KAPITEL 3 / *CHAPTER 3* [3]

SCIENTIFIC AND PRACTICAL ASPECTS OF SECURITY FLIGHT SAFETY

DOI: 10.30890/2709-2313.2024-26-00-026

Introduction

Ensuring flight safety is an important issue. As a result of flight events, people die, expensive aviation equipment is lost, the rhythm of air transportation decreases, and faith in the reliability of aviation equipment is undermined (Figure 1).

Figure 1 – Study of the biggest plane crashes in the world [20]

The work of large teams of representatives of aviation science and technology [1-27], aimed at increasing the reliability and improving the flight technical characteristics of aircraft, improving the technologies of production and operation of aviation equipment, caused a certain increase in the level of flight safety. At the same time, significant progress in aviation has given the problem of flight safety extreme urgency, which is due to several main reasons. 1) The complexity and responsibility of tasks that are solved using aviation around the world. The use of modern aircraft is characterized by a large information load for crews, rapidity of control processes, use in various

---

[3] ***Authors:*** *Lobunko Oleksandr*

external conditions of day and night, in areas of high air traffic density, over water areas, in the stratosphere and at extremely low altitudes (table 1).

Table 1 – Data from the study of the world's ten largest air crashes by the number of passenger casualties (1974-2023) [formed on the basis of 20]

№	Aircraft	Number of victims	Year	Disaster site	Country of aircraft owner	Reason disasters
1.	Boeing-747	578	1977	Canary Islands	Netherlands, USA	Incorrectly received dispatcher command
2.	Boeing-747	520	1985	Japan	Japan	Poor repair aircraft
3.	IL-76, Boeing-747	349	1996	India	Kazakhstan, Saudi Arabia	Clash in the air
4.	DC-10	346	1974	France	Turkey	Opening the hatch of the cargo compartment
5.	Boeing-737	329	1985	Atlantic	India	Terrorist attack
6.	Boeing-777	298	2014	Ukraine	Malaysia	Terrorist attack
7.	IL-76	275	2003	Iran	Iran	Collision with the ground in conditions of poor visibility
8.	A 300	264	1994	Japan	China	–
9.	DC-8	250	1985	Newfoundland	Canada	Loss of speed on takeoff
10.	DC-10	257	1979	Antarctica	New Zealand	Collision with the ground

2) The complexity and cost of aviation equipment, in connection with which the complexity of the implementation of the process of operating modern aircraft on the ground and in the air and the price of material damage from the loss of aircraft correspond. 3) Aviation has become one of the most massive spheres of human activity. Ensuring flight safety involves not only specialists who directly maintain the complex complex of on-board and ground equipment of modern aircraft, but also a large number of people who participate in design, production and testing. Shortcomings and miscalculations that are allowed at all these stages can, ultimately, be revealed in the process of operation and use of aircraft and be expressed in a decrease in the level of flight safety (table 1).

3.1. Theoretical and practical basis of flight safety

3.1.1. Aviation and transport system

Aviation and transport system – a set of jointly operating aircraft, a complex of ground facilities for training and support of flights, personnel involved in the operation and repair of aircraft and ground facilities, as well as a management system for the operation process. The aviation transport system is characterized by the following technical system features: 1) a single goal (flight efficiency and safety); 2) manageability of a system with a hierarchical structure; 3) interconnection of subsystems consisting of a large number of interacting elements; 4) availability of various sources of information; 5) vulnerability during the action of random factors; 6) features of self-organization. A special place in the aviation and transport system is occupied by the flight safety system. Comprehensive consideration of flight safety issues based on the study of the properties of the aviation transport system necessitated the use of research methods *reliability of complex technical systems*, and *human reliability* as an operator in a man-machine system. From the point of view of ensuring flight safety, the aviation transport system is a set of subsystems that interact in the processes of flight preparation and execution. Each subsystem has characteristics of complex systems and in the process of analysis can be considered as an independent system, which includes aviation equipment, aviation personnel and regulatory and technical documentation.

The "Flight crew – Aircraft" system – the main link of the aviation transport system, which ensures the use of aircraft as intended. Flight crew, as the final link of the aviation transport system, performing a flight, *feels the shortcomings of the aircraft design*, air traffic control, organization and provision of flights, as well as negative external actions.

The functional efficiency of the crew depends mainly on the level of professional training, discipline and psychophysiological state. The functional efficiency of aircraft is determined by its design and construction and ergonomic perfection, survivability and operational technology. The design and ergonomic perfection of aircraft is formed in the process of preliminary research at the stages of developing technical solutions, manufacturing prototypes and mass production (Figure 2).

Reliability and failure-free operation are characteristics that are formed at the stages of design, manufacture, testing, serial production of aircraft and during its operation. *Flight operation system* of aircraft determines the activity of the crew and other elements of the aviation transport system using regulatory documents that contain relevant recommendations for preparing and performing flights in expected and special flight conditions.

Figure 2 – Element of the aviation transport system

The effectiveness of the system is determined by the regulation of the preparation and execution of flights, the preparation and operation of aircraft, as well as the regulation of flight activities, admission to flights under the established conditions and admission to the performance of aviation works. *Air traffic management system* ensures the movement of the aircraft along the given routes in the relevant flight zones, as well as on the approach to the airfield and in the area of the airfield. The effectiveness of the air traffic management system is determined by its perfection, reliability and failure-free technical equipment, professional training of dispatchers, organization, discipline and professional training of service personnel. Effectiveness depends on indicators of the quality of functioning of the named components - accuracy, reliability and completeness of displaying information about the state of the airspace, the volume of performed tasks. *System of technical operation* of aircraft is inherently planned and preventive and is built on the basis of such principles as compliance with planning during maintenance forms, timely prevention of failures of functional systems and their most important elements, and ensuring economic efficiency of technical operation.

In the performance of the tasks facing aviation, an important place belongs to the aviation engineering service, the main purpose of which is to solve a complex of tasks of technical operation of aircraft and ensure technical progress in aviation. The technical operation of an aircraft is understood as a complex system of engineering, technical and organizational measures that ensure the most effective use of the capabilities of aircraft, their high reliability and flight safety, minimal downtime during maintenance and repair, as well as a high percentage of serviceability and readiness for flight and reducing the cost of maintenance

Along with solving tasks in the field of technical operation of aircraft, the aviation engineering service takes a direct part in the improvement of aviation equipment and, first of all, in increasing its reliability and improving operational and repair manufacturability. This work is carried out by developing and presenting requirements to the Developers and Manufacturers of aircraft, participating in the process of proving the equipment at the stage of acceptance into operation and during operation. The aviation engineering service is also called upon to improve organizational forms and methods of maintenance and preparation of aircraft for flight, to introduce new means of mechanization and automation of production processes, to improve production management. The development of aviation requires the development of methods that would allow quantitative assessment of the degree of influence of various factors on flight safety. For this assessment, it is first necessary to consider the structure and characteristics of the aviation transport system. Structurally, the aviation transport system includes a number of elements: 1) Crew; 2) Aircraft; 3) Flight operation system; 4) Technical operation system; 5) Flight support system; 6) Aircraft control system. Applying a systemic approach to considering the problem of flight safety, separate elements of the aviation transport system or their combination can be considered as an independent system. The technical complexity of the modern aviation and transport system, the number of personnel of the services involved in the organization, preparation, execution and provision of flights, the operation of aircraft in a wide range of weather and climatic conditions generate a variety of factors that affect the final result of the flight. When considering the influence of these factors on the safety of flights in the aviation and transport system, it is necessary to take into account the scientific and methodological apparatus of "aviation ergonomics". This is a scientific discipline, the object of which is the **energetic system** "Operator – Machine – Environment". The term "Operator" means an actor involved in controlling an aircraft with its systems (Figure 3).

Figure 3 – Ergatic systems "Crew – Aircraft"

The term "Machine" refers to devices designed to transform information, energy, and matter. The term "environment" includes the entire external environment that affects the operator and the machine. Environment - microclimate, light climate, external information. Ergonomics examines the relationship between technical objects and the psychophysiological capabilities of the human operator controlling the system. Thus, aviation ergonomics is a specific branch of cybernetics that studies the general principles, processes and laws of management in energy systems with the aim of the most effective construction and application of these systems. The main goal of aviation ergonomics is scientific substantiation and development of recommendations for designers, designers, technologists, production organizers and operators regarding the creation and application of optimal energy systems, based on the technical requirements for the system.

3.1.2. Factors affecting flight safety

The aviation transport system can be considered as a complex system, each element (subsystem) of which includes machine and human links, that is, it is a typical man-machine subsystem with its specific properties. Practically all elements of the aviation and transport system can be called general factors that determine the reliability of the functioning of these elements, therefore, and which affect the safety of flights. These include: the level of technical equipment of the subsystem (service); functional efficiency of technical means; reliability of technical means; the level of organization of functioning of the subsystem (service); professional training of operators; level of discipline of operators; psychophysiological state of operators; the level of quality control of the functioning of elements and the system (service) as a whole.

The numerous set of factors affecting flight safety can be divided into three groups: technical, human and non-systemic. These factors, respectively, are determined by the reliability or failures of aviation equipment, errors by aviation personnel and adverse external flight conditions. All subsystems of the aviation transport system make a certain contribution to ensuring flight safety. But at the same time, the special, defining role of the "Crew - Aircraft" subsystem should be taken into account in this provision. This is due to the fact that, firstly, this subsystem directly performs the flight and is the most complex of all subsystems from a technical point of view; secondly, the rest of the subsystems (services) in their impact on flight safety are mediated by the actions of the flight crew (Figure 4).

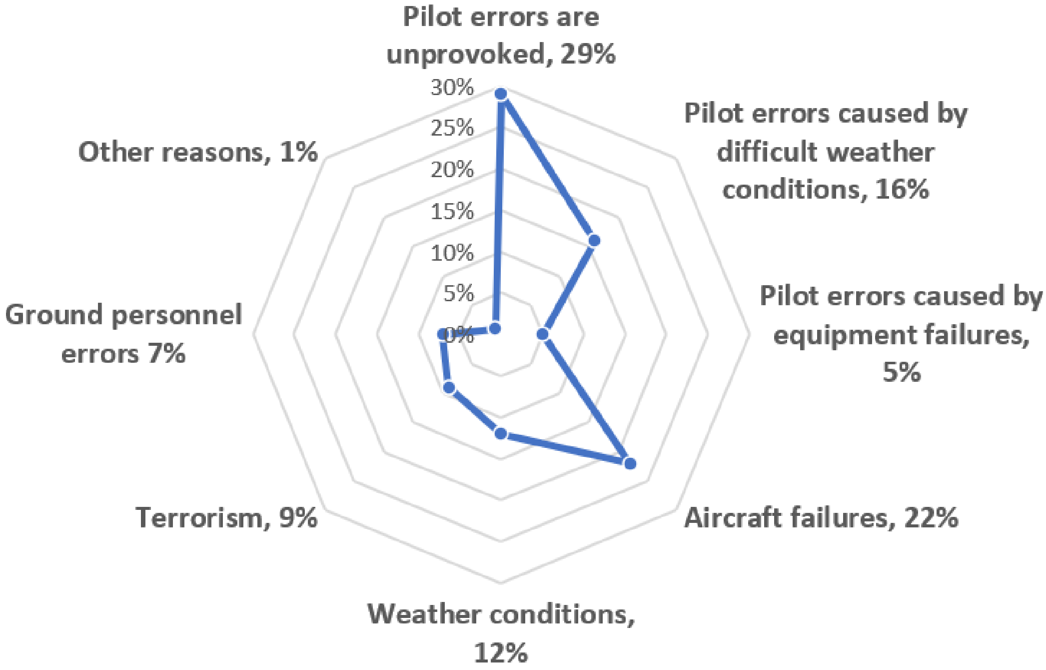

Figure 4 – Statistics of causes of aviation events

The second group of system factors is formed *Human factors*. These factors can be defined as violations, erroneous actions or inaction of persons related to the organization, preparation, execution and provision of flights. In this sense, these adverse factors appear as a consequence of very specific reasons embedded in the individual characteristics of people.

With regard to the "Crew – Aircraft" subsystem, according to the general scheme of the approach to establishing factors, as these reasons are considered those that determine the ability of flight crew members to successfully operate an aircraft, namely, professional level, psycho-physiological state, discipline, personal qualities of crew members Aviation event statistics maintained by ICAO show that the influence of each of these factors on the outcome of flights varies over time. This change is most clearly seen when comparing the influence of human and technical factors. Human error is not a kind of abnormal behavior, it is a natural by-product of almost all human efforts. Understanding how normal people make mistakes plays a key role in aviation safety management. They cannot be completely avoided, but they can be controlled through the use of improved techniques, appropriate training, and proper correction of procedures. Organizational procedures, including inadequate means of communication, unclear procedures, unsatisfactory schedules, insufficient resources, unrealistic planning, are fertile ground for many predictable human errors.

Errors can be divided into slips (an action that is not performed as planned) and omissions (failure of memory) and perceptual errors, that is, errors in recognition when we think we see something that is different from the fact. All these errors are radically different from violations, although both of them can lead to system failure. *Violation* – it is an intentional act, whereas a mistake is unintentional. That is, complete exclusion of errors is an unrealistic task. The challenge is not only to prevent mistakes, but also to learn how to safely overcome the inevitable mistakes.

3.1.3. Reliability indicators of personnel and the "Crew-Aircraft" system

The reliability of the flight crew's work within the framework of the ergonomic system "Crew – Aircraft" is determined by the concept of operator reliability. This is an important property, which consists in the failure-free performance of specified functions for a certain time under specified conditions. Quantitative indicators of system reliability include the probability of failure-free operation of aircraft, the frequency of failures, and the intensity of failures. The influence of psychological factors on the reliability of the operator's work is determined using the appropriate indicators: safety, timeliness, recoverability, readiness and psychophysiological tension.

Safety is the ability of the operator to maintain operational efficiency for a certain period of time before committing an error (error-free actions).

A probabilistic measure of infallibility

$$P_{INF} = n / N \qquad (1)$$

n – the number of successfully performed actions; N – the total number of performed actions.

The timeliness of the operator's actions is characterized by the probability of timely completion of tasks

$$P_{TIM} = n_{TIM} / N \qquad (2)$$

n_{TIM} – the number of actions performed in a timely manner.

Recoverability – the property of the operator to restore performance and maintain endurance is determined by the probability of error correction

$$P_{REN} = P_{INF} \cdot P_{DET} \cdot P_{COR} \qquad (3)$$

P_{INF} – the probability of providing information about a change in the position of the controlled object;

P_{DET} – the probability of detecting this representation;

P_{COR} – the probability of correction when the task is repeated.

The readiness of the operator is determined by the state of psychological readiness of the operator to perform the task, although this is not required at the moment. It is characterized by the readiness factor, defined as the probability of its inclusion in work at any arbitrary time.

$$R = 1 - (T_0 / T) \qquad (4)$$

T_0 – the time during which the operator is distracted from functional duties; T –

total time of performance of functional duties.

There are 3 levels (types) of psychological tension – moderate, elevated and stressful. *Moderate tension* – this is the normal state of the operator in the process of functional activity in uncomplicated conditions. It is characterized by normal well-being and confident execution of actions. *Increased tension* caused by the complication of the situation where the operator's activity takes place (complication of weather conditions, lack of time). Increased tension can be the cause of a decrease in working capacity, that is, a decrease in the reliability of the operator. *Stress* – a higher degree of tension arises in extremely unfavorable conditions of the operator's activity. Contributes to the disorganization of work, in which gross mistakes occur, attention is sharply narrowed. The degree of psychophysiological stress depends on the individual characteristics of the operator, that is, it is directly related to the personal factor. The reliability of the operator (crew) is characterized as

$$P_{CREW} = P_{INF} \cdot P_{TIM} \cdot P_{REN} \cdot R \tag{5}$$

Reliability of the "Crew - Aircraft" system

$$P_{CF} = P_{CREW} \cdot P_{E} \tag{6}$$

The technical capabilities of modern aircraft allow you to automatically perform certain operations and even solve certain tasks without human intervention, that is, the machine itself processes part of the information, forms command decisions and executes them. In this case, the operator (unlike simple ergative systems, where he always plays the active role of the executor) interacts with the machine primarily through information exchange. However, any automatic system of any complexity performs only the functions laid out in its program when it is turned on. The operator controls its operation, turns it on, turns it off, that is, maintains an active creative role in the flight process and is always the main functional component of the "Crew - Aircraft" system.

Non-system environmental factors (Figure 4) include those that do not depend on the internal properties of the aviation and transport system. Non-systemic factors can include: 1) strong wind, thunderstorm, rain clouds, hail, fog, dust storm, intensive icing of the plane, atmospheric turbulence; 2) the presence of birds, radiosondes, aircraft, and other foreign bodies in the airspace (the area where flights are carried out), creating a danger of collision with them. Non-systemic factors also include factors whose nature is not established.

Figure 5 – Extrasystemic risk factors

In many cases, it is not possible to strictly distinguish where the technology that provokes human error is to blame, and where the person himself is to blame. Therefore, all aviation accidents that occurred due to errors are often classified under the category of human factor, that is, part of the blame for technology is taken by a person. An aviation accident occurs, as a rule, as a result of the occurrence of several adverse factors in flight, which successively complicate the situation and can eventually lead to the loss of aircraft with or without the death of people. Thus, an aviation accident is a complex event, most often it does not occur according to a simple cause-and-effect scheme, but is a closing event in a chain of cause-and-effect relationships. The main requirements for the aviation transport system are the safety and regularity of flights, as well as the economy of aircraft operation. Airworthiness is a complex characteristic of an aircraft, which is determined by the principles and solutions implemented in its design and allows for safe flights under the expected operating conditions and according to the established operating methods. Preservation of airworthiness is ensured by carrying out a set of special measures during a certain stage of the life cycle of the aircraft and its components. The implementation of these measures ensures that at any moment during the entire service life of the aircraft, the current airworthiness requirements of the certification base are met and their condition ensures safe operation. The types of aviation events are: 1) aircraft breakdowns found in the parking lot; 2) a flight event that did not cause the death of people and the destruction of the aircraft; 3) a plane crash that caused the death of people and the destruction or damage of an aircraft.

All causes of an aviation incident must be established to prevent such an incident in the future. The most common cause of plane crashes is the human factor. According to statistics, the reasons are divided into groups, which are presented in Figure 4. The most dangerous parts of the flight are take-off and landing due to the low altitude of the flight and due to the lack of time to assess the problem that has arisen and solve it. Based on the generalization of statistical information, a diagram of the distribution of percentages of aviation events by flight sections was formed (Figure 6).

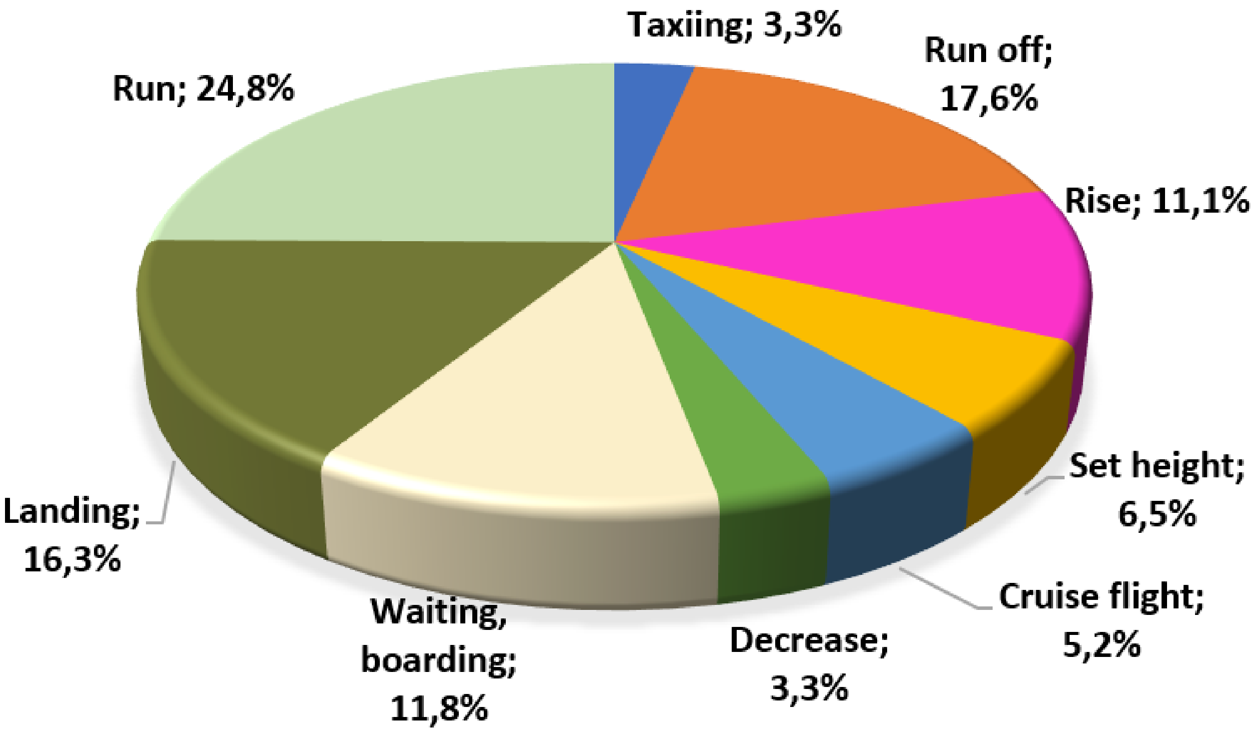

Figure 6 – Distribution of aviation events by flight sections

3.2. Multifactorial causes of aviation events

3.2.1. Special situations and aviation events

Expected operating conditions – conditions, which include the values of the calculated parameters, operational limitations, as well as the flight modes recommended and established for the aircraft of this type.

System functioning “*Crew – Aircraft – Environment*” always depends on many factors, the combination of which creates certain situations.

The degree of their danger can vary within very wide limits, in connection with which a certain gradation of situations that differ from normal flight has been adopted in international practice – *special situations*.

Depending on the degree of danger, four gradations of special situations are foreseen.

1. Complication of flight conditions – a special situation - characterized by a slight increase in the psychophysiological load on the crew, or a slight deterioration of the characteristics, controllability or flight characteristics. The complication of flight conditions does not lead to the need for an immediate, unforeseeable, change of the flight plan and does not prevent its successful completion. In the case of complicated flight conditions, the flight plan may be changed in accordance with the instruction of the Flight Operations Manual.

2. Difficult situation – a special situation characterized by either a noticeable increase in the psychophysical load on the crew, or a noticeable deterioration of stability, controllability or flight characteristics, or one or more flight parameters exceeding operational limits, but not reaching the limit limits or design conditions. Prevention of the transition of a difficult situation into an emergency or catastrophic one can be ensured by timely and correct actions of crew members (in accordance with the Flight Operations Manual), including an immediate change of the flight plan, profile or mode.

3. Emergency situation – a special situation characterized by either a significant increase in the psychophysical load on the crew, or a significant deterioration of stability, controllability or flight characteristics, which leads to reaching (exceeding) the limit limits or calculation conditions. Preventing the transition of an emergency situation into a catastrophic one requires high professional skills of the crew members.

4. Catastrophic situation – a special situation for which it is accepted that, when it occurs, it is practically impossible to prevent the death of people or the loss of an aircraft. Special in-flight situations are established based on pilot reports, objective control data, on-board documentation, personal observations of responsible persons, eyewitness accounts, and investigation results. The consequence of a special situation can be *aviation event*.

Aviation events, depending on the severity of the consequences, are divided into: disasters (aviation event with human casualties); aviation events without human casualties. Disasters also include the death of any of the persons on board during their emergency evacuation from the aircraft. Non-fatal aviation event: accident, aviation incident, serious incident. The following signs are characteristic of serious aviation incidents: flight of the aircraft beyond the expected operating conditions; the occurrence of significant harmful effects on the crew or passengers (smoke, vapors of caustic substances, toxic gases, increased or decreased temperature, pressure); a significant decrease in the working capacity of crew members; significant increase in psychophysical stress on the crew; receiving serious bodily injuries by any person who is on the aircraft; significant deterioration of stability and handling characteristics, flight or strength characteristics; emergence of a real possibility of damage to vital elements of the aircraft as a result of an explosion, fire, non-localized destruction of the engine, transmission; destruction or disconnection of control elements; damage to the elements of the aircraft, which is not related to the aviation event.

The connection between special situations and aviation events is not unambiguous and not always obvious. The practice of aircraft construction and operational activities of aviation enterprises allows us to assume that the airworthiness requirements of aircraft are met if it is shown (proved) that the total probability of a specific special situation due to functional failures does not exceed the following values for 1 hour of flight: for a catastrophic – 10^{-7} and less; for the emergency room – 10^{-6} and less; for complex – 10^{-4} and less These data are included in the airworthiness standards of aircraft.

3.2.2. Factors affecting flight safety

Flight safety is affected by many factors, which depend on the quality of the functioning of the aviation transport system. A factor is a moment, a significant circumstance in any process, phenomenon, for example: *time factor* – the role of time, duration, the factor of suddenness – unexpected actions and influences. A cause is a phenomenon that causes the emergence of another phenomenon. At the same time, each individual factor should be understood as any action, event, condition or circumstance, the presence or absence of which increases the probability of an unsuccessful flight termination. Considering the complexity and branching of the aviation transport system, it is practically impossible to list all the factors. All factors affecting flight safety can be divided into system and non-system factors. *Systemic* – factors determined by the internal properties of the aviation transport system. *Non-systemic* – environmental factors. They are constantly monitored (must be constantly monitored) by special technical means to prevent aircraft from falling into unexpected environmental conditions.

Most of the system factors are related to the crew's activities (human factor), and even to the efficiency of the equipment's functioning (technical factor). For each subsystem of the aviation transport system, the ratio of human and technical factors is different. For the "Crew – Aircraft" system, they are equal in number and importance of factors. The "Crew – Aircraft" system is central to the aviation and transport system and plays a decisive role in ensuring flight safety.

The classification of factors affecting flight safety can be carried out with varying degrees of detail. The human factor includes crew errors, aircraft maintenance errors, air traffic controller errors, and human-made documentation imperfections, etc. In order to assess the flight safety situation and develop measures to prevent them (comprehensive flight safety plan), all causes (factors) of aviation events are summarized into 10 groups. 1. Unsatisfactory management of flight activities (regulatory documents). 2. Unsatisfactory organization of flight work (flight organization and preparation). 3. Low professional level of the crew (knowledge). 4. Psychophysiological influence in flight (stress, fatigue, injuries, drugs). 5. Low level of discipline of specialists who perform and provide flights. 6. Design and production defects. 7. Unsatisfactory technical operation of the aircraft. 8. Unsatisfactory organization of air traffic. 9. Unsatisfactory provision of flights (navigator, meteorological). 10. Unspecified reasons.

To analyze the state of flight safety in ICAO, aggregated groups of causes of aviation events are used: a) due to the fault of the personnel of the aviation and transport system; b) due to the failure of aviation equipment of the aviation transport system; c) adverse environmental effects.

3.2.3. Causal relationships of events in flight

The analysis of the causes of aviation events and incidents shows that in most cases (up to 70%) during the development of aviation events, events occur that consistently complicate the situation in flight. Usually it is *a combination of various factors*, related to crew activity, functional efficiency of the aircraft, environmental conditions (Figure 7).

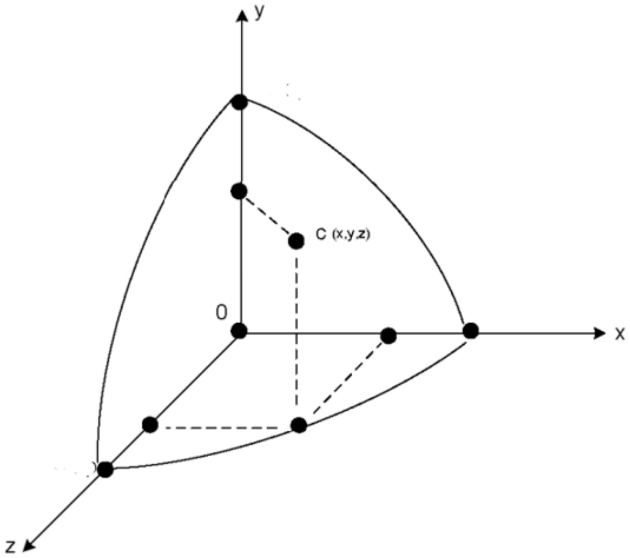

Figure 7 – Areas of safe and dangerous flight

In Figure 7, the axes are marked: *X* – functional efficiency of the aircraft, *Y* –

functional efficiency of the crew, Z – environmental conditions. X_M, Y_M, Z_M – limit values. Surface S divides the entire space into 2 subsets: *internal* – corresponds to a safe flight, *external* – emergency An emergency situation may occur if one of the factors exceeds operational limits and if all factors are within acceptable limits $C(x_1y_1z_1)$, but their unfavorable combination leads to critical consequences. Thus, an aviation event is, for the most part, a complex event and is the closing link in a chain of consecutive events that have cause-and-effect relationships. Hence, one of the concepts of ICAO regarding the prevention of aviation events is the timely detection and elimination of such events, which will lead to the "opening" of the chain to the emergency situation (Figure 8).

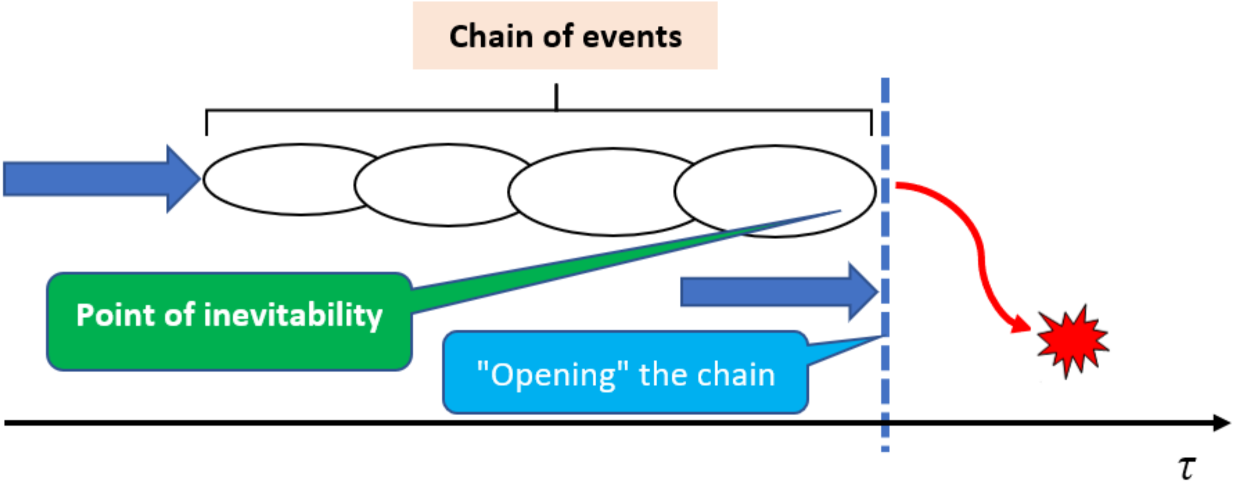

Figure 8 – Event chain diagram

Following the sequence of development of an adverse event, the following categories of causes of aviation events can be distinguished: main, direct and secondary. The main reason is that in this situation there is a real possibility of an aviation event. *Direct and secondary causes* – reasons that create real conditions for turning the possibility into reality (Figure 9). Thus, the direct cause is that which entails the occurrence of an aviation event. Usually, it is a consequence of the main cause. The general scheme of the development of an aviation event can be presented as follows.

The carriers of the main reasons are usually deficiencies in the design of aviation equipment, personnel training, imperfection of regulatory documentation, and others. Associated factors are superimposed or added to the main ones. Depending on the situation, the accompanying cause may act as a direct one.

A proximate cause is usually the last thing that happens before an aviation event. Elimination of secondary and immediate causes reduces the probability of an aviation event, but does not eliminate them, since the main causes are not eliminated. Thus, the most important thing in preventive activities is to eliminate the main causes. As a rule, they have a long-term nature. Their detection requires systematic work.

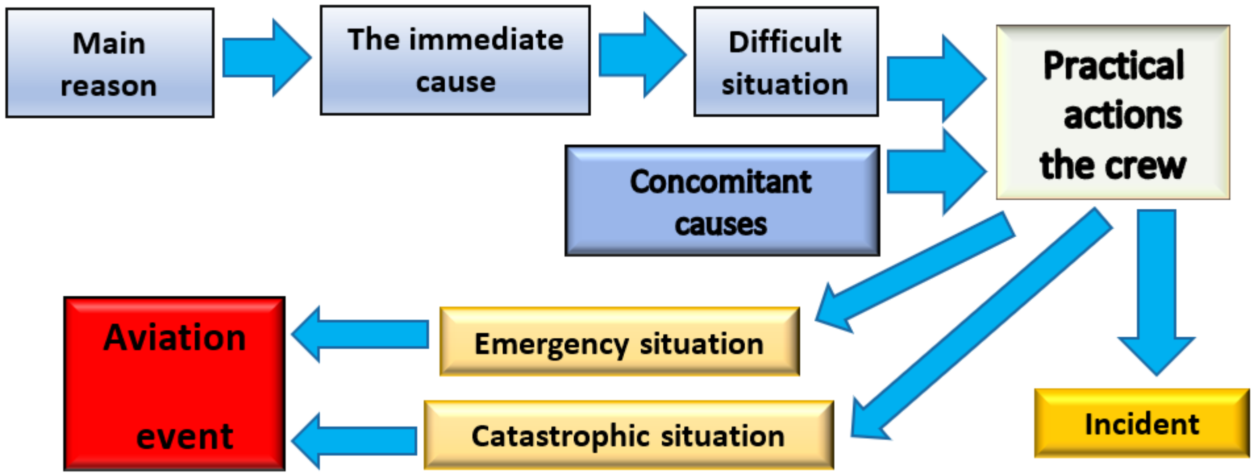

Figure 9 – Development scheme of an aviation event

3.3. Quantitative and qualitative assessment of flight safety

3.3.1. A model of the development of a special situation over time

The safety of flights is affected by the reliability of the functioning of the aircraft and its systems, ground technical means, the flight crew and the personnel of the services and units that provide the flight, as well as the external conditions of the functioning of the aviation system.

The state of the "Crew – Aircraft" system is characterized by a certain set of parameters, which include the coordinates of the spatial position of the aircraft, parameters of the engine and systems, the configuration of the aircraft, and the psychophysiological state of the crew. Among this population, parameters can be singled out, the change limits are limited by flight safety conditions, because the departure of their values beyond the limits creates a threat to flight safety. The state parameters of the "Crew – Aircraft" system, the values of which are subject to restrictions regarding flight safety conditions, are called *determining*. Examples of defining parameters are normal load n_y, aircraft flight time with near-zero and negative overload values, angle of attack α, speed V, Mach number and flight height H, roll angular velocity ω_x.

If the influence of adverse factors causes a change in the determining parameters that does not correspond to the flight task, then a special situation can be imagined as such a state of the "Crew – Aircraft" system, in which there is a danger of exceeding the limits of the values of at least one determining parameter. In the future, we will call the parameter that first reaches its permissible value under the conditions of flight safety *a critical determining parameter*. The characteristics of the process of changing the values of the critical determining parameter over time, caused by the impact on the "Crew – aircraft" system of some adverse factor or some combination of adverse factors, will be called the time characteristics of a special situation.

Let us consider the time characteristics of a special situation caused by the influence of an arbitrary adverse factor on the "Crew – Aircraft" system, in which some critical determining parameter X at a moment in time T_0 begins to deviate from the initial value X_0. Let the influence of an adverse factor at a time T_0 was such that the parameter X changes. That is, in the absence of the intervention of the crew or the autopilot of significance X will reach in time T_1 upper limit X_M. A period of time $T_{SS} = T_1 - T_0$ is called *during the development of a special situation*. Indeed, the smaller the value T_{SS}, that is, the faster the change process X in the interval $X_0 \rightarrow X_M$, the more dangerous the special situation and vice versa. The crew, having detected a parameter change that does not correspond to the flight program X with some delay $T_{INT} = T_2 - T_0$, intervenes in management and seeks to prevent the release of a critical determining parameter X for restrictions X_M. The success of the crew's actions in this special situation will depend on two factors: 1) The duration of the intervention delay, which is determined by the T_{INT}; 2) The nature of his actions, that is, the law of management that he implements.

A period of time $T_{INT} = T_2 - T_0$ – *intervention delay time*, or time of intervention, and is also a characteristic of a special situation. At the same value T_{INT} the result of the development of a special situation is determined by the law of intervention in the management of a change in value X. It is obvious that for each law of interference there exists, other things being equal, such a moment in time at which the implementation of this law of interference provides only a "touch" by the parameter X permissible restrictions X_M. The time interval between the moment of influence of an adverse factor and the moment of time, during which the intervention still ensures that the critical determining parameter does not leave the range of permissible values, is called *available time*. Available time T_P is together with T_{SS}, T_{INT} – characteristics of a special situation. Most often, the critical determining parameters are the flight parameters of the aircraft: n_y, α, V, H, ω_x. In this case, the amount of time for the development of a special situation T_{SS} is determined by the nature of the adverse factor, the dynamic properties of the aircraft and the flight mode and can be determined by integrating the equations of motion of the aircraft.

3.3.2. Qualitative assessments of flight safety

The purpose of a qualitative flight safety assessment is to identify the most potentially dangerous adverse factors for the "Crew – Aircraft" system, their causes and consequences. When it is carried out, quantitative calculations of the time characteristics of a special situation, the probability of the occurrence of adverse factors are performed, therefore the name "qualitative assessment" is quite conditional. The term "qualitative assessment" is used in the sense that the assessment results do not determine the quantitative level of flight safety, but only allow to judge the degree of potential danger of various adverse factors for the "Crew – Aircraft" system. A comparative assessment of the magnitude of the potential danger of adverse factors is the starting point for the development of measures to improve flight safety. This is precisely the independent value of a qualitative assessment. Qualitative assessment is based on a systematic approach and is performed in a certain sequence: 1. Study of the structure and properties of the object under investigation (Crew-Aircraft system, Aviation Engineering Service-Aircraft system, aircraft, technical equipment, personnel group), which is a potential source of adverse factors. 2. Identification of all possible adverse factors that may arise. 3. Determination of the possible causes of the occurrence of adverse factors, necessary for the development of measures to prevent them. 4. Determination of the consequences of unfavorable factors for the "Crew - Aircraft" system. 5. Determination of the degree of danger of the consequences ηF of the influence of adverse factors on the "Crew - Aircraft" system.

Since adverse factors cause a change in the determining parameters, the value η_F determined by the formula

$$\eta_F = \mathrm{e}^{-\frac{t_p - m_{t\text{в}}}{m_{t\text{в}}}} \qquad (7)$$

It follows from (7) that the value η_F depends mainly on the difference $t_p - m_{t\text{в}}$. The greater this difference, the lower the degree of danger.

At $t_p \to \infty$, $\eta_F = 0$, and at $t_p - m_{t\text{в}} = 0$, that is, when there is no time reserve $\eta_F = 1$.

To define η_F the method of expert evaluations on a five-point scale can be used: *ball 5* an unfavorable factor is evaluated, which, according to the expert, will not lead to a flight event under any circumstances; *ball 4* an unfavorable factor is evaluated, which, according to the expert, is more likely not to lead to a flight event; *ball 3* an unfavorable factor is evaluated, which, according to the expert, can lead to a flight event with equal probability; *ball 2* an adverse factor is assessed, which, in the opinion of the expert, is more likely to lead than to lead to a flight event; *ball 1* an unfavorable factor is evaluated, which, according to the expert, will necessarily lead to a flight event. Then

$$\eta_F = 1{,}25 - \frac{0{,}25}{m} \sum_{i=1}^{m} \eta Fi \qquad (8)$$

η_{Fi} – the point with which the expert assessed the degree of danger of the consequences of the influence of this adverse factor on the "Crew – Aircraft" system; m – number of experts.

6. Determination of the probability of the occurrence of adverse factors using the methods of probability theory, mathematical statistics, reliability theory and other branches of science.

7. Determination of the degree of potential danger

$$\varPi_F = \eta_F \cdot q_F \quad (9)$$

8. Ranking of adverse factors by size $\varPi_F$, which allows you to make decisions about the development of measures aimed at eliminating the causes of the appearance of those factors in the first place, the degree of potential danger of the consequences of which is the greatest, as well as at the improvement of the object under study. By repeating the qualitative assessment of flight safety after the measures have been taken, it is possible to evaluate their effectiveness in terms of expression

$$E_M = \varPi_F / \varPi^M_F \quad (10)$$

$\varPi^M_F$ – the value of the degree of potential danger of the consequences of the influence of some adverse factor after the measures taken.

3.3.3. Quantitative assessments of flight safety

Since an aviation event is a random event, the quantitative level of flight safety can be assessed only from a probabilistic, statistical point of view. Statistical and analytical criteria were used as a probabilistic measure of the level of flight safety. The statistical criteria of flight safety are based on statistical data on aviation events and flight of aircraft fleet for a certain calendar period.

Absolute and relative statistical criteria of flight safety are distinguished. The generally accepted absolute statistical criteria are: the total number of aviation events per calendar period; the number of accidents and catastrophes during the calendar period; the total number of prerequisites for aviation events; the number of dead crew members and passengers. The absolute losses of aircraft and people from accidents and disasters depend on the number and qualitative composition of the aircraft fleet, the total number of raids and many other factors. Absolute statistical criteria of flight safety are usually used when planning orders for aviation equipment taking into account its losses in aviation events, when clarifying items of costs for the development of aviation, when identifying general trends in the dynamics of accidents. The level of flight safety is more fully characterized by relative statistical criteria, which should primarily include:

1. Raid on one aviation event

$$T_{AE} = T_{SUM} / n_{AE} \qquad (11)$$

2. Raid on one disaster

$$T_{CAT} = T_{SUM} / n_{CAT} \qquad (12)$$

3) A raid on one prerequisite for an aviation event

$$T_{PAE} = T_{SUM} / n_{PAE} \qquad (13)$$

T_{SUM} – the total flight of the fleet of aircraft during the calendar period;

4) The relative number of victims of plane crashes on 10^8 passenger kilometers

$$\bar{m} = m \cdot 10^8 / \sum_{i=1}^{N} Lizi \qquad (14)$$

L_i – length in km of the i-th flight; z_i – the number of passengers transported in i-th flights; N – the number of flights performed by the fleet of aircraft during the calendar period.

In practice, ICAO uses indicators: the number of accidents per 100 million km flown, the number of accidents per 100,000 flights, the number of fatalities per 100 million passenger kilometers. Statistical flight safety criteria make it possible to: identify general trends in accident rate changes; conduct a comparative assessment of the level of flight safety for different types of aircraft, types of aviation, departments and states. Statistical criteria have a number of significant shortcomings that limit the scope of their application: they assess the level of flight safety already after flight events have occurred; they do not allow assessing the impact of a single adverse factor on flight safety; they cannot be used when solving the tasks of optimizing the level of flight safety taking into account efficiency and cost.

3.3.4. Analytical criteria of flight safety

As a result of the random occurrence of unfavorable factors in flight, successful and unfavorable flight results are random events. Therefore, it is possible to use the probability of a successful flight outcome as a criterion for quantitative assessment of flight safety P or the probability of an unfavorable flight outcome Q. The quantity Q can also be called the *risk level*.

Determining the probability of a successful flight outcome. In a separate flight, the "Crew – Aircraft" system can, in general, be affected by several unfavorable factors. When determining P, we will accept the following assumptions: unfavorable factors make up a group of independent events; the simultaneous occurrence of two or more adverse factors in flight is an unlikely event; events of countering the effects of adverse factors are independent. Under such assumptions and taking into account the fact that, in the general case, the quantity P is a function of time, we have

$$P(t) = \prod_{i=1}^{n} P_i(t) \tag{15}$$

$P_i(t)$ – the probability of a successful flight outcome in case of impact on the "Crew - aircraft" system i-th unfavorable factor; n is the number of adverse factors affecting the "Crew – Aircraft" system during the flight.

It is obvious that the flight will end safely with a probability P_i in the following two incompatible events: adverse factor with probability P_i will not occur in flight; adverse factor with probability $q_i = 1 – P_i$ will occur in flight, but the consequences of its influence will be countered with probability r_i. Then, bearing in mind that the probabilities P_i and q_i in the general case are functions of time that obtain the expression of the criterion P_i:

$$P_i(t) = P_i + q_i \cdot r_i \tag{16}$$

Having divided all adverse factors into three independent groups (personnel errors, equipment failures, adverse external conditions), the probability of a successful flight outcome can be presented in the form

$$P(t) = P_T(t) \cdot P_L(t) \cdot P_C(t), \tag{17}$$

$P_T(t)$ – the probability of a successful flight outcome in case of possible equipment failures; $P_L(t)$ – the probability of a successful flight outcome in case of possible human (crew members) errors the probability of a successful flight outcome; $P_C(t)$ – the probability of a successful flight outcome in the event of adverse external conditions (environment).

Determination of the probability of a successful outcome of a large number of flights. If some sufficiently large number N of flights are performed under the same flight safety level conditions, it is possible to record:

$$P_1 = P_2 = \dots = P_N = P; \; Q_1 = Q_2 = \dots = Q_N = Q.$$

Since flight events are rare and independent events, that is, the value of Q is very small, it can be considered that flight events as random events are subject to the Poisson distribution. Then the probability Q_{nLPN}, of what will happen in N flights n_{AE} aviation events ($n_{AE} = 1, 2, ..., N$), is equal to:

$$Q_{nLPN} = ((NQ)^{nAP} / n_{AP}) \, e^{-NQ} \tag{18}$$

Putting in the expression (18) n_{AE} = 0, we will obtain the expression of the analytical criterion of flight safety through the criterion of safety of one flight

$$P_{SF} = Q_{0,\, N} = e^{-NQ} = e^{-N(1-P)} \tag{19}$$

Expression (19) shows that the safety level decreases with an increase in the number of flights.

3.4. Reliability of technical objects in case of parametric failures

If failures are considered as going beyond the permissible limits of the value of the parameter of the technical object (component of the aircraft), which occur due to random changes of this parameter in time t (in the general case – as a function of any monotonically increasing value, which can be considered as), then these failures are called parametric (Figure 10). The reliability of the object in case of parametric failures is determined by the probability of failure-free operation $P\ (t)$, which is the functional $X\ (t)$ of some random process $\{t\}$, which characterizes the change of the object's parameters over time. Probability of fault-free operation of the object for a period of time $[t_0,\ t]$ is equal to the probability of finding the process $X(t)$ in the given permissible area Ω during this period of time

$$P\ (t) = P\{X\ (t) \in \Omega;\ \ \tau \in [t_0,\ t]\} \tag{20}$$

The object remains operational until the time-varying X value reaches the limit of the permissible working area Ω. The main technical parameter, which characterizes the object's performance and determines its degree of reliability, is called a *determining parameter*.

When solving a specific task, the values of deformation or mechanical stress, electrical or geometric parameters (characteristics) of the object, etc. can be considered as the determining parameter $X\ (t)$. If the determining parameter characterizes the

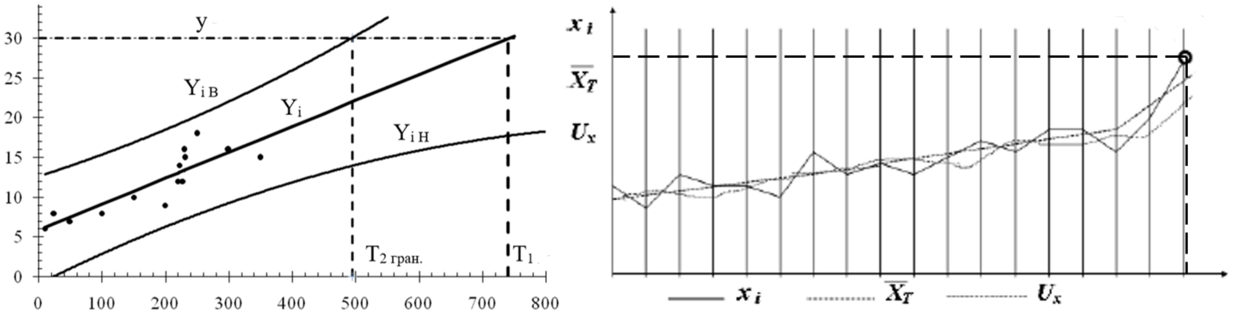

Figure 10 – Risks of changes in determining parameters over time

metrological indicators of the measuring instrument, its reliability, which is determined by the parametric failures of the determining parameter, is also called metrological reliability or information reliability.

In the general case, the determining parameter can be a vector, that is, have several components. The limit values that are set for each defining parameter of the object are the permissible values of the defining parameter that limit the working area (tolerance field). As long as the values of the vector defining parameter of the object are inside the multidimensional workspace, the object is considered operational. However, over time due to factors related to aging, wear, or misalignment, the end of the vector *X (t)* may reach the boundary of the working area *Ω*.

In this case, the object becomes inoperable (failure occurs). Due to the randomness of external and internal factors affecting the process of the object's gradual approach to parametric failures, changes in the determining parameter over time and the time each determining parameter reaches its limit are also random. Therefore, the most completely random process of the gradual failure of the object with respect to each determining parameter is described by the corresponding density of the distribution of the time of crossing the boundary of the working area by the determining parameter, that is, the density of the distribution of the time to failure. In the practice of operation of the object, it is more important to know not the density of the distribution of time to failure, but the specific time of serviceability, during which the determining parameter will not reach the limit of the working area. In the general formulation of the task, the time to reach the limits of the working area as a determining parameter can be considered as a system of random variables or a vector random process.

Let us consider the nature of the random process of approaching parametric failure using the example of an object whose performance is determined by a scalar determining parameter (one coordinate of a vector determining parameter). In this case, the space of the determining parameter X will be one-dimensional, and the working area Ω limited by a line segment (the limit value of the determining parameter X_M). Let there be a set $j = \overline{1,n}$, the same objects simultaneously included in the work ($t = 0$), and the defining parameters of each object are measured at the same points in time $t_i = (i = \overline{1,k})$. We will consider the change in the defining parameters of the same objects during operation as a random function of time $X(t)$. For each j-th object ($j = \overline{1,n}$) changing the defining parameters is an implementation (component) $X_j(t)$ random function $X(t)$. Crossing points of realizations $X_j(t)$ of a random process with a limit X_M of the working area (tolerance fields) correspond to the moments of failure of the j-th objects. Therefore, the random nature of the occurrence of gradual failures during the operation of the same objects is described by the density of the distribution $f\{X(t)\}$ time of crossing the border is a defining parameter X_M, that is, the density of the time-to-failure distribution.

If from the moment of inclusion in the work ($t = 0$), measuring with the same $\Delta t = t_{i+1} - t_i = t_i - t_{i-1}$ or with different frequency (interval) Δt, control the value of the defining parameter of each j-th object, it is possible to predict (extrapolate) further changes of the determining parameter, and therefore predict the moment of failure. This makes it possible to organize the maintenance of a group of objects, that is, to ensure the preventive withdrawal of objects for current or major repairs or sending them for regulation. Time interval from the beginning of operation of the object $t = 0$ until the moment when the output of individual implementations $X_j(t)$ random process $X(t)$ outside X_M work area is becoming a frequent phenomenon, they call it *during the maintenance of working capacity* t_{SL}. Right end of interval t_{SL} determined by the abscissa of the characteristic point of the distribution density curve $f\{X(t)\}$, starting from which a sharp rise in the curve is observed. Therefore, determining with the help of technical control means at fixed moments of time $t_1, \ldots, t_i, \ldots, t_k$ the value of the determining parameter $j = \overline{1,n}$ objects of the same type, implementations can be obtained $X_j(t)$ of the real process of changing the determining parameter. At the same time, the set of measurable y t_i, $i = \overline{1,k}$ the moments of time of the values of the determining parameters are characterized by a random value

$$X_i(t) = X(t_i) = \{x_1, x_2, x_3, \ldots, x_n, \}t_i$$

which has a density distribution $f(X)$ and evaluation of numerical characteristics - average value (mathematical expectation) m_{Xi} and variance D_{Xi}. A random variable $\{X\}t_i$ is called the value of realizations of the determining parameter under the i-th control. So, having information about the real process of changing the defining parameter for time $t_K < t_{SL}$ at the stage of operation or having the same information about analogues of the designed object at the stage of design, it is possible to analytically calculate the time of preservation of the object's operability, that is, make a reasonable forecast about its operability in the future. This will make it possible to warn in time of failure of aircraft in flight, as well as manage the state of objects, replacing their elements with spare ones or changing the operating modes of objects.

*Analysis of random processes of changing the determining parameter***.** A random process of changing the determining parameter $X(t)$ in the general case can be given by the sum of random processes

$$X(t) = x(t) + \xi(t) + \varepsilon(t), \tag{21}$$

$x(t)$, $\xi(t)$ – non-stationary and stationary random processes, respectively; $\varepsilon(t)$ – measurement errors.

Nonstationary random process $x(t)$ characterizes long-term irreversible changes in parameters as a result of wear, aging or misalignment. Process $x(t)$ – the main reason for failures, which we call the *wear process. A stationary random process* $\xi(t)$ reversible changes in parameters in the event of a change in external conditions causes intermittent (appearing/disappearing) failures. We note that they try to predict the possibility of reversible changes in parameters during the construction of objects. The process $\xi(t)$, if it is present, it cannot be neglected, but it is rarely found in aircraft and therefore is not considered here. Of course, when receiving a real process $X(t)$ as a result of measuring the determining parameter, the course of the process will also be affected by a stationary random process *ε(t) measurement errors*. And the processes *ε(t)* and *ξ(t)* it is not always possible to separate, that is, to separate real reversible changes of the determining parameter from imaginary ones caused by errors in measurements.

Let us present the random process of changing the determining parameter $X(t)$ according to expression (8) only by the irreversible wear process $X(t) = x(t)$. For random wear processes, fairly tight relationships between parameter values at successive time points are typical. Great impact on the type of process implementation $X(t)$ the physico-chemical structure of the material and the manufacturing technology of the object do. Objects of the same type give wear curves similar in shape, but with different wear rate values. Therefore, models of wear processes must be functionally dependent on time, and their random nature is determined by random parameters that do not depend on time. Such random processes are sometimes called *deterministic* or *semi-random*. In the practice of operating aircraft, even in the presence of built-in or portable control devices, it is not always possible to frequently measure the value of the determining parameter of individual objects. Therefore implementation $X_j(t)$ constructed from experimental data for moments t_i, $(i = \overline{1,k})$, have the form of broken lines, and one can only guess from the data of a limited number of vertical intersections (sections) what the random process looks like $X(t)$ actually.

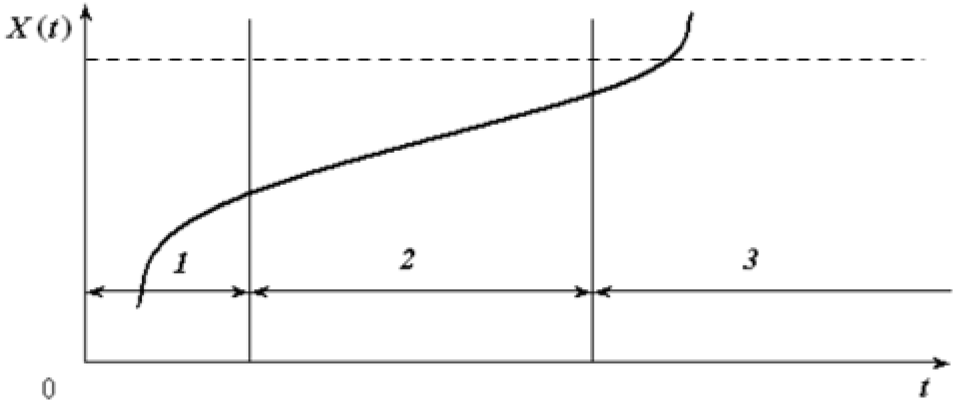

Figure 11 – Periods of change of the defining parameter of the object during operation

For this, it is necessary to put forward a hypothesis about the characteristic appearance of the wear curves, which is based on both experimental data and a priori information about the wear processes of similar objects. At the same time, for an arbitrarily chosen j-th object, the wear rate is random and individual for each object. Changes in the determining parameter depending on time or earnings (analogously with the intensity of failures) can generally be presented in three periods (Figure 6).

The first period is the profit of the object. The wear rate, which from the beginning of this period is not constant and changes over time, becomes a constant value by the end of this period. Of course, in the process of accretion there is a decrease in the rate of wear, however, although less often, there are cases of an increase in the rate to a stationary value. In order to increase the reliability and competitiveness of their products, large manufacturing companies carry out extra work at manufacturing enterprises, so their product can have a constant rate of wear from the beginning of operation. *The second period* characterizes the main (normal) period of operation, while the wear rate reached at the end of the service life remains approximately constant. *The third period* – the period of "aging" of the object: the possibilities of the object's functioning are exhausted, the rate of change of the determining parameter increases catastrophically.

The ratio of the rate of wear of the product during additional work (period 1) and main operation (period 2) can serve as an indicator of production efficiency and/or material quality.

3.5. Modeling the risks of the influence of the human factor

Taking into account the shortcomings in the prevention of aviation events due to the human factor, proactive modeling of dangerous events acquires special significance. The relevance of such modeling is confirmed by the still significant research results of General Designer Oleg Antonov (1906-1984), who established that only ergonomic modeling in the design of modern aircraft of various classes makes it possible to: 1) reduce the workload of flight crews by 20-40%; 2) increase piloting time for flight crews, while simultaneously improving working conditions by 30-60%; 3) reduce the probability of erroneous actions of flight crews and increase the reliability of their work in special cases of flight; 4) increase operational readiness of aircraft for flight by 15-20%; 5) optimize the processes of professional training of flight crews. Consider the ICAO SHELL model as a toolkit for systemic understanding of human factor problems (Fig 12).

The model contributes to the assessment of individual elements of the complex system "Flight crew – Aircraft – Environment – Air traffic organization" and a comprehensive representation of various processes and interactions that characterize it as a whole. All the blocks of the SHEL model, and especially their contact / non-contact, are usually considered as fundamental principles of human factors research. The central component of the SHEL model is a person - the most important and flexible element, which is characterized by certain advantages and disadvantages, which in most cases cannot be predicted in advance. The boundaries of this block are complex and amorphous, so neighboring blocks must be carefully adjusted to it to prevent unwanted tension and failure.

Figure 12 – Scheme of the SHEL conceptual model proposed by ICAO for human factors research (Edvards & Hawkins)

1. Block (interface) "subject" (L). The professional activity of the subject itself – the aviation personnel – is determined by factors characteristic of a person (physics, physiology, psychology). 2. Docking of blocks “subject – subject” (L–L) reveals the interaction of aviation personnel with other people in the working environment: flight crew of one aircraft, flight crews of different aircraft, colleagues from the shift and adjacent sectors (points) air traffic control, specialists of other services, as well as with

the flight director and other managers who are directly responsible for the proper work of subordinate units. 3. Docking of the “subject – machine” blocks (“L–H”) illustrates the interaction of flight crews with aircraft controls and on-board automated systems. 4. Docking of blocks “subject – rules (procedures, installations)” (“L–S”) explores aspects of airspace structure regulations, flight rules and SOP's, actions in special cases of flight. 5. The docking of the “subject – environment” (“L–E”) blocks determines the interaction between aviation personnel and the internal and external environment.

Corporate culture as an element of proactive flight safety management requires the study of complex patterns of behavior affecting the provision of an appropriate level of flight safety within aviation organizations. There are more specialized and more detailed compared to SHELL, models for the study of the human factor in the aviation and transport system.

Rasmussen (1980) proposed a three-level model (Rasmussen's model of human behavior in laparoscopy training) of activity based on skills, rules and knowledge.Heinrich's "domino theory" (1931) indicates that usually human errors form a false chain of sequences, where the first error inevitably leads to the occurrence of the second, the second - leads to the occurrence of the third, and so on. Heinrich believed that not only erroneous actions are important, but the whole range of conditions accompanying human activity. He introduced the "80 : 20" rule. That is, 80% of the causes of emergency situations depend on dangerous actions of personnel, and 20% – on dangerous working conditions. The "domino" theory contributed to certain achievements in the analysis of causes and modeling of industrial accidents in various fields of human activity. In particular, the concept of "chain of wrong decisions" was introduced in civil aviation. And during its growth, the chances of a successful completion of the flight go to zero.

"Each misjudgment" says Jerome Berlin, the head of the development of the so-called "ERAU Guidelines", a pilot who conducts research in the field of aviation psychology, reduces the options available to the pilot. The last link in the chain of events is that the pilot has no choice at all." This well illustrates the ICAO approach to the impact of emergency factors on flight safety (Figure 13).

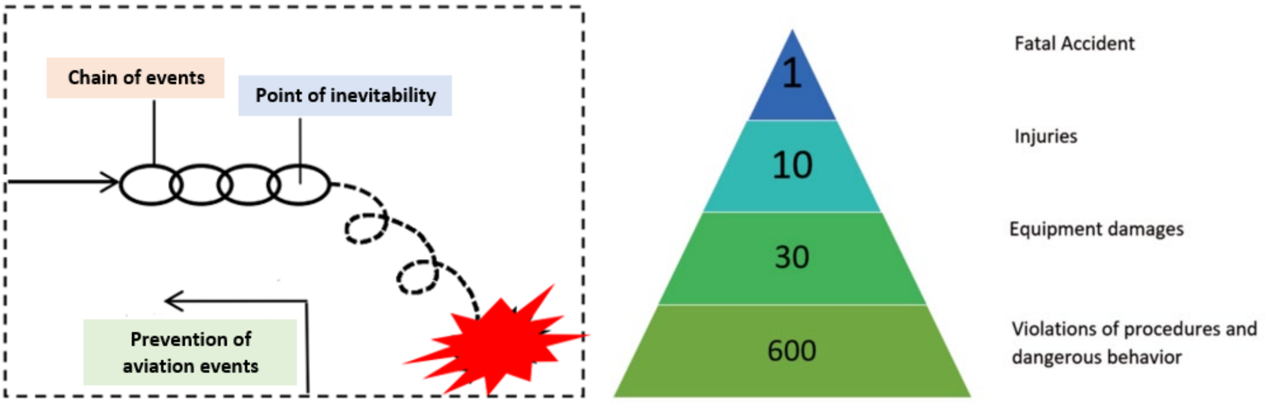

Figure 13 – Chain of adverse events, pyramid of risks (dangers)

In the practice of flight safety management, the scientific heritage of Heinrich (1969) is known - the "Rule 1: 600" (Figure 9), which is the result of many years of research into the state of flight safety in aviation and transport systems. The ratio of 1 : 10 : 30 : 600 in Figure 9 demonstrates the lost opportunities if aviation incident investigations are conducted in cases where there is serious bodily injury or substantial property damage. Contributing factors to such events can occur in hundreds of incidents and can be identified before serious injury or property damage occurs. In the "domino" theory (Figure 14), the development of an emergency situation goes through the following stages: *Stage I* – covers experience and the social environment in which a person performs the necessary production actions; *II stage* – determines the physiological and psychological shortcomings of the working person and the errors characteristic of him (poor memory or slow reaction, etc.); *Stage III* – contains dangerous human actions; IV stage – represents the emergency situation itself; *Stage V* – illustrates the negative consequences of the accident.

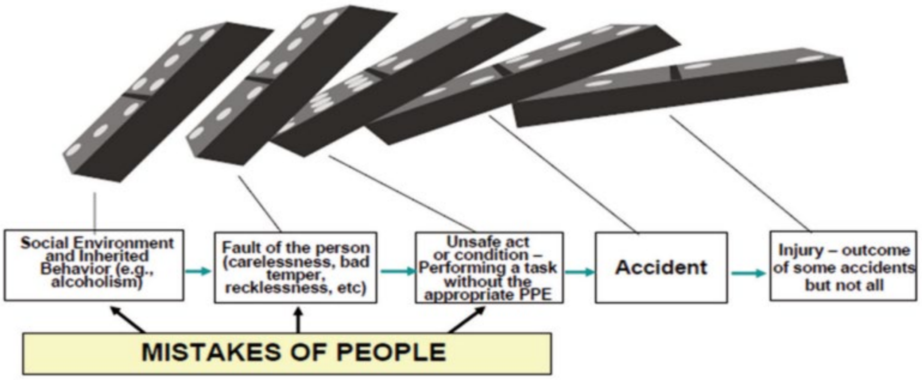

Figure 14 – Types of aircraft accident development models [6]

Adams' "domino" concept suggests that in the first three stages of the "domino" the heredity of the individual and his personal attributes do not always play a leading role in making mistakes, since specific organizational errors are of primary importance at these stages: *The first stage* – highlights false connections in management structure, when mistakes are made at its higher (strategic) levels; *II stage* – reflects errors of own management, provoked at I stage by unsuccessful selection of goals and tasks, planning and organization of the production process, as well as execution of individual operations; *Stage III* – includes tactical errors, when dangerous actions are already taking place directly or conditions are created that contribute to the occurrence of an accident. Adams' merit is that he was the first to discover the cause-and-effect relationship between strategic and tactical errors, that is, between the actions of top managers and those of lower management.

The model of Byrd and Loftas is based on Heinrich's theory, but the emphasis is shifted to the influence of management on the process of formation of the causes of industrial accidents. This model also contains five stages, but the first three of them are considered from a slightly different basis, since it is believed that: *Stage I* reflects deficiencies in management; *II stage* – related to the main causes of the accident; *III stage* – with direct causes. Rison's model of organizational "pathogens", in contrast to the "domino" theory, establishes exactly how the interaction of individual elements of the aviation and transport system leads to an accident. This approach was ignored during the investigations of aviation events, because as a result they sought to find the "culprits" of the events. Questions about the conditions in which decisions were made were considered secondary. And it was precisely this false trend that was advanced by Reason. His model uses the concept of the human immune system as a source for the analogy. In this model, each of the components of the system carries the causes of accidents in the form of some analogues of pathogens that disrupt the normal functions of systems. ICAO considers each aviation event as an emergency, the reasons for which may have accumulated over a long period of time.

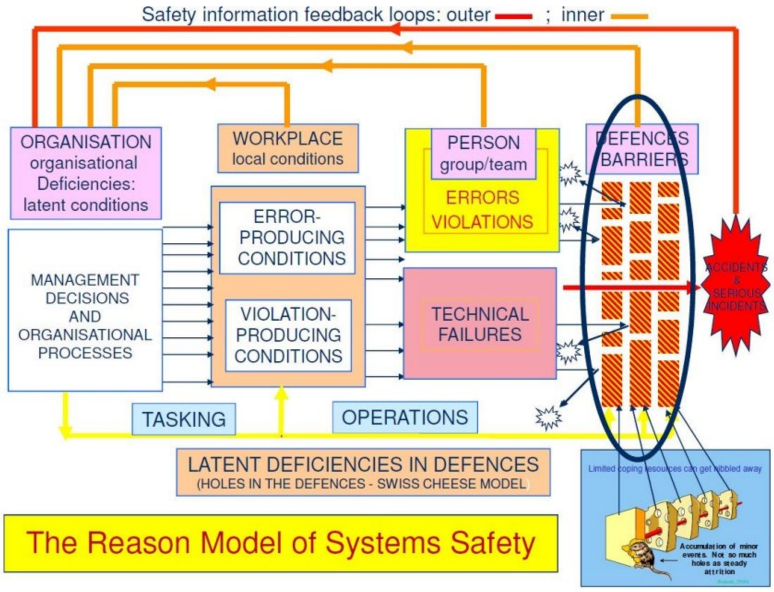

Figure 15 – Simplified diagram of Reason's model

Under conditions of reaching a certain "critical mass", regardless of the nature of the bases, the security system reaches the point of bifurcation, which leads to its destruction and loss of ability to eliminate any threat. In a bifurcation situation, any dangerous action that should be eliminated by the Flight Safety Management System leads to an aviation event, which is also seen in Reason's model, where different types of human "contribution" to the violation of the integrity of the control system are determined. The experience of systematic studies of the processes of the functioning and development of the aviation transport system shows that ensuring the appropriate level of flight safety is impossible without the use of effective proactive risk management measures, which are an integral characteristic of the systems and must be included in the concept of the so-called closed "safety cycle". And since it is about the management of flight safety by the human factor, the microstructure of risk factors should be taken into account in the relevant studies. Summarizing the global experience of proactive flight safety management measures, ICAO has issued a special "Flight Safety Management Guide", which proposes the assessment of threats in civil aviation using a special "risk triangle".

Safety is the state in which the risk of injury to persons or damage to property is reduced to an acceptable level and is maintained at that level or below through a continuous process of identifying hazards and controlling risk factors. Flight safety nowadays is increasingly viewed as the control of all possible risk factors.

Conclusions

Based on the generalization of the experience of creating and applying complex technical systems, important recommendations are formulated to ensure the reliability of aerospace products at various stages of the life cycle. Aerospace systems should contain the maximum possible number of elements tested in practice. Aerospace systems must contain protective devices that provide for the elimination of the possibility of catastrophic failures (limiting the increase in revolutions, temperature, pressure, torque); signaling devices that warn of a violation of normal operation (light signals). Loaded elements of aerospace systems must be carefully calculated for static, dynamic and probabilistic strength. Such a calculation should take into account the maximum loads, the most unfavorable working conditions (temperature, environmental impact), the minimum strength of the material, and the probabilistic nature of the geometric parameters of the assortment. It is necessary to control the study of the structural strength of parts and assemblies of aerospace systems with operational damage (corrosion, erosion, dents, wear). On the basis of such studies and operating experience, norms and standards for permissible damage and methods of tracking diagnostic parameters and signs are being improved.