	15	18	6	30	15	10	15
4	25	18	40	15	5	25	20
5	20	13	40	35	5	0	15
6	34	30	16	30	15	13	5
7	9	18	21	30	25	5	25
8	10	7	16	0	32	30	30
9	15	27	25	30	30	5	0
$m_x(t)$	16,11	16,22	20	24,44	17,55	15	13,48

To obtain a qualitative and quantitative picture of factorial resonance, for the first time not the calibration of parameters is used, but the method of index processing of a non-stationary random process in the “region of inevitability” according to Fig. 3.3.

In the theory of statistics, an index is understood as a relative number obtained by comparing the levels of complex indicators to compare them in time, space, or for comparison with the initial data. All parameters are measured in waveform millimeters. Parameters 1–9 (Table 3.1) are taken from the oscillogram according to the MAC.

The indices characterize the change in the level of heterogeneous parameters of the population, which represent unity, i.e. a set of parameters that are heterogeneous in their dimensions. Since direct unification (addition) of data is impossible due to incommensurability, the problem of commensuration of dissimilar elements arises, the solution of which is achieved using index processing.

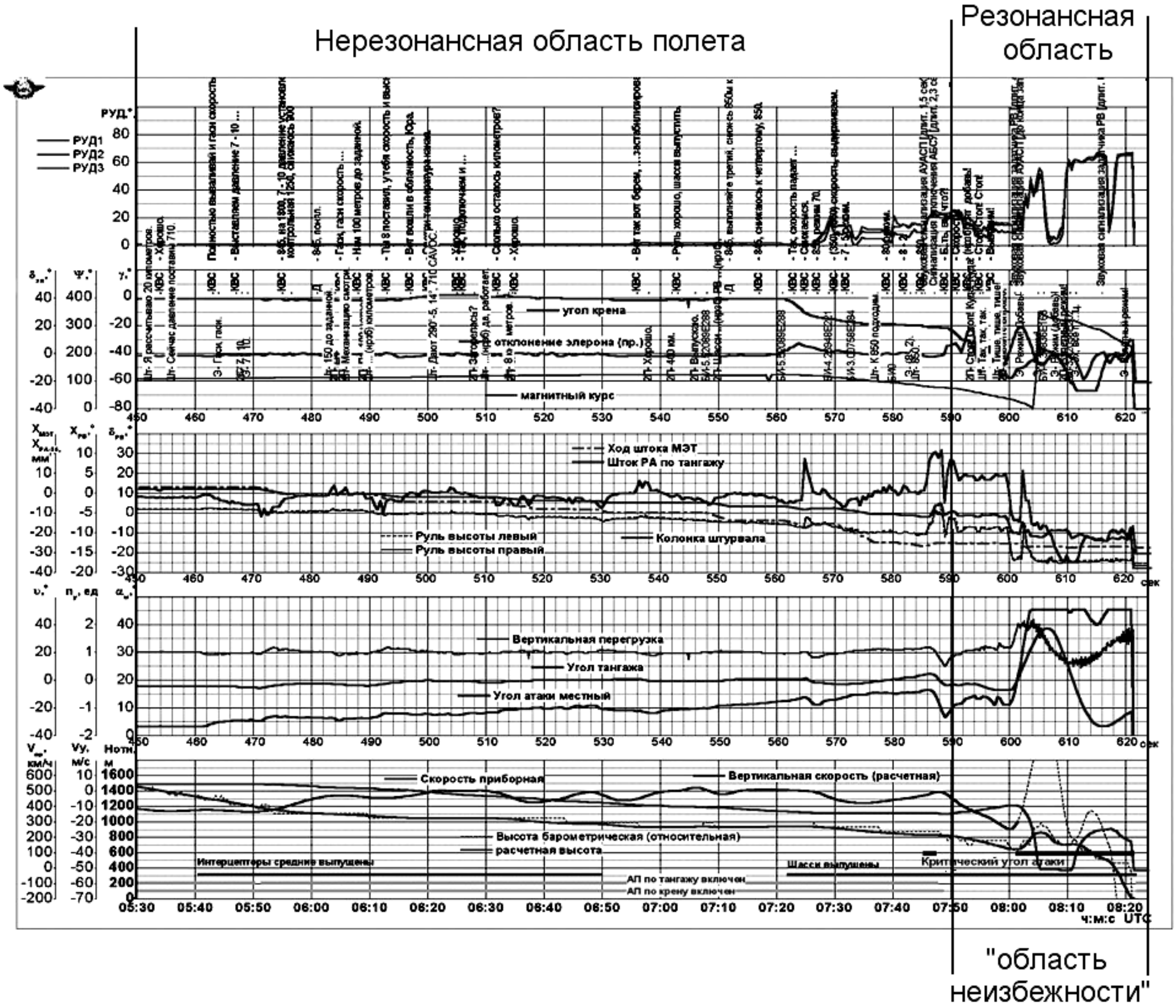


Figure 3.3. Flight parameters of Ty-154M RA-85845 (03.07.2001)

From fig. 3.3 it follows that when applying the methodology of Yu.A. Metropol'skiy and N.N. Bogolyubov to dividing the research area into resonant and nonresonant, we distinguish the nonresonant flight area and the resonant area as the “inevitability area” of the occurrence of a catastrophic situation (at the beginning of the AUASP actuation). It can also be seen that the selected ones differ qualitatively from each other by the change in the amplitude of the deviations of the parameters - in the area of a catastrophic situation, as the zone of factorial resonance, there is a qualitative increase in the amplitude of the deviations of the parameters, which is typical for any resonant process.

In fig. 3.4 shows the dependence of the change in parameters (throttle, roll angle, aileron deflection, RA rod in pitch, steering wheel column, vertical overload, pitch angle, vertical speed, barometric altitude) according to the average data in Table 3.1 ($\Delta t = 5$ ñåê). It follows from the figure that the index changes in the flight parameters in the "inevitable region" are resonant in nature and have a corresponding peak of the deviation and the characteristic shape of the classical resonance curve.

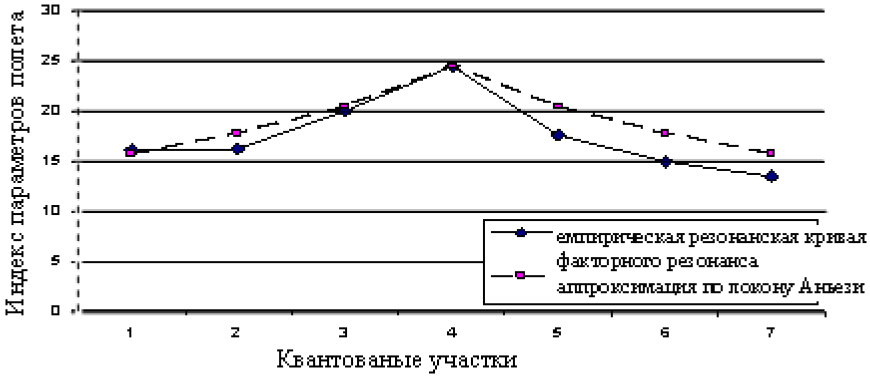


Figure 3.4. Type of polyparametric RC at the last phase of AA (at the "point of inevitability")

For the first time, for the analysis of the resonance region, a method of index processing of flight parameters, as a non-stationary random precession in the "region of inevitability" of an aviation accident, has been proposed.

The performed approximation by the Agnesi function showed that the index deviations of the parameters can also be represented by the following function:

$$\mathrm{I}_{ïï},\ F(\Delta t_i) = \frac{\mathrm{I}^3_{ïï\,\max}}{\mathrm{I}^2_{ïï\,\max} + \Delta t_i^{\,2}} ,$$

where $\mathrm{I}_{ïï\,\max} = 24$, $\Delta\ t_i = 1{,}2{,}3...7$, $\mathrm{I}_{пп}$ - index of deviations of flight parameters;

$\mathrm{I}_{пп\,\max}$ - maximum index value of flight parameters; □t - quantized areas.

The approximation results are shown in Fig. 3.5.

In the classical description of resonance curves, in addition to temporal quantization along the abscissa axis (for example, when studying resonance processes in quantum physics with the behavior of resonance spins), the abscissa axis is most often plotted on a frequency scale so that the moments of coincidence of natural frequencies with external frequencies are exponentially visible (for example, when the study of resonances in radio engineering, electrical engineering).

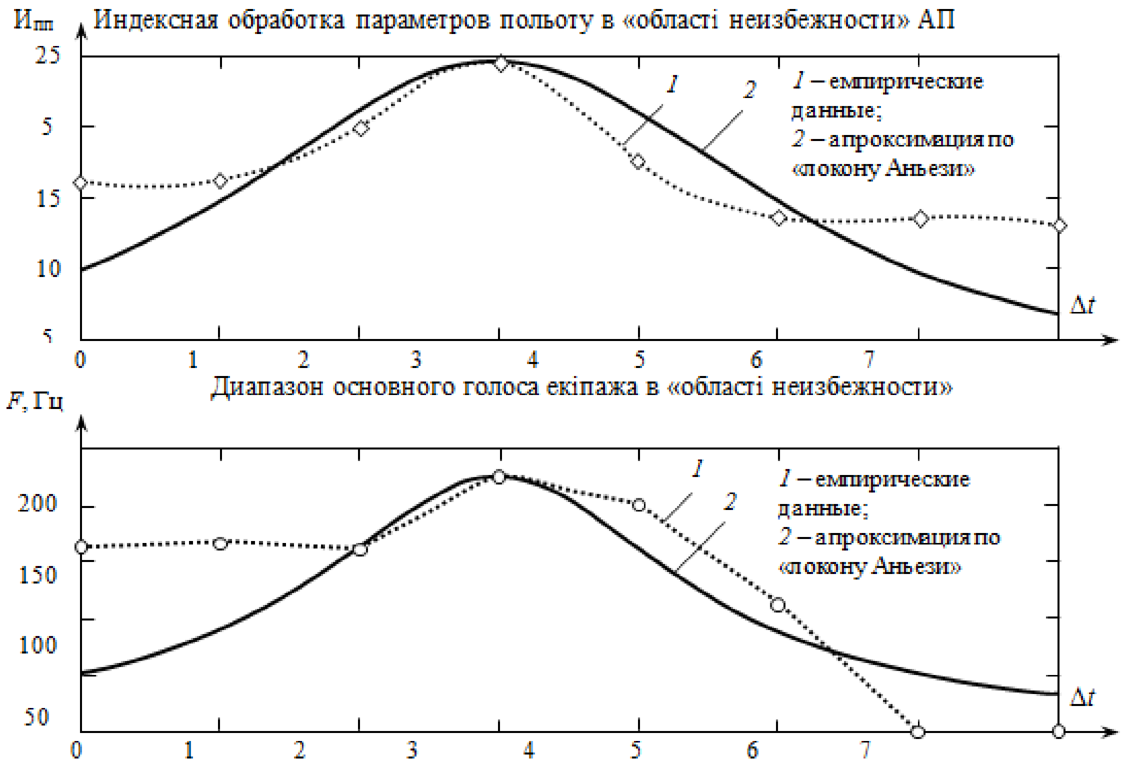


Figure 3.5. Index processing of flight parameters in the "area of inevitability" of the aircraft Ty-154M (03.07.2001)

With factorial resonance, as a more complex form of resonance processes, the picture is more complicated, since both the natural frequencies of the human operator and the frequency spectra of the group of acting factors change simultaneously. At a certain ratio between them, a sharp factorial increase in the amplitude of deviations of all parameters occurs, and an increase in the natural frequencies of the human operator also occurs as one of the conditions for the occurrence of the phenomenon of factorial resonance. Table 3.3 and 3.4 show the frequency characteristics of the phases of normal flight and the phase of development of a catastrophic situation in AA 03.07.01.

The tables show that the phases of a normal and a catastrophic situation have a qualitatively different frequency range and the average frequency of a phase of a catastrophic situation exceeds the average frequency of a normal flight phase by 1.53 times (the peak frequency is 1.73 times). It should also be noted that the frequency range of the catastrophic phase of the flight is 160–225 Hz and coincides with the so-called critical vibration frequency range, equal to 35–250 Hz [13].

Table 3.3. Frequency characteristics of the main tone of the voice during the negotiations of the crew members in the phase of normal flight and a catastrophic situation

Flight time	The frequency of the main tone of the voice, Hz	Arithmetic mean data
17:05:30 – 17:07:40	Phase of normal flight: 119, 110 , 111, 110, 122, 120, 121, 121, 118, 120, 117, 130, 122, 115, 117, 120, 121	118 Гц
17:07:50 – 17:08:20	Phase of catastrophic situation: 164, 162, 162, 165, 160, 225, 200, 212	181 Гц

Note: 1. Max frequency of fundamental tone of voice during negotiations - 225 Hz.

2. In the "area of inevitability" there is a sharp increase in the natural frequencies of the tone of the voice of the crew members due to the action of factor overlays.

Table 3.4.

Quantization frequency, Δt	1	2	3	4	5	6	7	8	9
Main voice frequency, Hz	164	162	162	165	160	225	200	212	–

It can be seen that with factorial resonance the flight crew falls into the most dangerous region of critical frequencies, then the so-called "vibration disease" develops intensively. This once again emphasizes that NFR is a very complex type of resonant phenomena leading to the development of emergency or catastrophic situations. Thus, the frequency condition for the occurrence of factorial resonance is that the frequency of the main tone of the crew's voice falls into the critical vibration range, which is very dangerous for the activities of a human operator in special flight conditions.

3.2. TYPES OF RESONANCES

To substantiate the given name of the discovered phenomenon - "polyparametric factorial resonance", it is necessary to consider the known types of resonance, to make sure that they have a general character of resonance curves.

Resonance is a phenomenon of a more or less sharp increase in the amplitude of forced oscillations in an oscillatory system when the frequency of an external force approaches the frequency of any of the natural oscillations of a given oscillatory system [1].

We will consider the following types of resonance: mechanical, electrical, paramagnetic, parametric, monoparametric and polyparametric factor resonance from the point of view of generality of laws.

Mechanical resonance occurs at frequencies of vibration of the driving force close to the frequency of natural vibrations and begins to exceed the static displacement many times:

$$A_{рез} \approx X_{0cmam} \cdot \frac{\omega_0}{2\alpha}$$

Where $A_{рез}$ is the amplitude of forced oscillations;

ω_0 - frequency of natural vibrations;

α - attenuation coefficient,

$$\alpha = \frac{r}{2m}$$

where r is the coefficient of friction, m is the mass.

The greater the damping coefficient, the smaller the steady-state amplitude of the forced oscillations. The resonance curve (RC) of this type of resonance is typical.

Electrical resonance - the amplitude of forced current I_0 oscillations increases sharply when $\boldsymbol{\omega \to \omega_0 = \frac{1}{2\pi\sqrt{LC}}}$, where

L, C - inductance and capacitance of the circuit.

Resonant amplitude: $\boldsymbol{\omega \to \omega_0 = \frac{1}{2\pi\sqrt{LC}}}$ where

$\boldsymbol{\xi_0 -}$ amplitude of voltage fluctuations;

R - active resistance of the circuit.

The greater the active resistance of the circuit, the lower the resonant amplitude of the current. The RC of this type of resonance is the same as that of mechanical resonance.

Paramagnetic resonance - when passing through a paramagnetic body placed in a constant magnetic field of radio waves, when the frequency of the waves coincides with the natural frequency of the paramagnet, the phenomenon of resonance will occur and an intense absorption of the energy of the incident wave will occur.

Parametric resonance is a resonance that occurs as a result of periodic changes in one of the parameters of the oscillatory system [2].

Monoparametric resonance - in the presence of small oscillations of the system, a periodic change in any parameter can lead to a significant increase in oscillations at an appropriate frequency.

Polyparametric factor resonance is a previously little-known phenomenon of factor resonance, which consists in the fact that when a group of interacting factors more than 4-5 ("factor overlap") appears in flight, the amplitude of the main flight parameters (roll, heading, pitch, etc.) increases. , which sharply complicates the piloting of the aircraft by the crew.

The analysis of the above definitions of the types of resonance allows us to single out two essential points in the very concept of “resonance”. This is, first of all, the external influence on the object and, second, the response of the object to the influence with a certain correspondence of the parameters of the external influence and the object. And the main thing is that all types of resonance have the same RC quality.

Currently, new types of resonant phenomena are the subject of scientific discoveries (Figure 3.6).

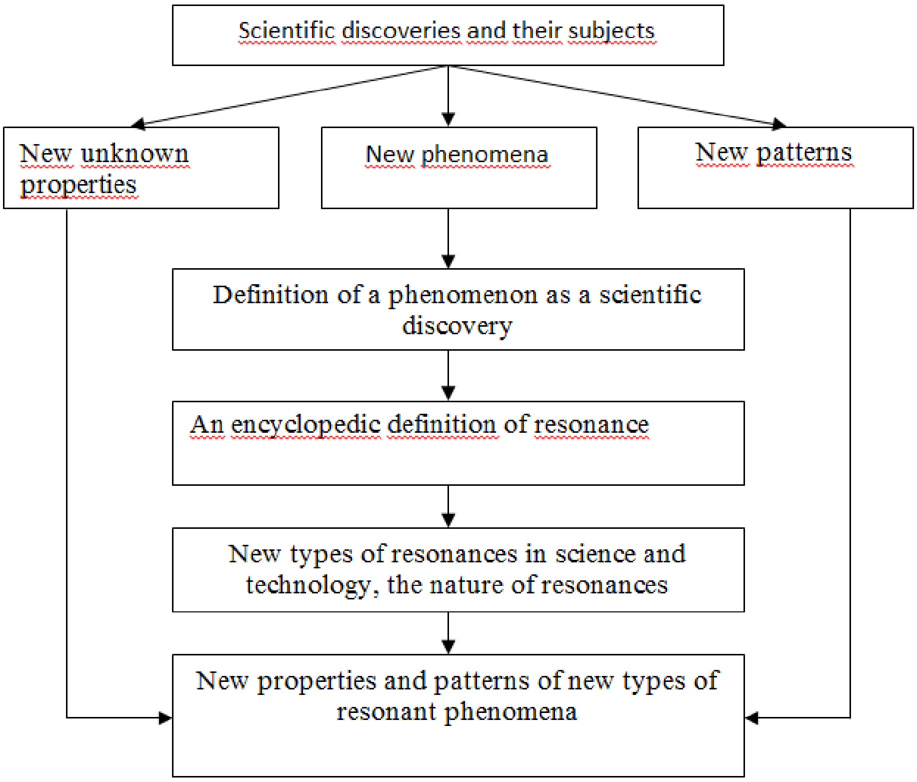


Figure 3.6. Resonant processes as an object of scientific discoveries

It is known from history that resonance phenomena were first discovered in mechanics. Mechanical resonances began to be used both positively and negatively. The first was taken into account, for example, in a device of the type of mechanical (acoustic) resonators, with the second they began to fight, since for mechanical structures resonant oscillations turned out to be the most dangerous and destructive. For example, resonant vibrations (vibrations) of an aircraft structure, vibrations of turbine blades, etc. The classification of known types of resonant processes (RP) is shown in Fig. 3.7.

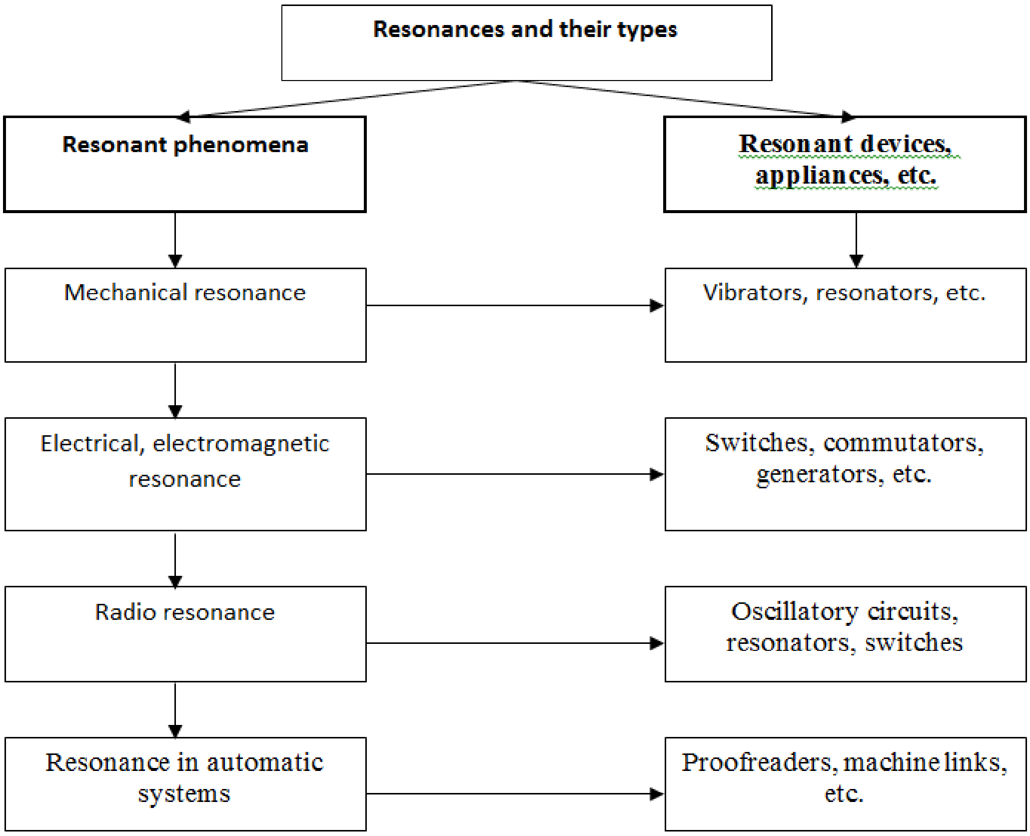


Figure 3.7. Classification of known types of resonance processes

Ignorance of resonance processes has always led to negative results in practice. Therefore, knowledge of the nature of resonance phenomena has always been an important part of scientific, practical, experimental research. Throughout the 20th century, work was constantly going on to discover new types of resonances in various scientific fields. Some types of new resonances are shown in Fig. 3.8 [3].

From Figures 3.7 and 3.8 it can be seen that resonance processes have general properties and general patterns, which consist in the fact that under certain conditions (a certain frequency, a certain interaction, a combination, etc.), there is a quantitative increase in the amplitude of oscillatory or other processes, which causes a qualitatively different result of the ongoing basic processes.

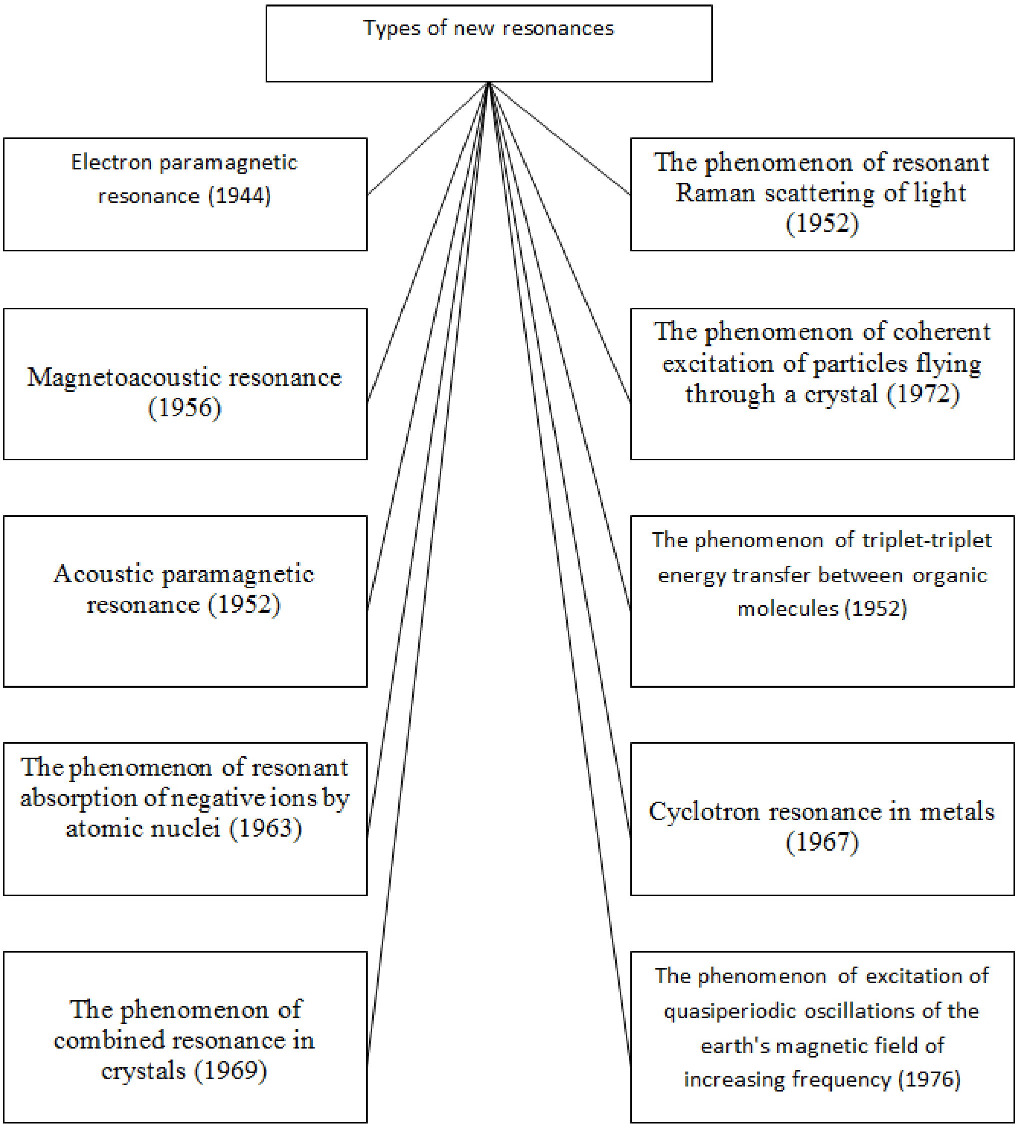


Figure 3.8. Classification of some new types of resonant phenomena (compiled according to Azarov)

<u>Resonances and radio equipment of an aircraft</u>

Another example of the use of resonant processes, but already as positive processes, is the radio equipment of modern aircraft.

Radio resonance processes, resonances in radio engineering are used as the main technologies for constructing radio engineering devices in all frequency ranges, from long radio waves to the full range of microwave (ultrahigh frequencies).

Radio resonance is no longer used as a negative, but as a positive phenomenon. The phenomenon of radio resonance is used to create modern superheterodyne receivers, cavity resonators, frequency meters, precision time meters with quartz stabilization, radio stations, radars and many other radio devices.

What is characteristic, in all these products, different in technical design, the phenomenon of resonance manifests itself qualitatively in the same way and consists in a sharp increase in the amplitude of oscillatory processes under certain conditions of coincidence of the internal characteristics of the product (circuit, resonator, receiver, etc.) with certain characteristics of the external force.

At one time (1965) Academician of the Academy of Sciences of the Ukrainian SSR Mitropol'skiy Yu.A. For a series of fundamental works on the problems of the asymptotic theory of non-stationary oscillations and the study of the phenomenon of passage through resonance during non-stationary processes of gyroscopic systems, he was awarded the highest scientific prize at that time (Table 3.5.) Mitropol'skiy Yu.A. and Bogolyubov N.N. in their works [2] proposed two approaches to the solution of "resonant" cases: 1) in the study of resonance, it is sufficient to confine oneself to considering only the resonance region itself; 2) in addition to studying the resonant region, it is also necessary to study approaches to this region from the nonresonant zone. It is noted that such a consideration requires the imposition of more stringent conditions on the character of the regularity of the functions included in the differential equations under study, and it is necessary to go further, i.e. go beyond differential equations when considering non-harmonic undefined input signals. Therefore, the study of resonant processes and new types of resonances is the most important section of any technical science [2].

Table 3.5. Investigation of resonance processes according to Bogolyubov and Mitropol'skii

	Input signal - disturbance	System behavior	Condition, indicators, resonance equation	System types
1	Harmonic exciting power $\varepsilon E\cos\nu t$	$\frac{d^2x}{dt^2}+\omega^2x=\varepsilon f\left(x,\frac{dt}{dx}\right)+\varepsilon E\cos\nu t$	The external frequency of the input signal is approximately equal to the natural frequency: $\nu\approx\omega$	Vibrators, type: single weight, shaft torsion
2	Harmonic signal $x=a\cos(n\omega t+\theta)$	$LC\frac{d^2i}{dt^2}+RC\frac{di}{dt}+i=i_a$, Where L is the inductance, C - capacity	Main resonance and resonance at harmonics: $\nu=\frac{\omega}{n}$	Relaxation systems: electric oscillatory circuit with self-induction, regenerative receiver
3	Periodic longitudinal force $y=x\sin\pi\frac{z}{l}$	$\frac{d^2x}{dt^2}+p(t)\frac{dx}{dt}+q(t)x=0$, Where p(t), q(t) are periodic functions t with a period Ω	Parametric resonance, where the resonance zone is: $\omega^2-\frac{1}{2}\sqrt{h^2\omega^4-16\omega^2\delta^2}\langle\left(\frac{\nu}{2}\right)^2\langle$ $\langle\omega^2+\frac{1}{2}\sqrt{h^2\omega^4-16\omega^2\delta^2}$ where, the width of the resonant zone: $\Delta=\sqrt{h^2\omega^4-16\omega^2\delta^2}$	Transverse vibrations of the bar under the influence of longitudinal periodic forces

The phenomenon of factorial resonance can be controlled in real flights by the first signs - an increase in the amplitude of the parameters in roll, pitch and other parameters with the registration of these deviations on the map of the first signs. Undoubtedly, this is an effective practical method for analyzing AP with polyparametric factor resonance (PPFR), since this method of analysis allows you to control the beginning of the development of emergency situations.

3.3. THE AGNESI FUNCTION AS A MATHEMATICAL APPARATUS FOR THE STUDY OF RESONANCE PROCESSES IN AVIATION.

The study of the properties and patterns of curves and resonance ranges based on the statistics of disasters and accidents makes it possible to identify specific properties and features of the manifestation of PPFR. However, it is better and more complete to analyze the dynamics of changes in the properties and regularities of the processes of factorial resonance by methods of mathematical modeling (Figure 3.9).

What part (area, point) of flight during accident should we model when studying the nature and patterns of manifestation of factor resonance? The answer to this question is very important for understanding the features and specifics of mathematical models of factorial resonance.

It should be assumed that the probability of occurrence of emergency and catastrophic situations in flight (according to the standardized frequency of events per 1 hour of flight) is up to 10^{-7}, i.e. this is an extremely unlikely event (probability or normalized frequency up to 10^{-9}).

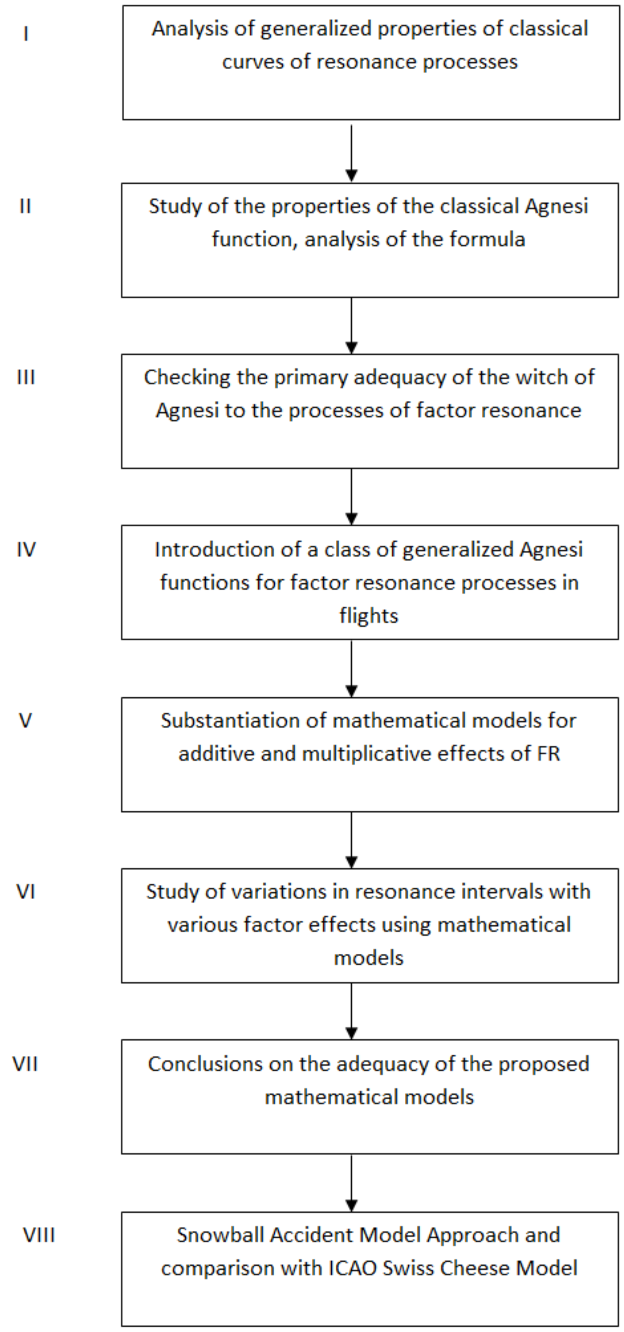


Figure 3.9. Justification of the stages of choosing the Agnesi function as a mathematical model for approximating real factor resonance curves

Modeling of such events is usually carried out using simulators or mathematical modeling methods.

Hence, PFR is also a highly unlikely or almost improbable event. The analysis of the nature and patterns of PPR can be carried out either on the basis of statistics of disasters and accidents or by mathematical modeling methods based on the theory of approximation, i.e. using approximation models or based on them.

What properties in the processes of factor resonance should be taken into account in the practice of flight operations analysis? It should be borne in mind that:

1. In general, PPFR is a negative process that reduces flight safety (at present, this phenomenon is unknown to pilots);
2. The PPFR makes up the content and structure of the last phases of the development of air crashes and accidents ("points of inevitability" according to ICAO);
3. PPFR, as a process, is a class of unlikely, multifactorial, non-stationary processes.
4. Analysis of statistics on PFR is a laborious process and can only be carried out using specially developed analytical models, etc.

Therefore, in the mathematical modeling of the PPFR, it is very important to choose:

- a class of quadratic, symmetric functions, taking into account the symmetry of any resonance curve;
- functionally significant indices or flight parameters, where the change in the range and resonance zones is most variable, i.e. where the resonance variations are maximal;
- to take into account the additive (sequential) and multiplicative (simultaneous) action of groups of factors and their influence on the resonance range.

Let us consider the selected class of quadratic functions and the main functional models of this class, as well as the possibilities of approximating the processes of factorial resonance.

Studies have shown that as a promising mathematical model for the development of a sequential phase of any AA, when we consider this phase taking into account the phenomenon of polyparametric factorial resonance, we can use the equation: $y(x^2 + a^2) = a^3$. This curve is named after the Italian mathematician

Agnesi Maria Gaetana and is known in mathematics as "witch of Agnesi" (Figure 3.7).

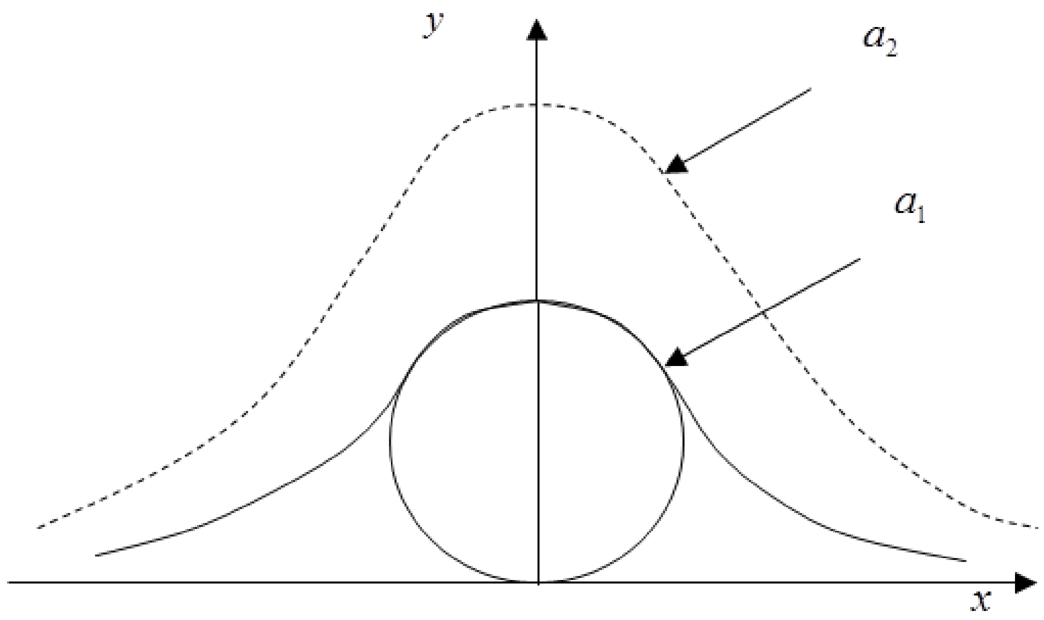


Figure 3.10. Witch of Agnesi

$y(x^2 + a^2) = a^3$, moreover (a_2> a_1), where a is the polyparametric hazard coefficient of the last phase of the accident.

From fig. 3.10 it can be seen that such an equation most likely approximates the factorial resonance phenomenon, since it represents a graphically symmetric convex curve.

Curl Agnesi is a flat curve (Figure 3.10), the equation of which in a Cartesian rectangular coordinate system is:. The abscissa is the asymptote for this curve. The convex curves, the maximum of the curve at a point, have a reference circle, which is very important for constructing an illustrative model of the development of aircraft accidents. It is known that ICAO pays great attention to the development of such visual models for the development of AP, such as the "Dutch cheese model", the ICAO factor chain [7].

The existence of the reference circle makes it possible to create a new illustrative model for the development of AA - the “snowball” model (Figure 3.11).

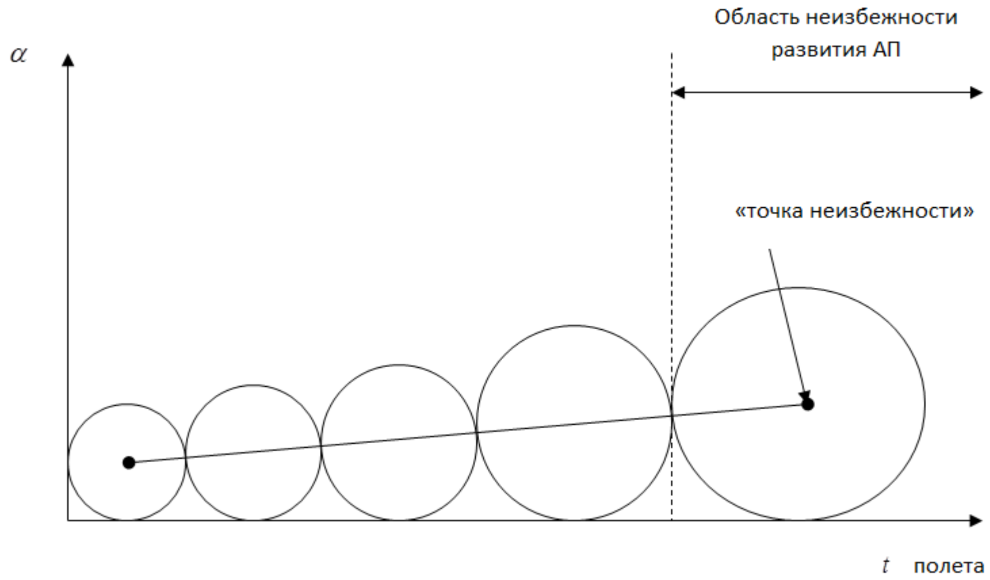


Figure 3.11. An illustrative model of the development of a snowball accident using the reference circle of witch of Agnesi

Consider the general properties of witch of Agnesi in Figure 3.12:

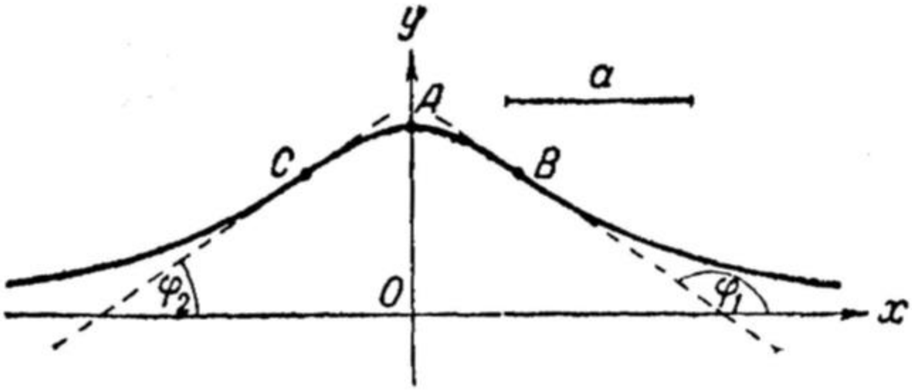


Figure. 3.12. General properties of witch of Agnesi

1. Equation: $y = \frac{a^3}{a^2 + x^2}$. Asymptote y=0. Maximum A (0;a); the radius of curvature in it $r = \frac{a}{2}$ (Figure 3.6)

2. Inflection points B, C $\left(\pm\frac{a}{\sqrt{3}};\frac{3a}{4}\right)$, the slope of the curve at these points $tg\varphi = \pm\frac{3\sqrt{3}}{8}$.

3. The area between the curve and the asymptote $S = \pi a^2$.

Agnesi function characteristics:

1. Witch of Agnesi belongs in argument to the class of quadratic functions, such as parabola, hyperbola, ellipse (in order to the class of functions of the third order, such as Descartes leaf, Nicolides conchoid, but in argument to the class of quadratic functions).

2. The Agnesi function is convex and symmetric.

3. Very characteristic inflection points for PPFR modeling. In the regions of small values, the function has asymptotes.

4. Belongs to the class of elementary functions close to the class of "wonderful curves".

5. Allows you to implement an illustrative model of the "snowball" type, since has a support circle.

6. It has variations in the form and appearance of graphs.

Let us consider the general principles of approximating classical (encyclopedic) resonance curves by Agnesi functions, using the example of resonances in oscillatory circuits (Figure 3.13). The nature of the resonance curve for high and low damping is different and is determined by the quality of the loop circuits.

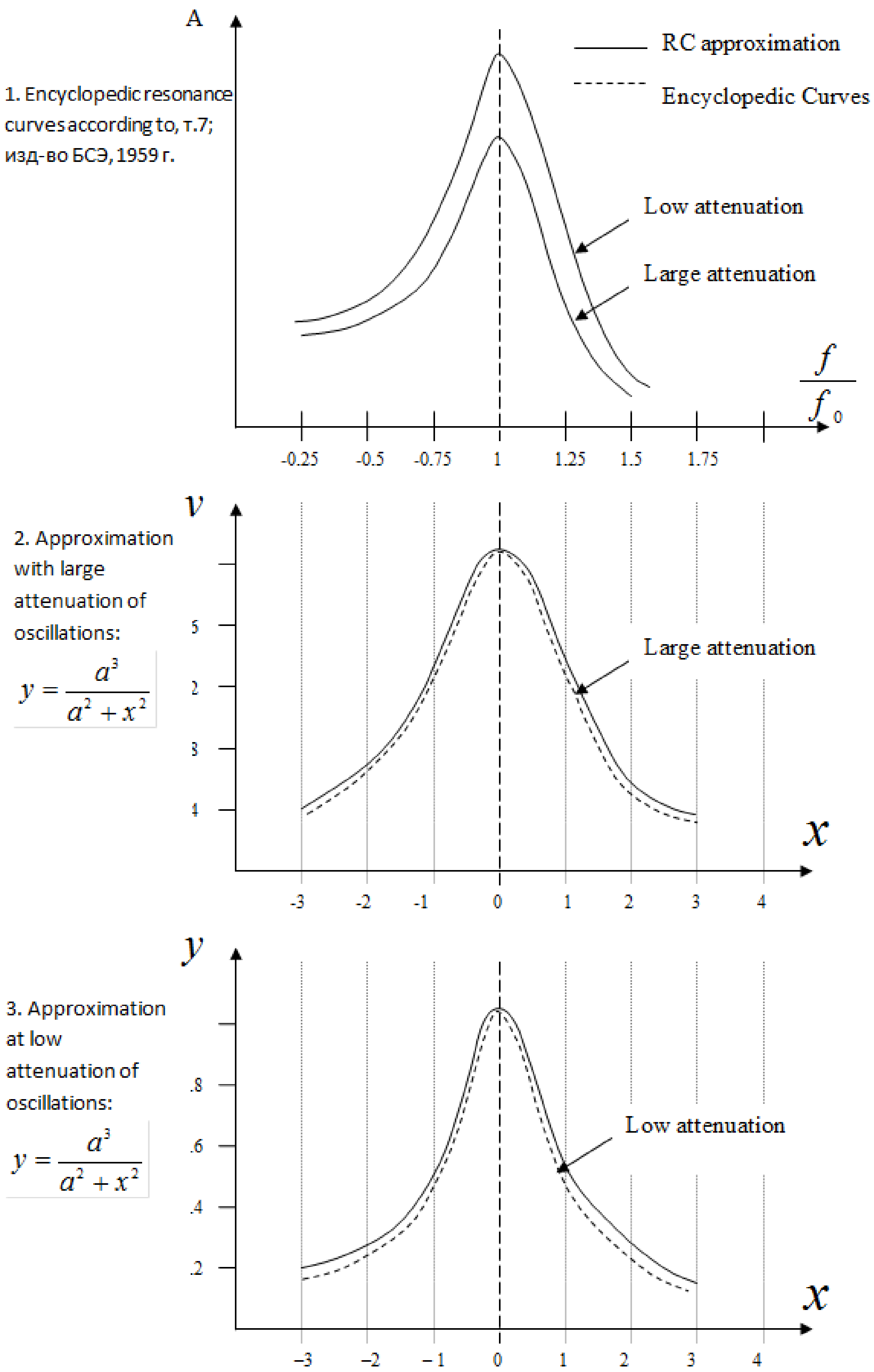


Figure. 3.13. Qualitative comparison of the approximation of encyclopedic resonance curves by the classical witch of Agnesi

Therefore, when approximating these curves by the least squares method (the minimum of the sum of squares of deviations of the real curve from the approximating one), it is necessary to use different values of the Agnesi function, choosing the minimum square root of the sum of squares of deviations at the approximation points (Figure 3.8). Figure 3.8 shows that such a curve fairly representatively approximates the encyclopedic resonance curves, even without introducing additional scale factors, since it has the form of a resonance curve for all attenuation values.

Thus, the mathematical model of the first signs of factorial resonance based on the witch of Agnesi equation can be used to represent the development of events in special flight situations, presenting some generalization of events.

3.4. ASSESSMENT OF THE RISK OF MULTIPLICATIVE AND ADDITIVE FACTOR OVERLAP USING A MATHEMATICAL MODEL OF FACTOR RESONANCE.

When studying new polyparametric forms of factorial resonance, it was necessary to choose a generalized indicator of such a phenomenon (Figure 3.9). In our opinion, the angle of attack possesses such properties. The angle of attack is the angle between the ram air vector and the wing chord. It is this indicator that determines the degree of danger of various phases of aircraft accidents.

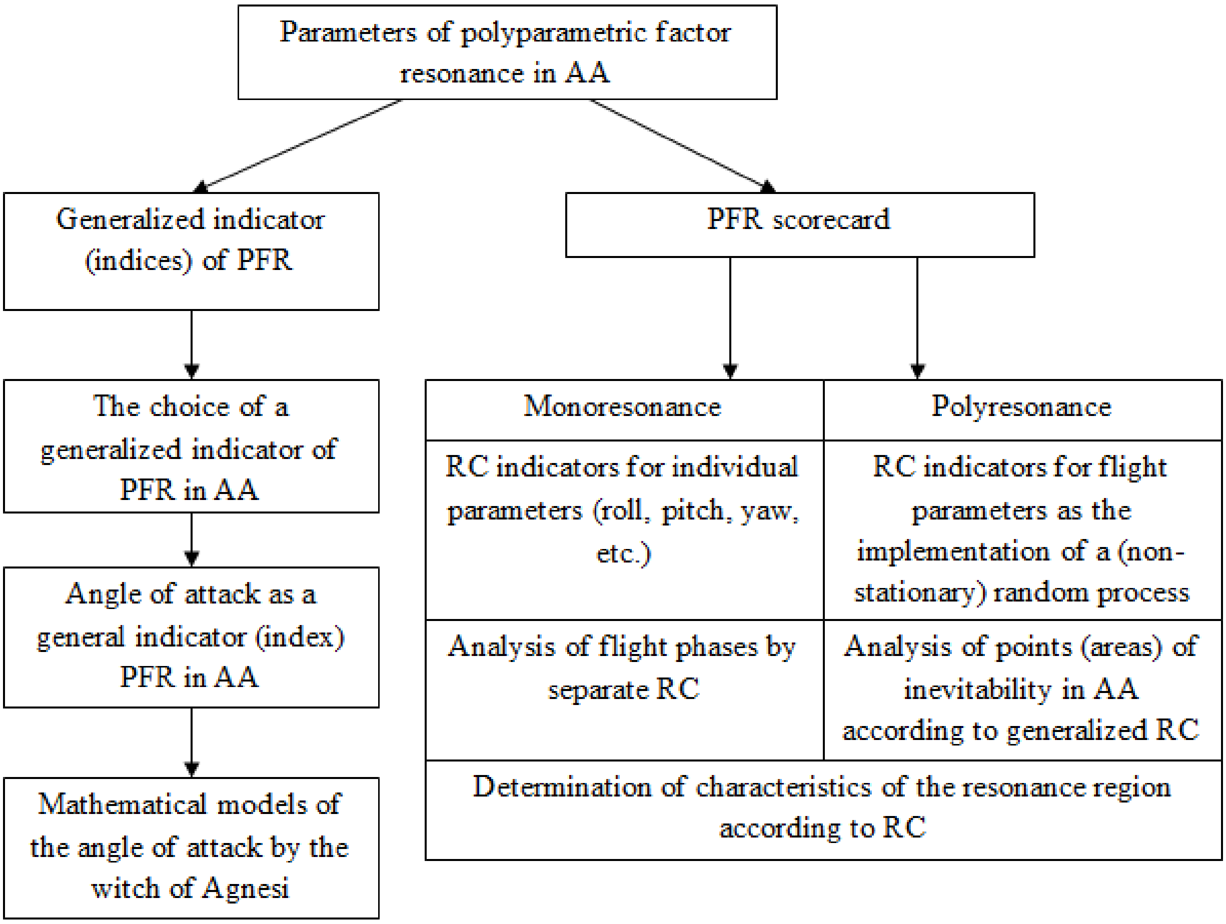


Figure 3.14. Indicators and criteria, characteristics of factor resonance during flight operations (occurrence of accident)

When investigating the laws and properties of PFR, the angle of attack meets all the requirements for the analytics of resonant polyparametric processes:

- is the angle of connection of several coordinate systems of the aircraft (connected and semi-connected);
- its value determines the boundaries of the aircraft flight (flight and non-flight - supercritical angles of attack);
- is a functional of communication of almost all parameters of the aircraft;
- is included in all contour equations of aircraft control systems;
- its value determines the integral area of flight hazardous factors;
- is used in the main aerodynamic dependencies for calculating stability, maneuverability of an aircraft, etc.

Mathematical PFR models based on angle of attack α are shown in Table 3.6.

In contrast to classical aerodynamics, where $\alpha_{\Phi P}$ is considered as a functional argument (in the equations of motion, aircraft stability, in aerodynamic dependences on the number M, etc.), when studying the phenomenon of factor resonance, $\alpha_{\Phi P}$ is considered as a subclass of a function in the class of quadratic functions. Depending on the total number of acting factors, the number of interacting factors, etc.

It should be noted that the phenomenon of factorial resonance is an extreme case of the manifestation of factorial multiplicative overlaps and is especially often observed in the last phases of flights with aircraft accidents. Therefore, we can assume that PFR in an aircraft accident is not just a random, but a natural phenomenon caused by the limiting action of a group of factors simultaneously (from 5 to 20 and more).

Table 3.6. The angle of attack as a generalized indicator of factorial resonance according to the mathematical model of witch of Agnesi

1. General formula	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \Delta H^2}$	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \Delta t^2}$
2. Coefficient B - scale factor	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + B\Delta H^2}$	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + B\Delta t^2}$
3. Formula for probabilistic additive factor effect	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \sum_i p_i \Delta H^2}$	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \sum_i p_i \Delta t^2}$
4. Formula for a probabilistic multiplicative factor effect	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \Pi_i\, p_i \Delta H^2}$	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \Pi_i\, p_i \Delta t^2}$
5. Formula with a general additive factor effect	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \sum_i k_i \Delta H^2}$	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \sum_i k_i \Delta t^2}$
6. Formula for the general multiplicative factor effect	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \Pi_i\, k_i \Delta H^2}$	$\alpha_{\Phi P} = \dfrac{\alpha_{\max}^3}{\alpha_{\max}^2 + \Pi_i\, k_i \Delta t^2}$

7. The formula for taking into account the additive factor effect in the general decision of TALNF	$\alpha_{ФР} = \dfrac{n\alpha^3_{\max 0}}{\alpha^2_{\max 0} + \sum\limits_{i=1}^{n} p_i \Delta H^2}$	$\alpha_{ФР} = \dfrac{n\alpha^3_{\max 0}}{\alpha^2_{\max 0} + \sum\limits_{i=1}^{n} p_i \Delta t^2}$
8. The formula for taking into account the multiplicative factor effect in the general decision of the TALNF	$\alpha_{ФР} = \dfrac{n\alpha^3_{\max 0}}{\alpha^2_{\max 0} + \mathit{\Pi} p_i{}_{i=1}^{n} \Delta H^2}$	$\alpha_{ФР} = \dfrac{n\alpha^3_{\max 0}}{\alpha^2_{\max 0} + \mathit{\Pi} p_i{}_{i=1}^{n} \Delta t^2}$
9. The formula for taking into account the additive factor effect according to the entropy model (for taking into account the interaction of factors)	$\alpha_{ФР} = \dfrac{\sum p_i \ln \sum p_i \alpha^3_{\max 0}}{\alpha^2_{\max 0} + \sum\limits_{i=1}^{n} p_i \Delta H^2}$ n $i=1$	$\alpha_{ФР} = \dfrac{\sum p_i \ln \sum p_i \alpha^3_{\max 0}}{\alpha^2_{\max 0} + \sum\limits_{i=1}^{n} p_i \Delta t^2}$ n $i=1$
10. The formula for taking into account the multiplicative factor effect according to the entropy model (for taking into account the interaction of factors)	$\alpha_{ФР} = \dfrac{\mathit{\Pi} p_i \ln \mathit{\Pi} p_i \alpha^3_{\max 0}}{\alpha^2_{\max 0} + \mathop{\mathit{\Pi}}\limits_{i=1}^{n} p_i \Delta H^2}$ n	$\alpha_{ФР} = \dfrac{\mathit{\Pi} p_i \ln \mathit{\Pi} p_i \alpha^3_{\max 0}}{\alpha^2_{\max 0} + \mathop{\mathit{\Pi}}\limits_{i=1}^{n} p_i \Delta t^2}$ n

Note: 1) the angle of attack is taken as a generalized indicator only for AP with going beyond the critical angles of attack (AP - "Irkutsk", "Sknilov", "Donetsk").

2) for other flight parameters (roll, pitch, etc.) - the FR formulas are similar.

$\alpha_{ФР}$ - current angle of attack of factor resonance,

$\alpha_{\max}$ -maximum angle of attack arising during AP (parameter a-f.Anezi)

B - coefficient taking into account the range of zooming,

p_i - the probability of the appearance of the factor (0 1) with additive or multiplicative factorial resonance,

k_i - weight coefficient,

ΔH - range (interval) of resonance in flight altitude,

Δt - range (interval) of resonance by flight time.

The analysis showed that under the multiplicative action of factors and when the entropy of the process is accepted as a generalized characteristic of all parameters, the entropy of the process is transformed into a resonance curve (Fig. 3.15).

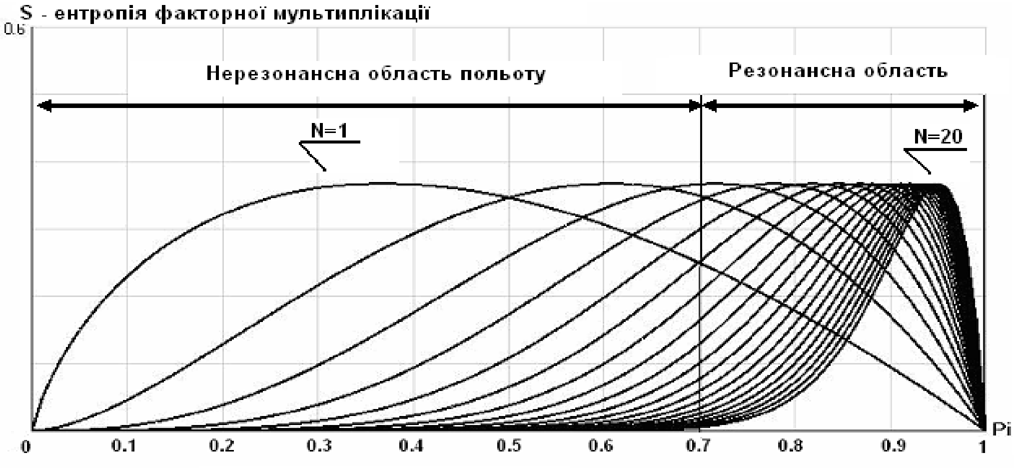


Figure 3.15. Transformation of the resonance curve under the action of factors (N = 20)

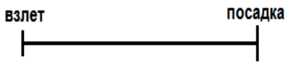
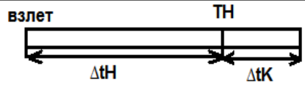
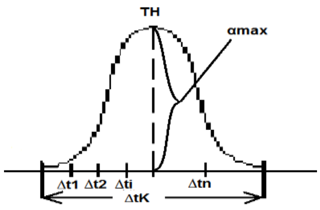
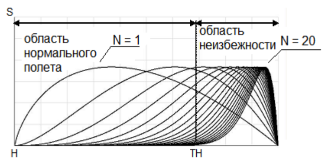
$S = \prod_{i=1}^{N} p_i \ln \prod_{i=1}^{N} p_i$, where p_i is the probability of occurrence of the i-th factor, N is the number of factors

In addition, this program proves the very fact of the existence of the factor resonance phenomenon. It has been proven that in the last phase of an accident (areas or points of inevitability) at least 15-20 factors operate simultaneously, this fact was theoretically established in 1985 by the Ukrainian Scientific School of Ergonomics, and experimentally confirmed in 1995 by Boeing [6, 7].

The study of the last phases of air crashes (accidents) - "points of inevitability" - requires the use of approximation models.

Let us consider the features of the analysis of the nature and nature of the laws of the processes occurring at the "points of inevitability", i.e. in the last phases of the accident (Table 3.7).

Table 3.7. Analysis of the processes of factorial resonance according to the witch of Agnesi in normal flights and plane crashes (accidents).

	Flights	Equations	Conditions	Graphs
1	Normal flight (no emergency) acting factors = const	$\alpha_{\Phi P} = S * \alpha_{max} (C_x, C_y)$ $\alpha_{\Phi P} = \lim \min S\alpha_{max} (C_x,$ no factor resonance α_{max} - the maximum value of the Agnesi function	$\Delta t_k = 0$ S = const = min$S$ $\alpha_{max} < \alpha_{п}$ $\alpha_{п}$ – flight (tolerance) angle of attack; Δt_k – catastrophic propagation time	 There is no factor resonance in this case. At min S it does not happen
2	ICAO crash model – no-return point and the condition for its occurrence $\frac{\Delta t_k}{\Delta f_n} \approx 0 \approx d\Delta t$	$\alpha_{\Phi P} \geq S \cdot \alpha_{max}$ S – var or S = const	$t_{п}$ – total flight time; $\Delta t_{н}$ – normal flight time $t_{п} = \Delta t_{н} + \Delta t_{к}$ $\Delta t_{н} >> \Delta t_{к}$ $\Delta t_{к} \to dt \sim 0$	 Factor resonance at $S_{20} = \prod_i^{20} p_i \log \prod_i^{20} p_i$
3	Analysis of the no return region by the Agnesi function as an approximation model (without analysis of the normal flight zone)	$\alpha_{ÔÐ} = \frac{S\alpha^3_{max}}{\alpha^2_{max} + B\Delta t_k^2} =$ $= \frac{S\alpha^3_{max}}{\alpha^2_{max} + B(\Delta t_1 + \Delta t_2) + ...\Delta t_i}$	$\Delta t_{н} \approx 0$ Quantization equation: $\Delta t_{к} = \Delta t_1 + \Delta t_2 + + \ldots + \Delta t_i + \ldots \Delta t_{п}$ S = const	Approximation of the "no-return area " function 
4	Transformation of the entropy of factorial multiplication into a resonance curve - analysis of the laws of transformation S with variation of up to 20 active	a) "no-return area" according to ICAO $S_{ÔÐ} = \prod_i^n p_i \log \prod_i^n p_i$ б) final "no-return area" $\Delta t_K \neq 0$; $\alpha_{ÔÐ} = \frac{\prod_i^n p_i \log \prod_i^n p_i \alpha^3_{max}}{\alpha^2_{max} + \prod p_i \Delta t^2}$	S – var up to 20 factors α_{max} equal to $\alpha_{п}$ or more a) $\alpha_{max} > \alpha_{п}$ б) $\alpha_{max} < \alpha_{п}$	When analyzing the nature and mechanisms of occurrence of resonance factors 

	emergency factors			

Basic formula (basic equation) FR: $\boldsymbol{\alpha}_{\text{фр}} = \frac{\prod_i^n \mathbf{p_i} \log \prod_i^n \mathbf{p_i} \boldsymbol{\alpha}_{\mathbf{max}}^3}{\boldsymbol{\alpha}_{\mathbf{max}}^2 + \prod \mathbf{p_i} \Delta \mathbf{t}^2}$ or $\boldsymbol{S} = \prod_i^n \boldsymbol{p_i} \log \prod_i^n \boldsymbol{p_i} = \boldsymbol{B} * \log \boldsymbol{B}$, $\boldsymbol{\alpha}_{\text{фр}} = \frac{\mathbf{S} * \boldsymbol{\alpha}_{\mathbf{max}}^3}{\boldsymbol{\alpha}_{\mathbf{max}}^2 + \mathbf{B} \Delta \mathbf{t}_{\mathbf{k}}^2}$, where S - factorial multiplication entropy; Δt_k is the duration of the emergency (catastrophic) situation; $\alpha_{max} = \alpha$ is the maximum of the Agnesi function; B - coefficient for the product of probability; αfr is the current angle of attack during FR processes.

Consider all cases of analysis of the processes of factorial resonance:

I. In the first case, a normal flight is taken. Since the flight is normal, then $\Delta t_K = 0$, i.e. no emergency situations

$$\boldsymbol{\alpha}_{\text{фр}} = \frac{\mathbf{S} * \boldsymbol{\alpha}_{\mathbf{max}}^3}{\boldsymbol{\alpha}_{\mathbf{max}}^2 + \mathbf{B} \Delta \mathbf{t}^2} = \frac{\mathbf{S} * \boldsymbol{\alpha}_{\mathbf{max}}^3}{\boldsymbol{\alpha}_{\mathbf{max}}^2 + \mathbf{0}} = \mathbf{S} \boldsymbol{\alpha}_{\mathbf{max}}$$

If $\alpha_{max} < \alpha_{flight}$, then the aircraft flies, if $\alpha_{max} > \alpha_{flight}$, then it can fall - this is known from aerodynamics,

since $\mathbf{C_y} = \mathbf{C_{y0}} + \mathbf{C_y^{(\boldsymbol{\alpha})}} \boldsymbol{\alpha}$,

where $\mathbf{C_{y0}}$ is the value of $\mathbf{C_y}$ at $\alpha = 0$, $\mathbf{C_y^{(\boldsymbol{\alpha})}}$) is the coefficient of proportionality.

Conclusion: the Agnesi function allows us to take into account the laws of aerodynamics of normal flight.

II. In the second case, the ICAO “point of inevitability” is considered. In this case, S-var, i.e. factor overlays change or S = const. Shown for the first time the equation of the ICAO illustrative model:

For S - var and $\alpha_{max} = \alpha_n$, factor resonance can arise only when

$$\boldsymbol{S} = \boldsymbol{S}_{\mathbf{20}} = \prod_i^{\mathbf{20}} \boldsymbol{p_i} \log \prod_i^{\mathbf{20}} \boldsymbol{p_i}$$

$\frac{\Delta \mathbf{t_H} - \text{часа}}{\Delta \mathbf{t_k} - \text{сек}} = \frac{\mathbf{1600}}{\mathbf{15}} \sim \mathbf{100}$ - for an hour flight

Conclusions: An illustrative ICAO aircraft model with an inevitability point is obtained when the total flight time is taken and compared with the duration of the emergency. At $\alpha_{max} = \alpha_n$, the FR arises only from the transformation of S.

III. In the case of the analysis of the region of inevitability by the Agnesi function as an approximation model (without the analysis of the normal flight zone: $\Delta t_H \approx 0$ i.e. the phase of normal flight can be excluded when analyzing the HP as an area (zone). Within the occurrence of an emergency (catastrophic) situation S as the rule is constant, that is, the factorial overlap is formed and it does not change in 30 - 40 seconds. - the duration of the emergency (catastrophic) situation. We carry out an approximation according to the "Agnesi curl" of individual control parameters γ, Θ and α, or the safety parameter α, or according to a generalized index in the range ΔtK - the duration of an emergency (catastrophic) situation.

IV. When transforming the entropy of factorial multiplication into a resonance curve - analysis of the regularities of the transformation of S with a variation of up to 20 operating emergency factors: a) If we are interested in the mechanism of occurrence of the PD phenomenon during the dynamics of the factorial overlap, then by the entropy of factorial multiplication it is possible to determine the nature of the RK; b) in other cases - taking into account the full dynamics $\alpha_{max} > \alpha_n$, S – var; Δt_K – var; α_{max} – var; according to the formula $\mathbf{S_{20}} = \boldsymbol{\alpha}_{\text{фр}} = \frac{\mathbf{S * \alpha_{max}^3}}{\mathbf{\alpha_{max}^2 + B\Delta t_k^2}}$.

On the basis of the Agnesi function, a class of generalized Agnesi functions is proposed for the study of "points of inevitability" according to ICAO (Table 3.7).

What interests us when analyzing the nature and character of regularities at points of inevitability?

Based on the analysis of the ТУ-154 aircraft crash near Irkutsk, we already know that any crash in its last phase is described by factorial resonance processes, and the resonance curve is the general characteristic of flight parameters in this area.

We will study the features of the manifestation of regularities using mathematical approximation models. Let's introduce the concept - the area of factorial resonance. This is the area, the contours of which are limited by the resonance curve (Figure 3.16).

Considering that PFR and its regularities are determined by the nature of the acting factors and the conditions of their interaction or the absence of interaction, it should be assumed that the resonance region in PFR should change when the effect of the acting factors changes.

Consider the models of approximation in the angles of attack:

1. Table 3.7 shows the classic formula:

$$\alpha_{ФР} = \frac{\alpha_{\max}^3}{\alpha_{\max}^2 + \Delta H^2} \quad \text{(similar for } \Delta t\text{)}$$

It can be seen from the formula that $\alpha_{\max}$ is the maximum value of the angle of attack ($\alpha_{\max} = a$ i.e., the diameter of the support circle or the maximum value of the Agnesi function at a fixed value of time or frequency). If $\alpha_{\max} = \alpha_{полетное}$, then the NPR curve fits into the region of flight (subcritical) angles of attack. If $\alpha_{\max} \geq \alpha_{полетное}$, then the NPR area can cover both the flight area (zone, section) and the “non-flight” section, i.e. gravitational attraction to the ground - stochastic fall at supercritical angles of attack (non-flight position of the aircraft).

Therefore, the general formula for can be considered as the initial position of motion along the Agnesi functions, if at the same time set equal to the flight (subcritical) position of the aircraft.

2. Investigation of the regularities at the point of inevitability at the last phase of the AP consists in analyzing the nature of the change (expansion, increase or decrease) of the NFR region, contoured by the resonance curve at some lower level, taking into account its asymptotic nature. The overall effect of changing the area can be changed by entering a coefficient and giving it various numerical or functional values:

$$\alpha_{ФР} = \frac{\alpha_{\max}^3}{\alpha_{\max}^2 + B\Delta H^2}$$

It can be seen from the formula that at values $B \rangle 1$ the resonance region will increase, and at $B \langle 1$ decrease (Fig. 3.61).

Thus, if we determine the nature of the coefficient B by the nature of the action of factors (sequentially or simultaneously), then we can study the patterns of action of groups of additive or multiplicative factors.

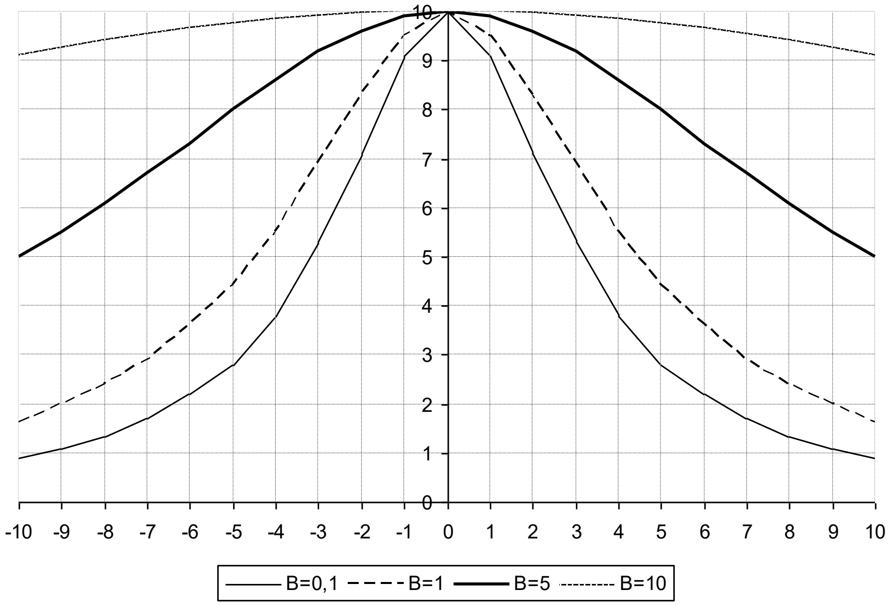


Figure 3.16. Estimation of the influence of the scale factor on the shape of the resonance curve

Taking into account the fact that in real flights the effect of factors can be different, the factors can act one after another, i.e. consistently; simultaneously - multiplicatively, therefore, it is necessary to study the patterns of factor effects on resonance curves. Let's consider these patterns using the example of Table 3.8.

3. Formula for the probabilistic additive factor effect:

$$\alpha_{\Phi P} = \frac{\alpha_{\max}^3}{\alpha_{\max}^2 + \sum_i p_i \Delta\mathrm{H}^2}$$

4. Formula for the probabilistic multiplicative factor effect:

$$\alpha_{\Phi P} = \frac{\alpha_{\max}^3}{\alpha_{\max}^2 + \mathit{\Pi}_i\, p_i \Delta\mathrm{H}^2}$$

Additive factorial effect - the formula of full resonance under the action of factors (change in the amplitude $\alpha_{\max}$ and resonance band):

$$\alpha_{\sum} = \frac{n\alpha^3_{\max 0}}{\alpha^2_{\max 0}} + \sum_{i=1}^{n} p_i x_i^2$$

where n is the number of operating factors;

$\alpha_{\max 0}$ - initial value $\alpha_{\max}$;

p_i - the likelihood of the appearance of the i-th factor;

x - resonance interval: $x = \Delta t(\Delta H)$;

α is the current angle of attack.

Example:

$\alpha_{max0}=13^o$;

$x = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10$;

$n = 1, 2, 3\ldots i\ldots 20$

Table 3.8. The results of taking into account the influence of a different number of additive factors on the shape of the resonance band

x	n_1	n_2	n_{10}	n_{20}
1	12.97	25.97	129.97	259.97
2	12.94	25.94	129.94	259.94
3	12.91	25.91	129.91	259.91
4	12.88	25.88	129.88	259.88
5	12.85	25.85	129.85	259.85
6	12.82	25.82	129.82	259.82
7	12.79	25.79	129.79	259.79
8	12.76	25.76	129.76	259.76
9	12.73	25.73	129.73	259.73
10	12.7	25.7	129.7	259.7

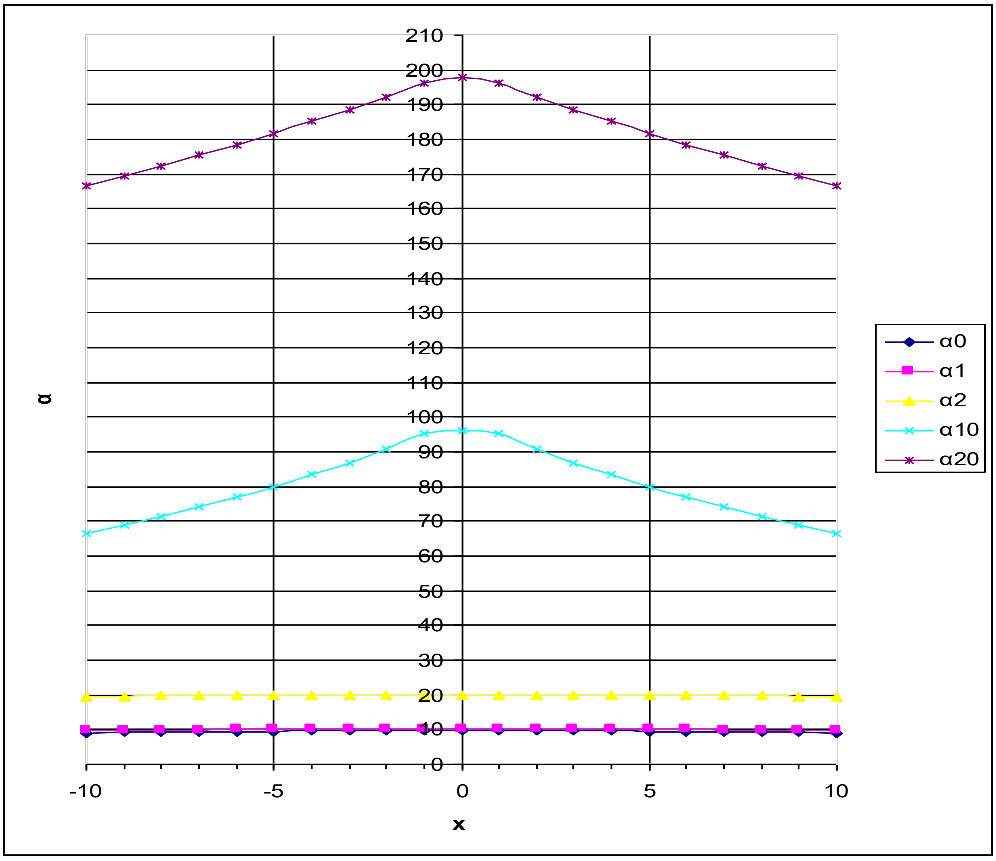


Figure 3.17. Evaluation of the resonance band and its type under the action of additive factors

The pure effect of factorial resonance - with an increase in the number of interacting factors, the amplitude and resonance interval increases (Figure 3.17).

Assessment of the risk of multiplicative and additive factor overlap using a mathematical model of factor resonance.

The development of an aircraft accident can occur either with a sequential (additive) action 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 PFR will be different. Let's consider this difference between additive and multiplicative factorial phenomena.

Example. Comparison by $\sum$ and by П.

Given:

$$\alpha_{max0} := 13$$

$$n := 10$$

$$p_i := 0.3$$

$$\Delta x := 1$$

$$\alpha_{mult} := \frac{n \cdot \alpha_{max0}^{3}}{\alpha_{max0}^{2} + \left(\prod_{i=1}^{n} p_i\right) \cdot \Delta x^{2}} = 130$$

$$\alpha_{add} := \frac{n \cdot \alpha_{max0}^{3}}{\alpha_{max0}^{2} + \left(\sum_{i=1}^{n} p_i\right) \cdot \Delta x^{2}} = 127.733$$

With the same values $\alpha_{\max_0}$, n, P_i, x the value of the current amplitude α is greater with a factor overlay (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 air 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 (АУАСП). The generalized table 3.9 shows the moments of АУАСП actuation of the ТУ-154M aircraft, (in minutes and seconds), as well as the actuation intervals (in seconds) between the previous and subsequent actuation. It can be seen from Table 3.9 that during the critical part of the flight there are 3-6 АУАСП operations in the supercritical angle of attack, which occur unevenly, with different time intervals Δt.

Table 3.9. АУАСП signals and intervals between them

№	1	2	3	4	5	6	7
t, c	11:33;13:06,7	11:33;12:30	11:35;11:43	11:35;12:42.5	11:35;12:15	11:36;12:59	11:38;37:2
Δt, c	93.7	57	8	67.5	40	83	-
ω, $\frac{1}{sec}$	0.011	0.018	0.125	0.015	0.025	0.012	

The irregularity of the АУАСП response intervals 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. 3.18 in coordinates:

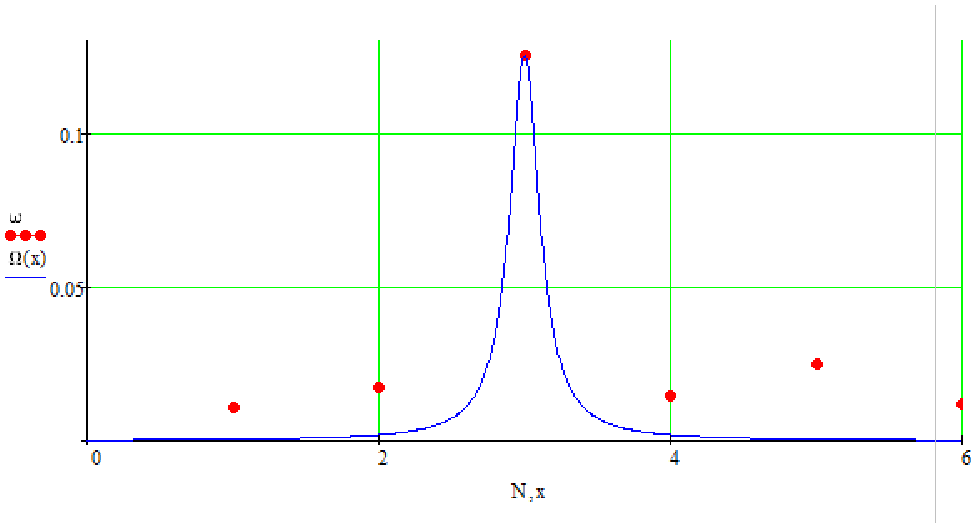


Figure 3.18. Resonance PFR curve and its approximation by the witch of Agnesi

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

ordinate - frequency of operation of АУАСП: $\omega = \frac{1}{\Delta t}$ $\left[\frac{1}{sec}\right]$

The peculiarity of the resonance curve in Fig. 3.10 is that it characterizes not only amplitude increases in the resonant process, but changes in response frequency.

Tables 3.10 and 3.11 present the data for constructing the resonance curve and the points of approximation of the resonance curve.

Table 3.10. Resonance curve data

Number of the interval, Δt	1	2	3	4	5	6
Frequency of operation of АУАСП	0.011	0.018	0.125	0.015	0.025	0.012

Table 3.11. Resonance curve fitting points

Δt , c	0	1	2	3	4	5	6
АУАСП	$2.166\cdot10^{-4}$	$4.864\cdot10^{-4}$	$1.923\cdot10^{-3}$	0,125	$1.923\cdot10^{-3}$	$4.864\cdot10^{-4}$	$2.166\cdot10^{-4}$

From fig. 3.10 and Tables 3.9-3.11, it should be concluded that in this AA 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 (АУАСП) when the aircraft reaches supercritical angles of attack.

CONCLUSIONS TO CHAPTER 3

1. A generalized class of the Agnesi function is proposed as a mathematical model for approximating the processes of factorial resonance in AA.

2. Checking by the method of least squares showed the fundamental possibility of using the generalized class of the Agnesi function as an approximation model with an acceptable level of error.

3. Studies of the angle of attack, as a generalized indicator of factorial resonance according to the mathematical model of Agnesi, taking into account the probabilistic additive effect, the probabilistic multiplicative effect, taking into account the entropy model, have shown that the most dangerous factor from the point of view of the occurrence of factor resonance is the factor overlap in the form of factorial multiplication (complex simultaneously acting factors).

4. The angle of attack, as a generalized indicator of factorial resonance, is the central indicator of flight safety. Therefore, the elimination of factor resonance zones in terms of the angle of attack should be carried out by all forms of flight management, which will increase the level of aircraft flight safety.

CHAPTER 4. LABOUR PROTECTION

4.1. INTRODUCTION

This diploma work is based on several experimental investigations. All of them should be performed by educated and skilled specialists to prevent harmful effect on someone`s health. The subject of this work is an engineer, who works under the investigation models of interaction of operational factors taking into account factor resonance to improve the degree of flight safety. In this chapter will be considered the working conditions in the scientific laboratory and safety precautions for its workers.

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

Scientific laboratory is designed to be a working place for 3-5 person. Its total area is equal to:

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

$$A = 6m \cdot 5m = 30m^{2,}$$

Where a – length and b – width (fig 4.1)

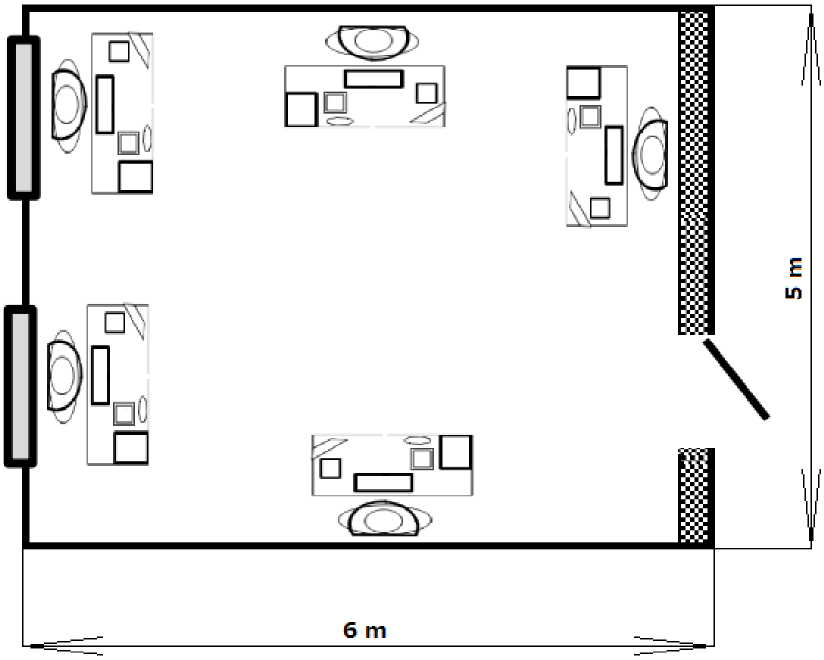


Figure 4.1. Laboratory facilities layout

The working area of one person is approximately equal to:

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

$$A_{person} = \frac{30m^2}{5} = 6m^2$$

Where n is number of workers.

The volume of the room can be determined as:

$$V = A \cdot h[m^2],$$

$$V = 30m^2 \cdot 3.10m = 105m^3,$$

Where h – height of the room.

Laboratory perimeter is equal to:

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

$$P = 2 * 6 + 2 * 5 = 22(m).$$

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

Laboratory is equipped with 12 ceiling lights and 2 windows. Also, it has sockets for 220V users.

The most favorable microclimate at the workplace according to ДСН 3.8.6.042-99 are:

- Temperature within 22-24^o;
- Relative humidity should be 40-60%
- Air velocity 0.1 m/s

To maintain optimal values of microclimate heater and air ventilation 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.

4.2.2.1. 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, º	22-24	20
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.

4.2.2.2. 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 370 lx, at nighttime – 350 lx.

Table 4.2. Comparison of illumination characteristics

Optimal	Actual	
	Daytime	Nighttime
400 lx	370 lx	350 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.

The following technical methods and means are used separately or in combination with each other to ensure electrical safety:

- protective earthing;
- zeroing;
- equalization of potentials;
- low voltage;
- protective unlocking;
- insulation of power lines;
- fencing devices;
- warning alarm,
- locks, safety signs;
- protective equipment and safety devices.

Protective grounding or grounding is used to protect people from electric shock due to insulation damage and voltage transfer to live parts of machines, mechanisms and tools.

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 60 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.

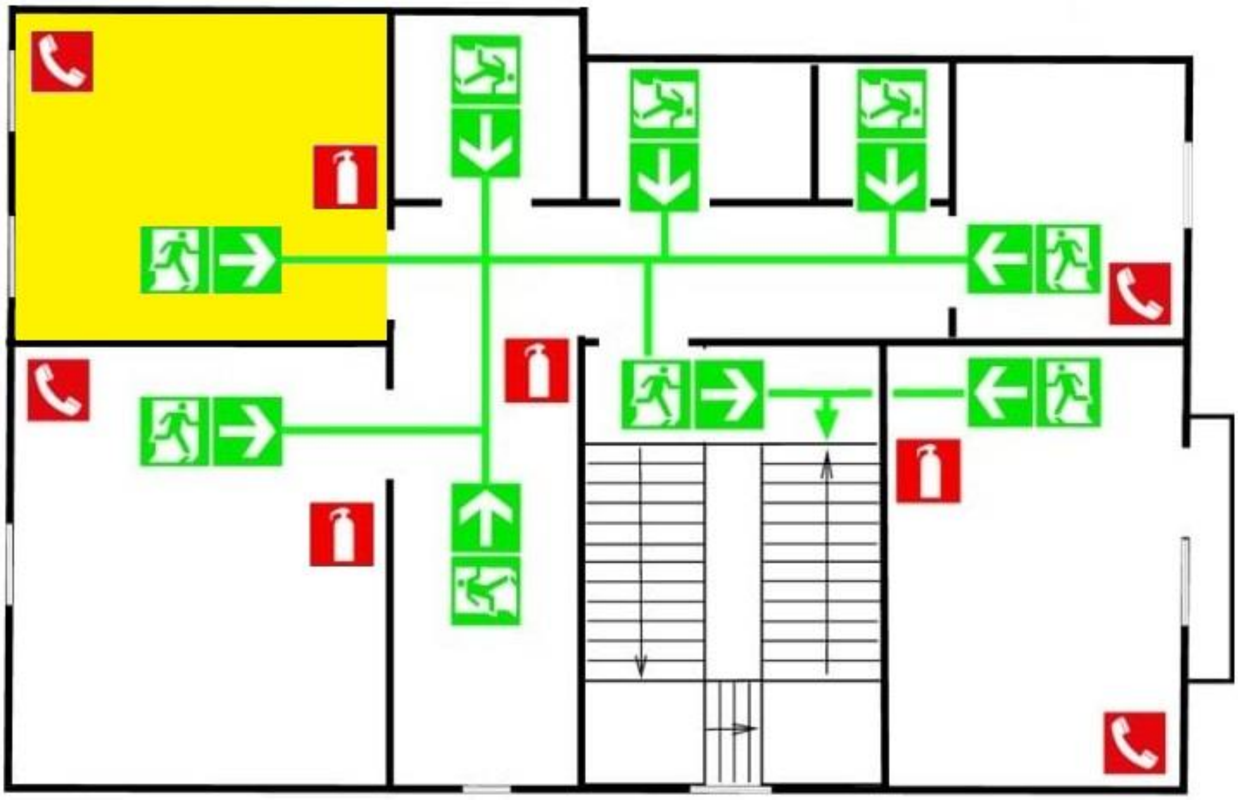


Figure 4.2. Emergency evacuation scheme

4.5. CERTIFICATION OF WORKPLACES ACCORDING TO WORKING CONDITIONS

Attestation of workplaces under working conditions - a comprehensive assessment of all factors of the production environment and labor process, related socio-economic factors that affect the health and efficiency of workers in the workplace.

Attestation of workplaces under working conditions is carried out at enterprises and organizations regardless of ownership and management, where the technological process, equipment, raw materials and materials are potential sources of harmful and dangerous production factors that can adversely affect the health of workers.

The main purpose of the certification is to regulate the relationship between the employer and employees in the field of realization of the rights to healthy and safe working conditions, preferential pensions, benefits and compensation for work in adverse conditions.

Attestation is carried out in accordance with the Procedure and methodological recommendations for attestation of workplaces under working conditions, approved by the Ministry of Social Policy and the Ministry of Health. The attestation is carried out by the attestation commission, the composition and powers of which are determined by the order of the enterprise, organization, within the terms stipulated by the collective agreement, but not less than once every five years. The commission includes an authorized representative of the elected body of the primary trade union organization, and in the absence of a trade union organization - an authorized person of employees.

Responsibility for timely and high-quality certification rests with the head of the enterprise, organization. Extraordinary attestation is carried out in case of a radical change in working conditions and nature on the initiative of the employer, trade union committee, labor collective, bodies of the State Labor Service. Design and research organizations, technical labor inspections of trade unions, territorial bodies of the State Labor Inspectorate may be involved in the certification.

Certification of jobs includes:

- establishing the factors and causes of adverse working conditions;
- sanitary and hygienic study of factors of the production environment, the severity and intensity of the labor process in the workplace;
- comprehensive assessment of factors of the production environment and the nature of work on the responsibility of their characteristics to occupational safety standards, construction and sanitary norms and rules;
- establishing the degree of harmfulness and danger of work and its nature according to the hygienic classification;

- justification for classifying the workplace with harmful (especially harmful), difficult (especially difficult) working conditions;
- determination (confirmation) of the right of employees to preferential pension provision for work in unfavorable conditions;
- compiling a list of jobs, industries, professions and positions with preferential pensions for employees;
- analysis of the implementation of technical and organizational measures aimed at optimizing the level of hygiene, nature and safety.

Hygienic studies of factors of the production environment and labor process are carried out by laboratories certified by the State Labor and the Ministry of Health in the manner prescribed by the Ministry of Social Policy together with the Ministry of Health.

Assessment of working conditions during certification of workplaces is carried out in order to establish classes (degrees) of harmful working conditions in accordance with the State Sanitary Norms and Rules "Hygienic classification of work on the indicators of harmfulness and danger of environmental factors, severity and intensity of the labor process."

Information on the results of job certification is entered in the map of working conditions, the form of which is approved by the Ministry of Social Policy together with the Ministry of Health. The list of jobs, industries, professions and positions with preferential pensions for employees after approval by the trade union committee is approved by order of the enterprise, organization and is maintained for 50 years. The results of the certification are used to develop measures to improve working conditions and health of workers and in determining the right to an old-age pension on preferential terms, benefits and compensations from enterprises, institutions and organizations, justification of proposals for changes in lists of industries, jobs, professions, positions and indicators in which employment entitles to an old-age pension on preferential terms.

Control over the quality of attestation of jobs by working conditions, the correctness of the lists of industries, works, professions, positions and indicators, employment in which entitles to an old-age pension on preferential terms, Lists of industries, works, shops, professions and positions, employment in which entitles to additional annual leave for work with harmful and difficult working conditions and for the special nature of work, the List of industries, shops, professions and positions with harmful working conditions, work in which entitles to reduced working week, harmful and especially difficult and harmful and difficult working conditions, which set increased wages, and other regulations, in accordance with which benefits and compensation are provided to employees for working with harmful working conditions, relies on the State Labor.

CONCLUSIONS 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. ENVIRONMENT PROTECTION

5.1. SOIL CONTAMINATION

Soil pollution is understood as a change in its physicochemical composition due to the introduction of substances harmful to living organisms (bacteria, microorganisms, fungi, arthropods, etc.), as well as vegetation and animal life, and human health. Soil depletion is a decrease in fertility, a decrease in nutrients, a layer of humus, a violation of the structure (permeability, lumpiness, etc.).

Plants come into direct contact with the soil. The direct impact on a person of contaminants introduced into the soil can be only in special cases, the ingress of earth on the wound, work in conditions of strong dustiness, severe contamination of food. Typically, hazardous pollutants enter living organisms through the soil-plant-human and soil-plant-animal-human chains.

Aviation influences the ecological state of the soil, first of all, in the areas where airports are located. Complexes of large airports occupy tens of square kilometers. In addition, due to noise and chemical pollution of the environment, the area around the airport within a radius of a kilometer and more limited usability.

The main sources of pollution are aviation technical bases, aircraft, special vehicles, aircraft repair shops, air traffic control facilities, warehouses for fuels and lubricants, including aviation chemical works, as well as pollution due to aviation chemical works. The airport, as the main production unit of the industry, concentrating the main complex of air transport operations, can be considered as an integral total source of harmful factors.

Soil, surface water bodies, groundwater are polluted by industrial and surface runoff of rain, melt and irrigation water from the contaminated areas of the airport. Surface runoff from the airport, primarily from the runway, taxiways and parking areas, is contaminated with oil products, chemicals used to combat glaciation, and various chemical compounds formed during engine operation.

The results of studies carried out by American specialists at the airports of Dallas, Washington, Chicago and Kansas City showed that at these airports in the area of aprons, parking lots, as well as in hangars and workshops, up to 36 tons of various substances enter the soil annually, in particular , hydrocarbons, chemical compounds used for aircraft cleaning, anti-icing agents, mineral and organic oils, phenols, etc. Soil pollution is especially high due to fuel leaks and spills. For example, the share of hydrocarbons in the total soil pollution at Chicago airport is 75-80%. A large amount of pollution products enters the soil and spreads in it over long distances along with surface and soil waters, disrupting the normal life of soils, polluting groundwater and surface water bodies. Studies carried out by the Research Institute for Water Protection have shown that surface runoff from the airport is characterized by a high content of impurities harmful to soils and water bodies: oil products, organic impurities, ethylene glycol, ammonium nitrogen, etc.

As a result of studies carried out by the Institute of Mineralogy, Geochemistry and Rare Earth Elements, a high content of a number of elements not typical for these geochemical regions was found in the soils around the airports.

These zones of chemical pollution extend to a significant distance from the point of entry into the environment. It was also found that chemical elements accumulate in the bottom sediments of water bodies and in plants in the territories adjacent to the airport.

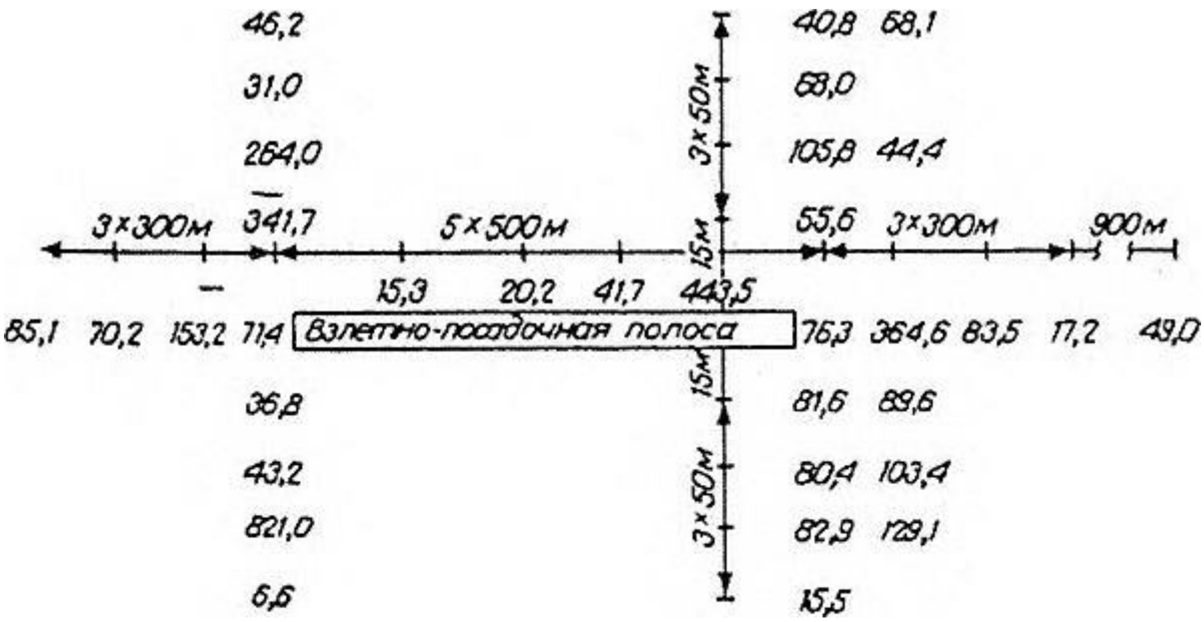


Figure 5.1. Distribution of benzopyrene in soil in the Ferihegy airfield area (in µg / kg)

The paper studies the effect of PAH emissions from aircraft engines on the degree of soil pollution. A significant emission of gasoline from aircraft engines is observed during takeoff and landing. In fig. 5.1. shows the distribution of benzopyrene in soil in the airport area. The highest concentrations of benzopyrene in soil are found in the runway area.

5.2. WATER CONTAMINATION

Warehouses for fuels and lubricants play a significant role in the pollution of open water bodies and groundwater. These contaminants are formed from leaks during storage, transportation and unloading operations with oil products, flushing water during cleaning and flushing of tanks and pipelines, and settled water from tanks.

Fuels and lubricants spilled on the surface of the water first form streaks, then films. These films are emulsified and biodegradable and can settle after oxidation. Fuels and lubricants spilled on water are removed using barriers (slats, flexible tubes), sorbents, reagents that bind fuels and lubricants, scraper devices, etc.

Fuels and lubricants penetrate into the soil mainly under the influence of gravity and surface-active forces. The distribution of fuels and lubricants depends on the type and structure of the subsoil, hydrological conditions and properties of fuels and lubricants (density, viscosity, wetting ability, content and types of additives and other properties). Permeability and capillarity - physical parameters characterizing sedimentary rocks, depend on particle size distribution and bulk density. Non-porous rocks are characterized by cracks, crevices, exfoliated surfaces and karst phenomena. The permeability of the soil or rock, which characterizes the seepage rate and lateral spread of fuels and lubricants, ranges from 10'2 to 10 "5 m / s for water-saturated sedimentary rocks and decreases with an increase in the water content in the rock. a certain "volume", the shape and size of which depends on the above factors.

In fig. 5.2 shows an example of the spread of mineral oil in a multilayer subsoil, and Fig. 5.3 shows the spread of oil at the water table in a subsoil of the same type (vertical section). On contact with water in the subsoil, some of the oil components may dissolve and migrate with the water.

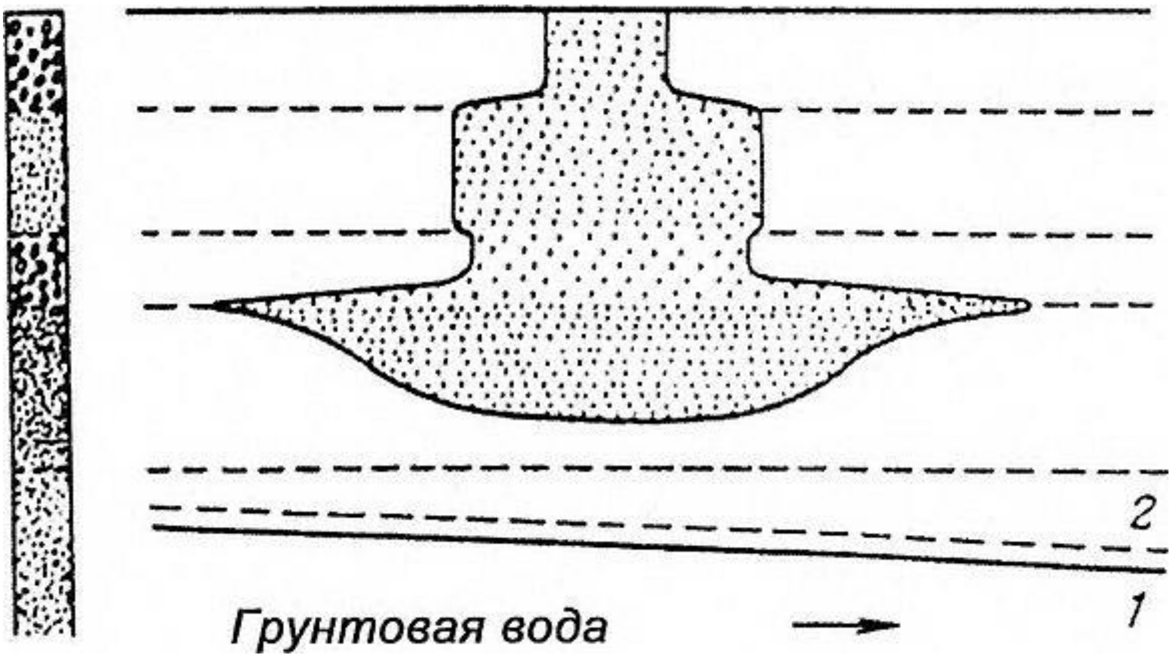


Figure 5.2. Distribution of mineral oils in a multilayer subsoil (vertical section): 1 - groundwater level; 2 - capillary layer

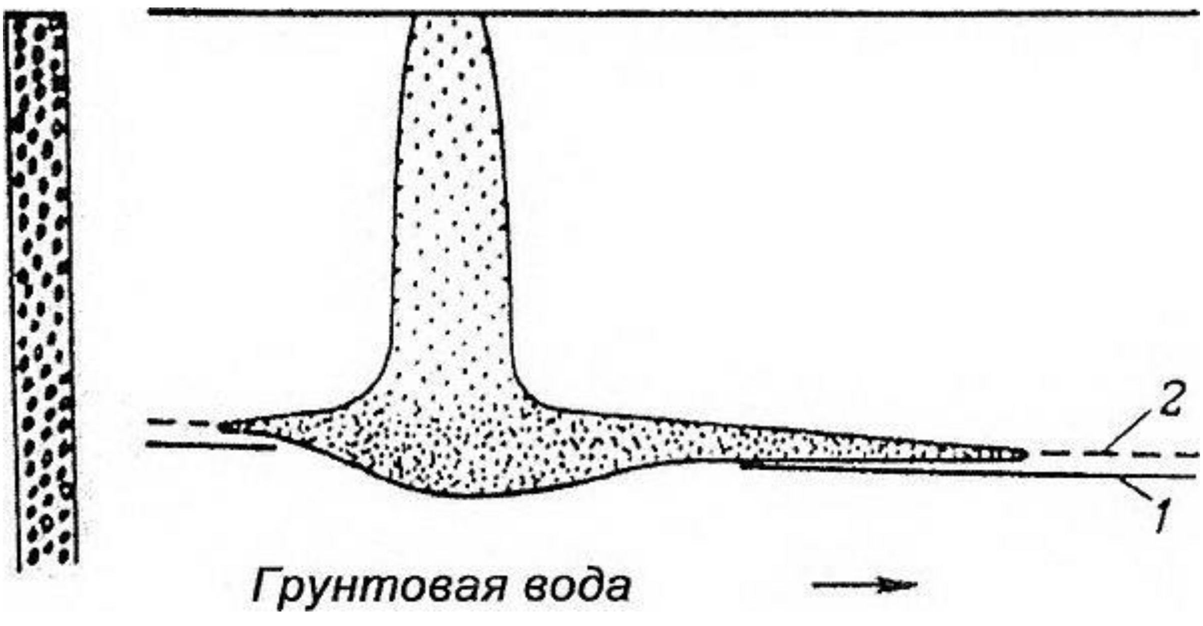


Figure 5.3. Distribution of mineral oil in the zone at the water table in the case of a homogeneous subsoil (vertical section): 1 - groundwater level; 2 - capillary layer

5.3. PECULIARITIES OF SEEPAGE OF CHEMICAL SUBSTANCES

Mineral oil seepage depends on the composition and physical properties of sedimentary rocks. In layers of increased permeability, oil products spread mainly in depth. With a decrease in the permeability of the layers, seepage slows down and the contamination zone grows mainly in width.

Depending on the chemical structure (aromatic hydrocarbons, naphthenes, paraffins), the content of heteroorganic compounds and additives, molecular weight, etc. Oxygen and microorganisms (bacteria, fungi) act differently on fuels and lubricants. Under aerobic conditions, the rate of decomposition depends on the content of mineral salts and trace elements, temperature and pH value. In the case of hydrocarbons dissolved in water, the rate of their decomposition is determined by the chemical structure and oxygen content of the water. Olefins and aromatic compounds are oxidized to oxygen-containing compounds (alcohols, ketones, phenols, carboxylic acids) in a relatively short time. The biological decomposition of hydrocarbons consumes oxygen with the formation of ammonia, hydrogen sulphide and salts of ferrous iron and manganese under the prevailing reducing conditions.

Natural self-cleaning of the soil, depending on natural and climatic conditions, requires at least 5-10 years, and in the Far North and Siberia - 15-20 years, since low temperatures in these regions slow down biological processes. Oil products spread over the lens of permafrost, as a result, the temperature balance and gas exchange are disturbed, the permafrost thaws, and the structure of the soil changes. As a result, the already fragile ecological ties of soil life are destroyed, and after that the entire biocenosis of this tundra region is destroyed.

Oil products entering the soil change its physicochemical properties (microelement composition, water-air and redox regime), suppress the nitrifying ability, reduce the species formation of microorganisms, inhibit the development of bacterial microflora, disrupt the balance of substances, etc. An excess of organic hydrocarbon substances entering the soil with oil products changes the normal ratio of carbon and nitrogen, and also leads to a deficiency of oxygen, nitrogen and phosphorus.

In soils contaminated with oil products, two differently directed processes arise: microbiological destruction of bituminous substances and their physicochemical weathering, as a result of which there is a gradual decomposition of oil products and the interaction of bituminous substances with soil organic compounds, which leads to a rearrangement of the group composition of humus and partial fixation in soils. introduced organic carbon. The intensity of certain processes varies depending on the characteristics of the local landscape-geochemical conditions.

It has been established that in soils with a heavy texture, along with a real threat of excessive accumulation of pollutants as a result of the high sorption capacity of soils, in conditions of rugged relief and excess precipitation, there is a danger of contamination of local water bodies and river floodplains. Light texture soils with low absorption capacity and high water permeability are less susceptible to oil pollution than loamy soils. On sandy soils, the risk of contamination of soil and groundwater by mobile components increases.

The biological properties of the soil change depending on the amount of oil products entering the soil. When the soil contains 100-200 t / ha of oil products, the vital activity of all studied groups of microorganisms is stimulated, with an increase to 400-1000 t / ha, inhibition of the biological activity of soils is observed, which consists in a decrease in the growth and development of microorganisms, the level of enzymes and the intensity of soil respiration.

5.4. THE CONSEQUENCES OF SOIL AND WATER CONTAMINATION

The consequences of soil contamination with chemical compounds are manifold. First, the presence of these substances in the soil, many of which are chemically aggressive and biologically active, disrupts the processes of its normal life, has a detrimental effect on the organisms living in it, suppressing, accelerating or changing their life cycles. Secondly, they can accumulate in water, algae, plants and enter the organisms of animals and humans along the food chain. Thirdly, entering open water bodies, underground waters, they enter the body of animals and humans with water. And, finally, fourthly, a certain amount of them enters the atmospheric air in the form of vapors and dust and, being transported over considerable distances, also sooner or later enter living organisms. One way or another, on the way of their complex migration, pollutants are included in the life cycles of biological organisms, ultimately causing damage to all life on Earth.

5.5. WAYS OF SOLUTION

The impact of industrial and economic activities of airports on the state of soils, water bodies and groundwater requires serious and careful study, as well as the implementation of measures to prevent soil pollution. This includes, first of all, the rational use and prevention of spills of aviation fuel, oils and other harmful chemicals, the correct organization of the collection and delivery of waste oil products, as well as the collection, treatment and disposal of contaminated effluents. Relatively high concentrations of harmful impurities are contained in the surface runoff from the territories of large airports performing large volumes of air transport operations. Research carried out by the Research Institute for the Protection of Waters showed that the sources of surface runoff pollution are unevenly distributed throughout the airport, therefore, first of all, it is necessary to ensure the treatment of effluents from aircraft maintenance areas, areas with heavy traffic of special vehicles and aerodrome equipment.

Wastewater from storage facilities, fuel and lubricants, before being discharged into the sewer, must be cleaned in oil traps or flotation plants.

Of great importance is the participation of airlines in the fight against soil erosion, including turfing and planting of greenery in areas prone to threatening erosion, equipping test sites and engine racing with jet deflectors.

To develop methods for cleaning oil-contaminated soils, studies of the microbiological breakdown of oil and oil products have been carried out.

The decomposition of organic matter entering the soil consists of two main stages - mineralization and humification. The result of the first stage is the gradual disappearance of organic and the formation of mineral compounds that are included in the biological cycle. The second stage ends with the conservation of organic matter and newly formed humic compounds resistant to decomposition. Biochemical processes of decomposition of organic matter in the soil occur with the direct participation of biological catalysts - enzymes of microorganisms.

The rate of decomposition of oil products in the soil is influenced by the physicochemical and biological properties of the soil, climatic conditions, as well as the chemical composition of oil products. According to the rate of destruction in the soil, organic matter can be divided into 3 groups:

• comparatively easily degraded and do not form transformation products that are stable in the soil (anaphthol, phenol, thymol, cresol, etc.);

• substances stable in the soil (a-naphthylamine, etc.);

• substances that form long-lived, stable in the soil transformation products (indole, p- and o-toluidine, etc.).

To activate the microbiological processes of decomposition of oil products and accelerate soil self-cleaning, an effective means is the introduction of soluble nitrogen and phosphorus fertilizers into the soil; in case of severe pollution, it is advisable to add surfactants. For the reclamation of soils contaminated with oil products, the following methods are advisable: mechanical cleaning, burial and incineration, agrotechnical and biological reclamation, the use of dispersants and intensifiers of microbiological decomposition of oil products.

Soil pollution results in groundwater pollution. Particular attention should be paid to the protection of groundwater intakes.

To protect groundwater from pollution, special measures are also used both to prevent pollution and to localize or eliminate a site of contaminated groundwater already created in the aquifer. A detailed composition and a feasibility study of these measures, depending on the nature of the source of groundwater pollution, hydrogeological conditions, should be developed according to a special project.

CONCLUSIONS TO CHAPTER 5

1. Aviation influences the ecological state of the soil, first of all, in the areas where airports are located. The main sources of pollution are aviation technical bases, aircraft, special vehicles, aircraft repair shops, air traffic control facilities, warehouses for fuels and lubricants, including aviation chemical works, as well as pollution due to aviation chemical works.

2. The consequences of soil contamination with chemical compounds are manifold. The biological properties of the soil change depending on the amount of oil products entering the soil.

CONCLUSIONS

1. The developed algorithms are the basis for compiling automated control programs and for confirming messages
2. For the most frequent distribution laws of deviations of the quality indicator, the reliability of diagnosis depends on the ratio of the a posteriori and a priori values of its standard deviations.
3. The most common way to organize control programs based on frame-by-frame data processing is to build them in the form of sequential checking of conditions
4. A generalized class of the Agnesi function is proposed as a mathematical model for approximating the processes of factorial resonance in AA.
5. Checking by the method of least squares showed the fundamental possibility of using the generalized class of the Agnesi function as an approximation model with an acceptable level of error.
6. Studies of the angle of attack, as a generalized indicator of factorial resonance according to the mathematical model of Agnesi, taking into account the probabilistic additive effect, the probabilistic multiplicative effect, taking into account the entropy model, have shown that the most dangerous factor from the point of view of the occurrence of factor resonance is the factor overlap in the form of factorial multiplication (complex simultaneously acting factors).
7. The angle of attack, as a generalized indicator of factorial resonance, is the central indicator of flight safety. Therefore, the elimination of factor resonance zones in terms of the angle of attack should be carried out by all forms of flight management, which will increase the level of aircraft flight safety.

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