RIGA TECHNICAL UNIVERSITY

Aleksandrs Bitiņš

DEVELOPMENT OF THEORETICAL AND METHODOLOGICAL APPROACHES TO FLIGHT SAFETY INFORMATION DATABASE SYSTEM

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Mechanical Engineering, Transport and Aeronautics
Institute of Aeronautics

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on 20 of May at the Faculty of Mechanical Engineering, Transport and Aeronautics of Riga Technical University, Ķīpsalas Street 6b, Room 204

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Engineering Sciences is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Aleksandrs Bitiņš (signature)
Date: 23.01.2022.

The Doctoral Thesis has been written in Latvian. It consists of an introduction, 4 chapters, conclusions, 48 figures, 5 tables; the total number of pages is 110. The bibliography contains 77 titles.

Saturs

Acronyms and Definitions

CAA Civil Aviation Agency
EASA European Aviation Safety Agency
FAA Federal Aviation Authority
FAR Federal Aviation Requirements
IATA International Air Transport Association
ICAO International Civil Aviation Organization
IOSA IATA Operational Safety Assessment Audit
JAA Joint Aviation Authority
SMS Safety Management System
Medium-sized enterprises: less than 250 employees and with either an annual turnover to EUR 50 million, or a balance sheet total of no more than EUR 43 million.

General Description

Topicality

The main task of the airline is to maintain an adequate level of safety in accordance with the *ICAO* recommendations and to develop measures to analyze, assess and take measures to reduce risks to an acceptable level, as well as to control risks.

Aviation safety is the state of an aviation system in which the risks associated with or directly supporting the operation of aircraft are reduced and controlled to an acceptable level [11]. Safety management is based on a systematic approach to the identification of sources of hazards and the control of risk factors that exist in an airline, and their planning therefore requires organizational measures to identify and address them, which means an orderly approach involving responsibilities, principles, policies and procedures. In this way, the safety management system makes it possible to anticipate and rectify problems before they occur. Experience in flight safety determines that an airline needs a structured and targeted process organization that works against potential risks. In addition, the organization of this process must involve not only the people responsible for the field, but also professionals, airline management, and senior airline staff.

However, to date, there is no common approach to risk management in aviation safety within a single airline, and the guidance provided by *ICAO* and *EASA* documents is not sufficient to establish an effective safety system at this level. In the absence of common requirements, standards and rules in this area, each airline develops its own safety concept. As the process approach is very popular in the company's operating system, it is widely used as a methodology to manage and improve work processes in various areas, including management and safety processes. In order to improve the efficiency of a complex structure such as a flight safety system, it is necessary to develop an automated system for the collection, processing and use of risk data (deviations from the standards for staff of different structures and airlines). To improve the efficiency of such a complex structure, automated systems for the collection, processing and use of data have been developed to ensure the required level of flight safety in the airline. The proposed approaches to building an information base will allow airlines and decision-makers at airlines to identify, process and provide timely information on the areas where the risk of adverse events is greatest, as well as to identify trends in flight changes. Such an airline database with an integrated management system makes it possible to determine the expected level of safety in a timely and reasonable manner. The research data are devoted to the development of theoretical and methodological approaches to create an information database for the flight safety system in an airline of one of the Latvian Airlines. This approach means moving to a new level of safety management in the airline.

The aim of the Thesis

Development of theoretical and methodological approaches to create an information base for the aviation safety system, including identification, compilation and processing of risk factors.

Tasks

1. Analysis of approaches to solving transport safety problems.
2. Development of airline information system model.
3. Development of an algorithm to identify and analyze anomalies and irregularities in the performance of departments and airline personnel under conditions of uncertainty.
4. Development of a methodology for developing indicators for airline safety decision-makers.
5. Development of methodological approaches for safety performance assessment.
6. Development of a generalized model of the influence of the technical factor on flight safety.

7. Development of methodology for aircraft maintenance impact on the safety of flight operations
8. Approbation of methodologies for determining Group C safety performance related to aircraft and operations.

Research object

Safety level of airline.

Subject of research

Information base for assessing the level of safety using an airline's integrated management system. Medium-size airline, *ICAO, IATA, EASA, ISO, CAA* documents, airline statistics and documents.

Research methods

The following scientific methods were used in the study:
1. Mathematical modeling.
2. Probability theory.
3. Statistical data processing.
4. Expert assessment.

Theoretical and methodological tools used in solving the tasks

The following scientific methods were used in the research:
1. Semiotic modeling.
2. Statistical methods.
3. Expert evaluation methods.
4. Method statistics processing using *Microsoft Office Excel 2016* software.
5. Calculation mathematical software Matlab.
6. Methods for risk assessment: *ICAO, IATA (IOSA), EASA, ISO, SHELL, DEMATEL*, etc.

Research site

All the specific calculations and statistics used in this work are provided for a medium-size airline.

Scientific novelty

1. Development of an airline information system model.
2. Development of an algorithm to identify and analyze anomalies and irregularities in the activities of department and airline personnel under conditions of uncertainty.
3. Methods for developing safety performance indicators for airline structures and decision-makers.

Practical significance

The implementation this system in the airline will allow timely provision of the necessary information to the airline's entities and decision-makers in the areas with the highest risk of adverse events, as well as identify trends in safety performance, based on information flows from the airline's integrated management system, which allows the expected level of safety to be determined in a timely and reasonable manner.

Theses to be defended

- An airline information system model that takes into account all types of deviations from standards and violations within the airline.
- Algorithm for identification and analysis of anomalies and irregularities in the operations of airline structural units and personnel under conditions of uncertainty.
- Mathematical modeling of flight safety indicators for the developed system.

Results of the work

1. An information database model has been developed for the airline to identify, process and provide information in a timely manner, allow the airline and decision-makers to provide objective information on areas at risk of adverse events, and identify trends in safety performance based on information flows from the various areas of the airline's operations with an integrated management system that allows the expected level of safety to be determined in a timely and reasonable manner. This makes it possible to minimize the risk and thus maintain an acceptable level of safety for the airline, as well as to forecast the safety performance for the next period. This approach can be as a transition to a new level of safety management at airline level.
2. An algorithm has been developed for the detection and analysis of anomalies and irregularities of departments and errors of airline personnel under conditions of uncertainty, which allows the analysis of safety aspects based on factual information coming from various sources to airline information database, which is collected, classified, stored and analyzed using analytical methods and techniques. Based on this algorithm, software for automated information processing and analysis has been developed.
3. A system of indicators has been developed for the assessment of flight safety (6 groups of indicators for the general directions of the airline's operations), each of which should include a specific set of indicators, as well as the methodology for their assessment.
4. A methodology has been developed to determine the level of flight safety using Group C indicators related to the aircraft and its operation by assessing that as the multi-level functional system, which takes into account the probability of failure of each level and the severity of the consequences.
5. The developed methodology was tested on the basis of the airline's performance, the results of which show that the implementation of this system in the airline's practice will allow timely provision of the necessary information to the airline's entities and decision-makers in those areas where the risk of adverse events is highest, as well as the identification of trends in safety performance based on information flows from different areas of the airline's activities, with an integrated management system that allows for the timely determination of expected levels of flight safety in a reasonable manner.

Accuracy of research results

- All research results are based on the author's practical calculations, regulatory requirements, and the airline's documents.
- The mathematical models, methods, algorithms, diagrams and organizational structures developed by the author have been tested in practice and implemented in methodological and regulatory documents, taking into account the standards of airlines, the practice of airlines, including international airlines.
- The developed system is checked against the airline's data

Thesis approbation

The results of the research have been presented in 6 international scientific conferences in Latvia and Poland, in 11 publications in three scientific journals.

Participation in international scientific conferences

1. Seminar II Institute of Aviation Warsaw Poland, 05.02.2021. Report: Analysis Of Approaches Ensuring Safety In The Transport Industry.
2. READ 2020 / 15th EWADE Rzeszow University of Technology 21-23.10.2020. Rzeszow Poland. Report: Using the Heinrich's (Bird) Pyramid of Adverse Events to Assess the Level of Safety in an Airline.
3. RTU 60 International Scientific Conference, 16.10.2019. Riga, Latvia. Report: Algorithm for Analyzing Deviations and Irregularities in the Functioning of the Airline's Structural Units and Personnel in the Face of Uncertainty.
4. KLICK 2nd Aviation and Space Congress Rzeszow University of Technology, 18-20.09.2019. Rzeszow, Poland. Report: Development of Information Database for the Evaluation of Flight Safety Level of Aviation Companies Using the Integrated System of Management
5. V International Scientific-Practical Conference. Transport. Education. Logistics and Engineering. Riga Aeronavigation Institute, Riga, Latvia, June 29–30, 2018. Report: Development of methodology for safety risk - based airline
6. RTU 58th International Scientific Conference, 20–21.10.2017. Riga, Latvia. Report: Development of an Information Database for the Integrated Airline Management System (IAMS)

Publications

1. A.Bitinš, J.Maklakovs, R.Bogdane, R.A.Chatys ,V.Shestakov, "Using Adverse Event Pyramids to Assess Probabilities in Airline Safety Management" in Transactions on Aerospace Research No.1 (262)2021 Poland, DOI: https://doi.org/10.2478/tar-2021-0012, pp. 71– 83.
2. V.Šestakovs, J.Tereščenko, J. Maklakovs, A.Bitiņš, R.A.Chatys, "Algorithm for Analyzing Deviations and Irregularities in the Functioning of the Airline's Structural Units and Personnel in the Face of Uncertainty" in Lihuania Vilnius TECH Journal Aviation Volume 24 Issue 2 2020, DOI: 10.3846/aviation.2020.12375, pp. 51–56.
3. A.Bitinš, J.Maklakovs, V.Shestakov, K.Stefański, "Positive Culture As Element Of Safety And Efficiency Of Airline Operation" in conference SELECTED ISSUES OF MODERN AVIATION TECHNOLOGIES Kelce Poland 2021, pp. 9–25.
4. V.Šestakovs, A.Bitiņš, J.Maklakovs, K.Stefanski, "Development of Information Database for the Evaluation of Flight Safety Level of Aviation Companies Using the Integrated System of Management" in conference 2nd Aviation and Space Congress KLIK Poland 2019, pp. 22–23.
5. J.Maklakovs, A.Bitiņš, V.Šestakovs, R. A.Chatys "Positive Culture as an Element of Safety and Effectiveness of Functioning of Aviation Company" in conference 2nd Aviation and Space Congress KLIK Poland 2019, pp. 124–125.
6. J.Tereščenko, A.Bitiņš, V.Šestakovs, R. A. Chatys "Relationship of Reliability and Safety of Aircraft Flights in Airlines" in conference 2nd Aviation and Space Congress KLIK Poland 2019, pp. 202–203.
7. R.Bogdane, A.Bitiņš, V.Šestakovs, Y.Bandara Dissanayake "Airline Quality Assessment Methodology Taking Into Account the Flight Safety Level Based on Factor Analysis" in Transport and Aerospace Engineering RTU Press Vol1. Latvia 2018, DOI: 10.2478/tae-2018-0002 ISSN: 2255-9876, pp. 362–366.
8. A.Bitiņš, A.Suharevs, L.Miķelsons, "Development of Methodology for Safety Risk – Based Airline" in Collection of articles Transports. Izglītība. Loģistika un Inženierija RAI Latvia 2018, pp. 23–30.

9. R. Bogdane, Y.Bandara Dissanayake, S.Andersone, A.Bitiņš , “Development of an Information Database for the Integrated Airline Management System (IAMS)” in Transport and Aerospace Engineering RTU Press Vol4 Latvia 2017, DOI: 10.1515/tae-2017-0002 Part of ISSN: 2255-9876, pp. 11–21.
10. J.Maklakovs, A.Bitins, R.Bogdane, V.Shestakov, “Using Heinrich’s (Bird’s) pyramid of adverse events to assessthe level of safety in an airline” in TRANSACTIONS ON AEROSPACE RESEARCH 4(265) Poland 2021, DOI: 10.2478/tar-2021-0020 eISSN 2545-2835 pp. 11–20.
11. A.Bitins, R.Bogdane, V.Shestakov, A.Stepanova,“Theoretical and Methodological Approaches to the Information Base for an Airline’s Flight Safety System”TRANSACTIONS ON AEROSPACE RESEARCH 1(266) 2022, DOI: 10.2478/tar-2022-0006 eISSN 2545-2835 pp.75–83.

Structure of the work

The work contains an introduction, six chapters, summary, conclusions, 38 figures, 5 tables, appendices; total number of pages is 110 . The Bibliography contains 77 titles.

Chapter 1. Analysis of flight safety approaches at company level

In this chapter, based on the analysis of modern flight safety requirements and practical approaches, the author offers his approach to safety assessment using regularities defined by Henry and Berd.

Chapter 2. Developing a model for an airline risk analysis system

This chapter presents a model of a process approach to air safety in an airline, a model of a system for the collection, storage, processing, analysis and use of airline performance data.

Chapter 3. Development of a methodology for determining the composition of safety indicators for departments and decision-makers

This chapter shows the algorithm for organizing expertise, selecting experts and methods of expertise processing.

Chapter 4. Development of a methodology for determining the level of safety

This section presents a process approach model for assessing the operational airworthiness of an aircraft and its components by dividing the aircraft into multi-level structures taking into account risk factors.

Chapter 5. Risk assessment methodology and flight safety indicators. The risk assessment methodology presented in this section for flight completion by incident and the selection of safety indicators taking into account various factors.

Chapter 6. Approbation of the results obtained in the Doctoral Thesis

In this chapter the approbation of the methodology has been performed according to the proposed model of the determination of reliability indicators.

Summary

The main conclusions are published in this section.

Conclusions

This chapter publishes the conclusions of the research and approbation of the results in the practical activities of the airline.

1. Analysis of Safety Approaches at a Company Level

Safety is a state of an operational condition in which the occurrence of a hazard is excluded with a certain probability or there is no excessive hazard. Safety in all areas of life is a pressing socio-economic issue.

In manufacturing and transport, as in all other areas of life, there are safety-related problems: terrorist and man-made threats, negligence and human factors, economic problems – the irrational use or management of resources, etc. Within the framework of legislation, safety means "the state of protection of the vital interests of the individual, society and the state against internal and external threats". One of these interests is entrepreneurship. At the same time, the main purpose of ensuring the safety of an organization is to protect its property and employees from internal and external threats, to identify and, where possible, to address their causes. The purpose of ensuring the safety of an organization is to protect the two basic interests of society: the first is to preserve and increase the property of the organization, and the second is to ensure and protect the business reputation of the organization. An effective safety system requires governance based on clear coordination of all its elements. A high level of interaction between departments is possible only if there is a general regulation of departmental activities, which is clearly defined in the organization's policies and procedures, as well as in the regulatory framework. Modern technical tools and means make it possible to prevent situations related to the above-mentioned problems or to deal with their consequences. The problem of safety establishment is complex, which means that a system of targeted measures needs to be put in place to help prevent and reduce the number of accidents and economic losses and prevent consequences. At the same time, there are both general and specific approaches to addressing safety issues in different areas of life.

1.1. General safety aspects of production and transport

Risk is a function of the expected frequency or probability of a hazard, the probability of an adverse event occurring and the potential for harm.

There is currently no uniform formula for risk assessment, the general approach to risk assessment can be expressed as

$$\{\text{Risk}\} = \{\text{probability of occurrence}\} \text{ x } \{\text{harm from an event}\}. \tag{1.1.}$$

Risk is most often defined as the frequency or probability of an event. It can be calculated on the basis of statistical information:

$$R = \frac{N(t)}{Q(t)}, \tag{1.2.}$$

where $N(t)$ is the number of unfavorable events at time t;
$Q(t)$ is the number of common events at time t.

For example, the risk of death from lightning is $R = 10^{-7}$/ year; risk of death due to a technological accident is $R = 10^{-6} - 10^{-8}$/ year; risk of death at work as a result of an accident or occupational disease is $R = 10^{-2} - 10^{-4}$/ year. There are more than 200 types of risks in the scientific literature.

Depending on the degree of danger followed by the emergency, the adverse event may also vary in severity. The terms "threat" and "danger" are synonymous. If the probability of an adverse event occurring is significantly greater than zero, then there is talk of danger; if it is significantly greater than zero, then it is a threat. Adverse events are divided into incidents and disasters. Disasters are associated with death and/or serious property damage; incidents are only related to actual or potential threats that do not result in a catastrophe.

The development process of an adverse event is shown in Fig. 1.1. It also shows that the person (operator) is able to intervene in the process and reduce or eliminate the consequences of the risk or completely eliminate the threat to the safety of the facility.

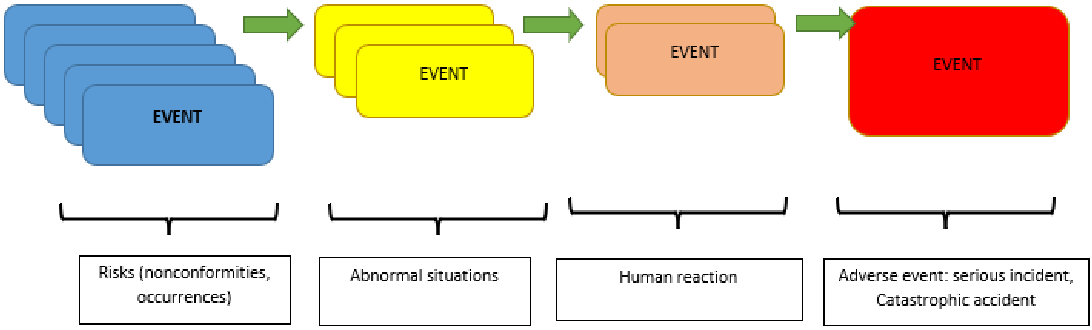


Fig. 1.1. Development of adverse event in production and transport.

1.2. Signs of events (precursors) in industry and transport

Signs of an adverse event (precursors) have already existed before the events take place and only become clear later. Latent unsafe conditions may have existed before the accident. An objective and in-depth risk analysis is needed to identify and prevent these latent conditions. Therefore, a systematic approach to safety breaches is needed, based on the systematic identification and prevention of precursors to these events, which requires an objective and in-depth risk analysis. Although it is very important to fully investigate adverse events with a high number of deaths, this is not the most effective way to identify safety deficiencies in an organization. It must be ensured that the analysis of the rational (acceptable) risk and unsafe conditions of the operation of the facility does not diminish the "vital priority" that is often revealed after fatal events. There are different models that determine the relationship between the signs of adverse events (precursors) and the events themselves. One of the first to establish such a link in the field of occupational safety was Herbert William Heinrich.

Herbert William Heinrich formulated the Injury Law in 1931, essentially defining a scientific approach to preventing adverse events in the workplace. The Heinrich Law (Injury Pyramid, Accident Pyramid, or Heinrich Triangle) states that for every major accident at work, there are 29 minor injuries and 300 potentially dangerous events without consequences.

In 1969, scientist Frank Birds [8] also carried out a safety study in the industrial sector, and a serious statistical analysis concluded that for every 600 low-level incidents, 30 accidents with property damage (accidents without serious injuries) can be considered to occur: 10 accidents with seriously injured people and 1 fatal accident. Thus, a pyramid was obtained, called the 1 : 600 rule [39], [42], [57].

1.3. Adverse events pyramid of safety for the assessment

Cause-and-effect relationship stability between pyramid levels allows us to introduce correlation coefficients K_I – incidents and events ratio, and K_N – staff and personnel raised non-compliance to the ratio of incidents in order to determine the relationship between the pedestal level of non-compliance incidents and incidents (Fig. 1.2).

This allows the pyramid to be used to build a safety management system and to shift the focus from traditional, more incident-based methods to systematic activities to reduce the pyramid pedestal by systematically reducing the number of non-compliances in the organization's services and staff.

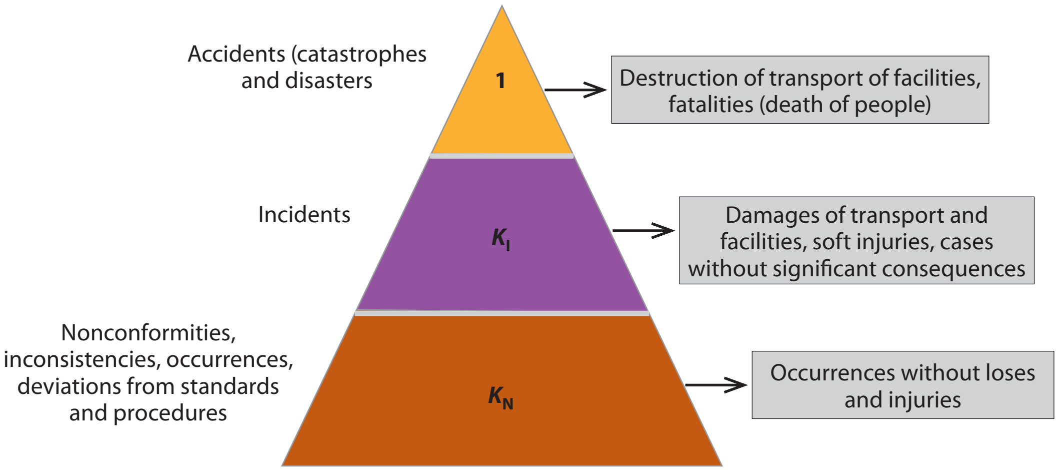


Fig. 1.2. Compliance factors.

The stability of compliance in the Heinrich pyramid allows to quantify the level of safety in a particular object as a probability indicator for the "upper level" of the pyramid – the level of incidents (disasters and accidents). It is suggested to use the number of events per unit of time as the main indicator. This intensity can be estimated as a linear combination of three estimates based on the pyramid (Fig. 1.2). The result will be a comprehensive indicator of safety, or safety level K_{DL}:

$$K_{DL} = \frac{1}{3}\lambda_a \frac{1\lambda_{K_I}}{3K_I} + \frac{1\lambda_{K_N}}{3K_N}. \qquad (1.3.)$$

1.4. Reactive control method

Reactive management methods are essentially creating the influence of management in response to major incidents. The reactive management method (Fig. 1.3) consists of investigating the causes of accidents and planning corrective actions. The main disadvantage of the retrospective management method is that an accident (catastrophe or accident) is a signal to work on improvement of operational processes at the top of the pyramid. Improvements in the organization's operations are made only after a serious accident.

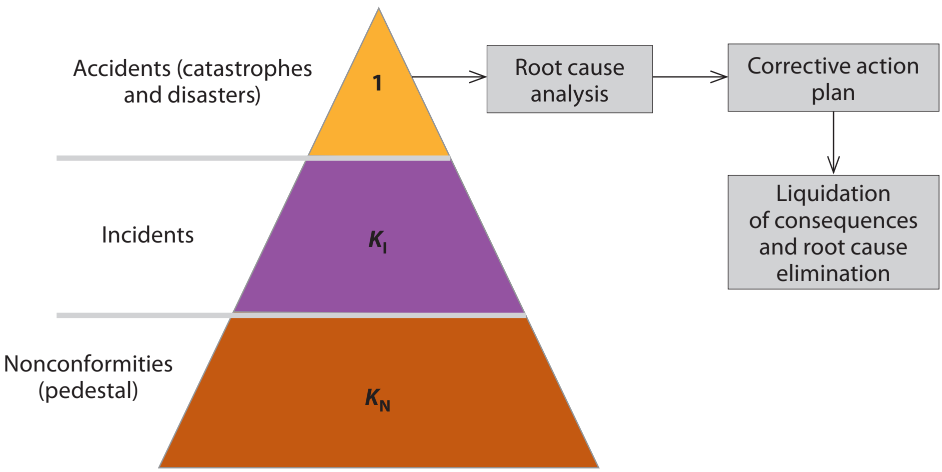


Fig. 1.3. Principle of the reactive management method

1.5. Proactive safety strategy

Proactive safety strategy is an active collection of information from various sources that could indicate new safety issues. Organizations implementing a proactive safety management strategy shall consider that the risk of accidents can be minimized by identifying vulnerabilities before they constitute a hazardous situation and by taking the necessary measures to mitigate those risks. Accordingly, systemic unsafe conditions are proactively identified using appropriate tools (Fig. 1.4).

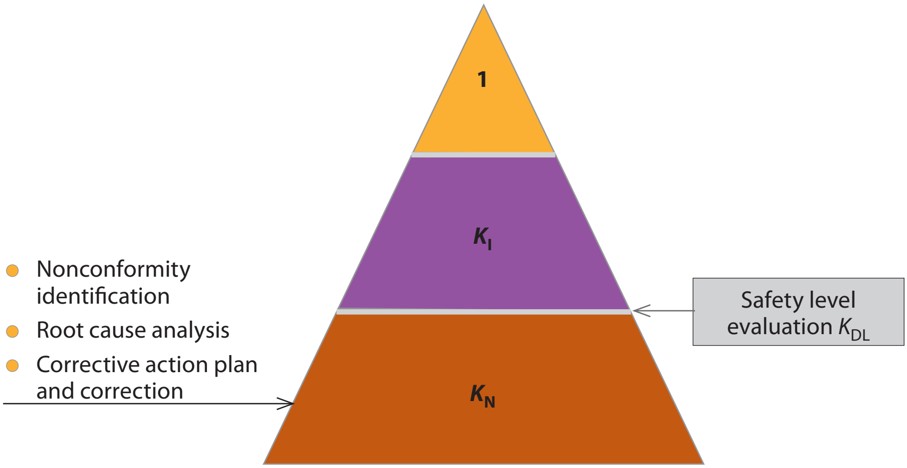


Fig. 1.4. Proactive safety management method

1.6. Predictive safety method

The predictive safety method approach is based on the principle of identifying deficiencies before they occur. Thus, the risk factor forecasting system collects and integrates data from various sources of information that may indicate the possible cause of the risk factors.

2. Developing a Model for an Airline Risk Analysis System

The basis for an airline's safety management is a systematic approach to identifying sources of hazard and controlling risk factors, as required by *ICAO*. This includes the compilation and analysis of deviations in the airline's departments, services and staff, and the use of their results in the development of management measures and the implementation of corrective actions. Such a system allows the organization to anticipate and eliminate problems before they lead to an adverse event (incident or catastrophe) [70].

Non-compliance raised by personnel means violation of the norms and regulations governing the operation of the elements of the aviation complex, as a result of which such non-compliance poses a threat to flight safety.

Non-compliances in the work of structural units and airline personnel include intentional or unintentional violations of regulations, such as non-compliance with technological documentation, non-compliance with management orders governing the operation of aviation components. Such discrepancies and deviations can lead to special situations during the flight and create risks that can lead to an adverse event (incident or catastrophe) [76], [77].

2.1. Development of the airline information system model

The safety of the airline is ensured by an effective safety management system. The safety management system is an orderly approach to aviation safety, including the necessary organizational structures, responsibilities, guidelines, policies and procedures.

The airline's management information system must record, store and analyze the required data set, work with all levels of events, follow a built-in algorithm and at the same time comply with the latest *ICAO* and *EASA* safety requirements.

The model of the airline's operational data collection, storage, processing and use system with integrated management system can be schematically represented as shown in Fig. 2.1.

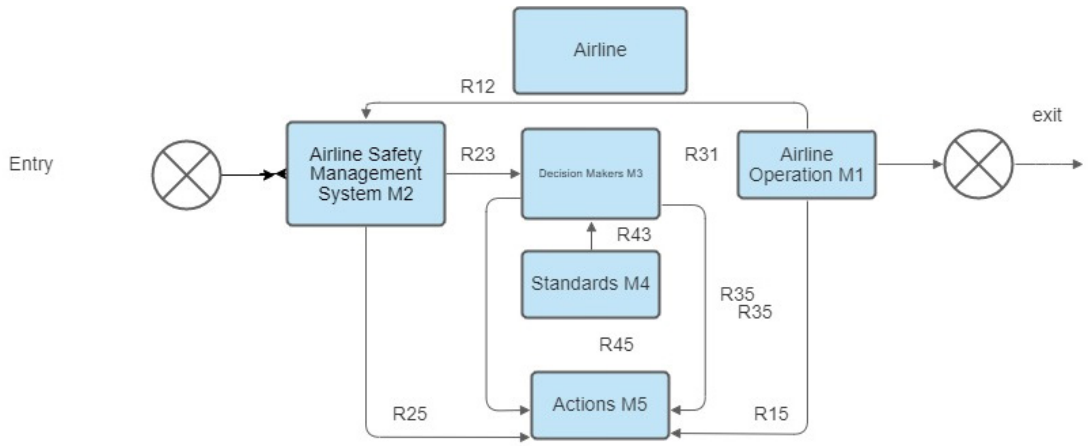


Fig. 2.1. Model of an airline with an integrated management system

Subsystem M_{11} – "Airline operation"; control-command objects of the functional subsystem in which unfavorable situations $S_1 \ldots S_n$ occur in-flight and on the ground, or adverse events. This is where the unfavorable events take place. It is characterized by productivity indicators:

- flight crew duty time (hours);

- number of flights (landings);
- operating time of units (hours);
- number of passengers carried (persons)
- other indicators.

Subsystem M_2 – "information base", includes deviations in the airline's operations in all areas of activity and adverse events that have occurred in the air and on the ground over a specified period of time. Here they are collected, stored and processed. Adverse events during flights are due to the fault of various services. Information about them is also collected here.

Subsystem M_3 – "organizations and people who make decisions"; includes the company's departments and people who in exceptional cases make operational decisions and strategic decisions for a certain period of time. Each participant in this subsystem must provide automated workstations. Automated workplaces must be designed strictly for their intended functional purpose. It can be a laptop or desktop computer with the ability to connect to the system, or it can be a set of computer service and software designed to automate the employee's work within his/her tasks.

Subsystem M_4 includes regulatory documents in accordance with the various areas of the airline's operations, as well as the units and persons assessing the compliance of operations with the standards.

Subsystem M_5 has services and staff that develop safety performance plans. At the airline level, they control the level of safety and make decisions. And at the same time, there are sources of information M_3.

Thus, we have a closed model of system dynamics, between the elements of which there is a constant exchange of information. The sequence of steps in the model is shown as direction arrows – R_{ij}. Using the model decisions may be immediate (tactical decisions) and long term (strategic decisions), based on a deep and comprehensive analysis of the data entered into the M_2 database.

There are information links that operate between subsystems :

R_{12} – risk factor data transfer information database M_1;
R_{23} – submission of results for information processing in subsystem M_3;
R_{31} – management decisions based on information from database M_1;
R_{35} – assignment of tasks in the development of enforcement measures M_5;
$R_{25\times}R_{15}$ – transmission of information to airline departments developing measures M_5;
$R_{43\times}R_{45}$ – submits requirements and installation of standard indicators M_3, M_5.

2.2. Development of algorithm for analysis of deviations and violations of airline units and personnel in uncertainty

Factor analysis tasks in uncertainty are characterized by the lack of a clear form to clarify the analytical dependence of system performance on various factors with sufficiently representative statistics on factors, performance and events in the airline.

The tasks of deterministic factor analysis assume that the analytical relationships between factors, indicators and events are given, as well as the facts, indicators and events themselves are determined.

Solving of these and other tasks involves:

- the organizational structure of the system with functional and informative links between the elements;
- a set of indicators or factors organized in a certain way (database systems);
- specialists trained to perform analysis, make decisions, and have the appropriate authority;
- statistical materials on deviations and irregularities in services and departments;
- mathematical methods and models for processing information on aircraft operations;
- technical means and computers for analysis and decision making;
- criteria for assessing the impact of deviations and breaches on flight safety;

- criteria for evaluating the effectiveness of the developed measures and the costs of their implementation.

The algorithm developed by the author summarizes and analyzes the deviations in the airline's operations. The algorithm was developed taking into account the sufficiency of the powers of a specific department (service) manager in the airline.

3. Development of a Methodology for Determining the Composition of Safety Indicators for Departments and Decision Makers

3.1. Method of organizing expertise and processing techniques of expertise

The analysis of different methods of organizing expertise: commission methods, court methods, brainstorming methods, Delphi methods, decision matrix methods, predictive graph methods and other methods allowed to choose the "leader" method for determining the composition of information system indicators, which is a pairwise comparison method [25], [28], [31], [34].

The essence of the pairwise comparison method is to offer the expert a list of objects (indicators) to be compared with each other according to some criteria (in our case, the role of the indicator in solving flight safety improvement problems).

It is convenient to compare pairs when the number of objects is large, as well as when the differences between objects are insignificant. When comparing objects in pairs, the expert notes the advantages of only one object compared to another or its equivalence. It is like a "win", a "loss" or a "draw" in a team playing in a round.

If n objects are compared in pairs, and the desirability property satisfies the wishes of the expert, that is, if objects a_i and a_j are related to P, and at the same time objects a_j and a_e are also related to P , it follows that a_i and a_e are also related to this relationship, in which case the objects are ranked.

The results of each expert's comparison are summarized in a square table (Table 3.1). As in the best-known circular sports system (each with each other), the result is summarized in the overall ranking table.

Table 3.1

Expert Table

Creator No.	1	2	…	N
1	●			
2		●		
…				
n				●

In the table, at the intersection of the corresponding line i, the object and the column corresponding to j, the object is placed "2" if object j is preferred for i, "0" is otherwise, and "1" if the object is undecided (equivalent) (as "victory," "loss" or "draw").

The total number of comparisons in one pair will be equal to $n(n-1)/2$.

Adding preferences (points) to each object according to the rows of the table allows to discover the rows (rank) of the objects.

Mathematically, expert table can be represented as an order relationships procedure $n \cdot n$ ratio of $\left\| P_{ij} \right\|$ square matrix with the following elements:

$$P_{ij} = \begin{cases} 2 \text{ if } a_i > a_j \\ 0 \text{ if } a_i < a_j, \\ 1 \text{ if } a_i \cong a_j \end{cases} \tag{3.1.}$$

where i is the matrix line number;

j is the column number;

notation $a_i > a_j$ means preference a_i for a_j;

sign $\cong$ means equivalent (equal).

To remove the matrix P_{ij} principal diagonal of the at the uncertainty element values $i = j$ of the given by symbol ● in the table, these elements are assigned the value of "1" (the game is "by itself").

A visual representation of the implementation of the pairwise comparison method can be an oriented multigraph with vertices i corresponding to comparisons a_i $(i = 1, n)$, where it is preferred that a_i over a_j is represented by two arcs directed from vertex i to vertex j, but equivalence a_i and a_j with one circle from i to j and one circle from j to i.

For a relationship matrix to have a graph adjacency matrix, each vertex must have a loop.

An example of a graph of 5 objects showing one of the possible $2^{(n-1)n/2} = 2^{10}$ situations is shown in Fig. 3.1 [32].

In this case, the adjacency matrix will look like this:

$$A = \begin{vmatrix} 1 & 0 & 2 & 2 & 1 \\ 2 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 2 & 2 \\ 0 & 2 & 0 & 1 & 1 \\ 1 & 2 & 0 & 1 & 1 \end{vmatrix} \tag{3.2.}$$

The elements of the matrix meet the conditions:

$$a_{ij} + a_{ji} = 2 \tag{3.3.}$$

By summing up the elements of a contiguous matrix in a row, the objects can be ranked.

However, experience with the use of pairwise comparisons has shown that there may be situations where the transit condition is not met. Thus, if the expert preferred object a_1 over a_2, preference object a_2 for a_3, and at the same time for object a_3 preference for a_1, then forming a closed cycle, and preference between objects a_1, a_2, a_3, is a difficult task.

Routes $\overrightarrow{142}$, $\overrightarrow{1342}$ and $\overrightarrow{1352}$ (in Fig. 3.4) are forming a closed loop.

The use of the "leader" method [32], [34] makes it possible to overcome these difficulties and to rank the objects more correctly.

2.2. Ranking of objects using the "leader" method

The method is based on the property that there is a path length in graph λ when matrix $A^2 \neq 0$, and there is no contour when $A^2 = 0$, if it starts from a λ.

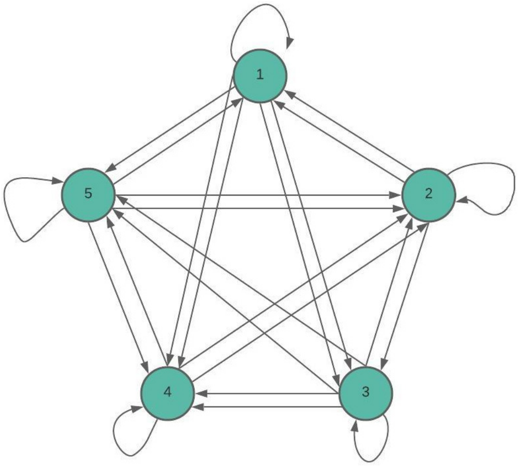


Fig. 3.1. Advantage graph.

The essence of the method is to find the "relative force" of individual objects and its rank (row) according to the obtained values of this strength.

It is determined by finding the number of possible path lengths λ (λ = 1, 2, 3,…n) from vertex i to vertex j in the Advantage graph (Fig. 3.1). In defining $P_{ij}(\lambda)$, the matrix of common elements A^{λ} which equals the length of the path number λ from i to j, summing up the elements of each of the rows of the λ matrix, we will find "Integrated Force" first λ object, $a_i - P_i(\lambda)$ means that

$$P_i(\lambda) = \sum_{j=1}^{n} P_{ij}(\lambda) \tag{3.4.}$$

In general, "relative power" P_i of object a_i is

$$P_i = \lim_{\lambda \to \infty} \frac{P_i(\lambda)}{\sum_{i=1}^{n} P_i(\lambda)} \tag{3.5.}$$

Practically, for object ranking a_i, it is sufficient to construct the degrees of the adjacency matrix sequentially A–A^1, A^2, A^3 and to compare the classification of the "relative forces" in each step with the rankings of the previous step.

If the rank of the "relative forces" coincides in two consecutive stages, the process is stopped and the object rank is accepted according to the rank of the "relative forces" of the obtained objects.

When completing the ranking of objects, the most desirable object is assigned Rank (place) 1, the next is assigned Rank 2, etc.

By processing the tables of different experts, the sum of the rankings of each indicator is calculated from all tables. The indicator with the lowest ranking amount is the most appropriate. The scores are then ranked in ascending order, and the amounts themselves are added up. The involvement of middle and senior management in the work of aviation professionals does not guarantee high quality of all members of the expert group. The quality of an expert is influenced by work experience, complete understanding of the tasks to be solved, psychophysiological characteristics, external factors and much more. In order to isolate an objective component from the conclusions of individual experts, the suitability of each expert must be assessed. A sufficient number of scientific papers are devoted to the study of this problem [25], [27], [28], [31], [34].

The following parameters shall be used for the quality of examination and the assessment of the conformity of individual experts:

- the degree of absolute reliability of the expert, which is equal to the number of cases in which the assessment coincides with the preliminary result, the ratio of the number of assessments determined by the expert;

- the relative degree of reliability of the expert, which is equal to the ratio of the absolute degree of reliability of the expert to the average degree of reliability of the group of experts;
- coefficient of coherence (agreement) for the ranking of experts or groups of experts;
- the number of excluded indicators due to the low ranking level compared to other indicators;
- the presence of indicators that are "mandatory" in accordance with the requirements of regulatory enactments or basic documents, technological or other reasons, or on the basis of ignorance not listed or poorly assessed by experts.

2.3. Preliminary ranking of the composition of indicators

Preliminary ranking of the composition of indicators and processing of expert information according to the "leader" method is performed on the basis of qualitative characteristics, without precisely quantifying the advantage of some indicators over others. The problem of finding path length l from vertex i to vertex j in the ratio graph can be solved by successively increasing the adjacent matrix of the graph (it is the expert advantage matrix) to a greater degree up to and including the resulting matrices and by performing proper ranking of indicators. The preferred indicator is ranked 1, the next is ranked 2, and so on.

When processing multi-expert tables, the sum of the steps of each indicator is calculated from all tables. The indicator with the lowest ranking amount is preferred. The scores are then sorted in ascending order of ranking amounts, and the amounts themselves are normalized and accounted for.

The reliability of the obtained results and the quality of the expertise, as well as the examination of individual experts shall be performed using the following parameters:

- absolute degree of reliability of the expert;
- relative degree of reliability of the expert;
- ranking coefficient of the classification of experts or groups of experts (agreement);
- the number of excluded indicators due to the low ranking level in relation to other indicators;
- the presence of indicators that are "mandatory" in accordance with the requirements of regulatory or basic documents, which for technological or other reasons are not listed or poorly assessed by experts for some reason ("directive" indicators).

Experts with a low degree of confidence may be excluded from the analysis, and their expert tables should be canceled and the rankings of the indicators recalculated. A similar recalculation should be made by deleting the least desirable indicators.

If experts M indicated the ranking of objects n according to the wishes, then the consistency (coherence) of the expert opinions can be assessed using the coordination coefficient W, i.e., the correlation coefficient of the rank, which is common to the whole group of experts [27], [28]

To calculate the value of the consistency-coherence factor, the first the sum of the rankings of each object received from all experts is found $\sum_{k=1}^{M} r_{ik}$, and then the difference between this sum and the mean of the rankings, i.e., the deviations of all rankings from the mean, must be found:

$$\Delta = \sum_{k=1}^{M} r_{ik} - \frac{\sum_{i=1}^{n}\sum_{k=1}^{M}\overline{r}_{ik}}{n}, \tag{3.6.}$$

where $\overline{r}_{ik} = -\frac{1}{2}M(n+1)$ is the average of the ranking sums.

The sum of the squares of the differences is calculated as follows:

$$S = \sum_{i=1}^{n}\left\{\sum_{k=1}^{M} r_{ik} - \frac{1}{2}M(n+1)\right\}^2 \tag{3.7.}$$

If all experts give the same preferences, the maximum value of S will be equal to

$$S_{max} = \frac{1}{2} M^2 \left(n^3 - n \right) \tag{3.8.}$$

The more consistent the agreed expert results, the closer the value of S to $S_{\max}$.

The more disagreement there is, the closer is the ranking of the amount of the average value $M(n + 1) / 2$, while value S is closer to 0.

Thus, the harmonization expert characteristics M is the harmony-consistency factor that is determined by expression

$$W = \frac{S}{S_{max}} \tag{3.9.}$$

or according to the formula suggested by Kendall [27]:

$$W = \frac{12S}{M^2 \left(n^3 - n \right)} \tag{3.10.}$$

The value of W varies from 1 if the ranking of the experts is exactly the same, to 0 if there is no consistency.

A low coherence factor value usually indicates either a lack of common expert opinion or the presence of subgroups of experts with a high degree of coherence (like-minded people) in the overall group, but the views of these subgroups are opposite.

The identification of like-minded subgroups of experts is ensured by excluding one expert from the group and calculating the coherence factor for the other experts. If the value of the new coefficient is higher than the coefficient for the whole set of experts, then this expert is excluded, but if its value is lower, this expert remains in the group. Performing such calculations sequentially for each expert identifies the experts with the “original” opinion and increases the rest of the degree of coherence.

4. Development of a Methodology for Determining the Level of Safety

The main purpose of evaluating the performance of this group is to control the frequency of dangerous failures and to assess the effectiveness of the measures taken to prevent them. It also helps to identify and quickly rectify the airline malfunctions related to the technical condition of aircraft. In order to achieve these objectives, statistics are needed on failures that have caused accidents or incidents, as well as on previous in-flight accidents, their frequency and severity. Data obtained during the monitored period are compared with previous periods to identify trends in their change.

4.1. Aircraft as a complex multi-level technical system

An aircraft as a semiotic model of a multi-level technical system has the form shown in Fig. 4.1.

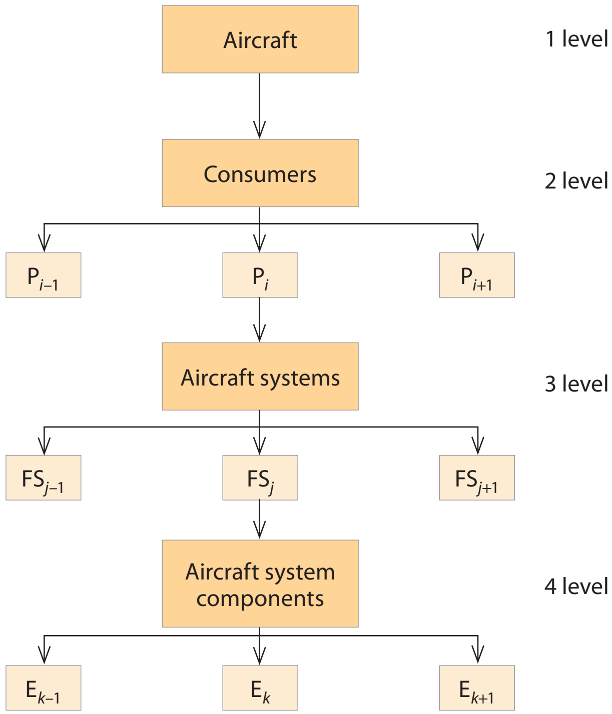
Level 1: Airplane.

Level 2: Consumers – airplane systems and components whose characteristics directly determine their position in flight (control systems, braking, wing mechanization, etc.)

Level 3: Functional aircraft systems serving customers (hydraulic, fuel, etc.)

Level 4: Elements of functional systems.

Failures of individual functional system elements are recorded quantitatively and qualitatively, which allows a mathematical relationship to be established between aircraft failures and in-flight emergencies, but must determine the conditions for the aircraft to transition to different conditions.



P – consumer; i – consumer sequence number; FS – functional system; j – functional system sequence number; E – component; k – component sequence number

Fig. 4.1. Semiotic model of aircraft as a multilevel technical system

5. Risk Assessment Methodology and Flight Safety Indicators

5.1. Risk assessment methodology for a flight terminated by an incident

The pre-determined degree of severity of failure situations reflects the upper limits of their probability of occurrence. The airline information base that is being developed needs to get the current values of these probabilities. This will allow to constantly monitor the dynamics of safety level changes and take appropriate action if necessary. To do this, it is necessary to know the number of different situations of failure during the flight during the supervised period. We will determine it on the basis of the failure criteria specified in the regulatory documents and in the analysis of the consequences of the different levels of specific failure shown in the figure, as defined in the technical documentation of this aircraft. Let us observe several examples using the calculation of the airworthiness indicators of aircraft functional systems and their elements of the cockpit air conditioning system. This functional system provides the aircraft consumer with vital passenger and crew functions during the flight.

We assume that the completion of the flight with an accident is valued at generalized risk probability, R. In this case, the total value of risk R is determined by the sum of the risks of all possible failure situations during flight Q_i:

$$R = Q_{KAS} + Q_{AAS} + Q_{SAS} + Q_{ASLAS} + Q_{ASBLAS} = \sum Q_i, \qquad (5.1.)$$

where ASBLAS – failure situation without complication of flight conditions;
ASLAS – failure situation with complication of flight conditions;
SAS – complicated failure situation;
AAS – emergency failure situation;
KAS – catastrophic failure situation.

When assessing the risk of a catastrophic failure situation with each specific failure situation Q_i, we will use Expression (5.1), knowing the number and quality of failures and the hours flown, we can estimate the frequency of each failure condition ρ_i per flight hour:

$$\rho_i = \frac{n_i}{T_1}, \qquad (5.2.)$$

where n_i is the number of relevant failures during the flight;
i = ASBLAS, ASLAS, SAS, AAS, KAS;
T_1 is flight hours;
η_{Ti} is the degree of hazard;
and i is the degree of hazard of a repeated failure situation in flight.

Then we get the catastrophic risk due to a catastrophic failure situation with a certain degree of hazard $\eta_T \cong 1$:

$$Q_{KAS} = \rho_{KAS} = \frac{n_{KAS}}{T_{KAS}}, \text{ because } \eta_{T\,KAS} = 1, \qquad (5.3.)$$

where Q_{KAS} is catastrophic risk;
ρ_{KAS} is probability a catastrophic failure situation;
$\eta_{T\,KAS}$ is the degree of catastrophic failure situation hazard.

Analogous to an emergency failure situation

$$Q_{AAS} = \rho_{AAS}\eta_{T\,AAS} = \eta_{T\,AAS}\frac{n_{AAS}}{T_{AAS}}, \qquad (5.4.)$$

where Q_{AAS} is emergency failure situation risk;

ρ_{AAS} is emergency failure probability;
$\eta_{T\,AAS}$ is the degree of emergency failure situation hazard.

For a complicated failure situation

$$Q_{SAS} = \rho_{SAS}\eta_{TSAS} = \eta_{TSAS}\frac{n_{SAS}}{T_{SAS}}, \tag{5.5.}$$

where Q_{SAS} is the risk of a complicated situation;
ρ_{SAS} is the probability of occurrence of a complicated situation;
$\eta_{T\,SAS}$ is the degree of complicated situation hazard;
n_{SAS} is the number of complicated situations during observation time interval T_{SAS}.

Withdrawal situation flight conditions complications:

$$Q_{ASLAS} = \rho_{ASLAS}\eta_{T\,ASLAS} = \eta_{T\,ASLAS}\frac{n_{ASLAS}}{T_{ASLAS}}. \tag{5.7.}$$

where Q_{ASLAS} is the risk of failure with flight complication conditions;
$\eta_{T\,ASLAS}$ is the degree of hazard of failure with complicated flight conditions;
ρ_{ASLAS} is the probability of failure with complicated flight conditions;
n_{ASLAS} is the number of failures per observation interval for failure situations with complicated flight conditions, T_{ASLAS}.

For a group of events without complicated flight conditions (ASBLAS)

$$Q_{ASBLAS} = \rho_{ASBLAS}\eta_{T\,ASBLAS} = \eta_{T\,ASBLAS}\frac{n_{ASBLAS}}{T_{ASBLAS}}, \tag{5.8.}$$

where Q_{ASBLAS} is the situation risk;
$\eta_{T\,ASBLAS}$ is the degree of hazard of the situation;
ρ_{ASBLAS} is the probability of occurrence of the situation;
n_{ASBLAS} is the number of situations during the observation time interval T_{ASBLAS}.

Finally, the risk of completing a flight by crash can be calculated as follows:

$$R = Q_{KAS} + Q_{AAS} + Q_{SAS} + Q_{ASLAS} + Q_{ASBLAS} =$$

$$= \frac{n_{KAS}}{T_{KAS}} + \eta_{T\,AAS}\frac{n_{AAS}}{T_{AAS}} + \eta_{TSAS}\frac{n_{SAS}}{T_{SAS}} + \eta_{T\,ASLAS}\frac{n_{ASLAS}}{T_{ASLAS}} + \eta_{T\,ASBLAS}\frac{n_{ASBLAS}}{T_{ASBLAS}} = \sum \eta_i \frac{n_i}{T_i} \tag{5.9.}$$

$$R = \sum \eta_i \frac{n_i}{T_i} \tag{5.10}$$

5.2. Identification of failure situation during the flight

The third characteristic of "abnormal" situation is based on the standard of aircraft system, which establishes three parameter fields that describe the "crew-aircraft" states:

1) range of permissible parameter values, $A_i > X_i$;
2) performance constraint zone, $B_i > X_i \geq A_i$;
3) zone of maximum allowable parameters, $C_i > X_i \geq B$,

where X_i is the parameter from the expected operating conditions;
A_i – range of permissible values;
B_i – operating limit;
C_i – other the maximum limit.

The first zone includes the **recommended flight modes (RFM)**. They are determined by the expected operating conditions, selected according to the intended operational objectives and tasks of the airplane, and are recorded in the technical documentation.

The operating and maximum limits specified in Zones 2 and 3 are also specified in the relevant operational documentation (AMM Technical Operations Manual, AFM Flight Operations Manual, etc.). The crew is informed of the value of the Xi parameters close to the flight limitations with special technical devices or natural features. Based on this, Table 5.1 summarizes the failure scenarios that occur during an in-flight failure.

Table 5.1

Failure Indicators in the Event of an Aircraft Failure

Failure situation indicators / Type of cancellation situation in flight	Changes in the psychophysiological state of the crew	Changes in aircraft stability and handling characteristics and aerodynamics	One or more parameters exceed the operating or maximum limits	Need to change profile, mode, or flight
Failure situation, no complications in flight conditions	Minor	Minor	No	No
Failure situation, with complications in flight conditions	Small	Small	No	No
Complicated failure situation	Remarkable	Remarkable	One or more parameters exceeds the operating limit	No
Emergency failure situation	Significant	Significant	One or more parameters exceeds the operating limit	Changes to flight profile, mode or schedule are required
Catastrophic failure situation	Saving an airplane and human lives becomes an almost impossible event ($Q = 10^7$ per flight hour)			

Thus, the analysis of each of any aircraft component damage on the basis of technical documentation makes it possible to identify the failure of the situation and assess it in a specific period of time (flight time in the aircraft per hour).

Methodology for assessing the pilot's response in failure situations.

From the time an airplane moves from a normal to a defeated state, the flight mode parameters *Xi*, such as flight speed, overload, angle of attack and slip, etc., as well as aerodynamics and airplane stability and handling characteristics, begin to change. At the same time, the psychophysiological state of the crew is changing. It is a human factor, which is not considered within the scope of the Thesis. In such circumstances, the crew begins to use control actions to compensate for the adverse effects of the failure and to return the aircraft to a normal condition.

The nature of the change in parameter X_i can be different, there can be many variants (Fig. 5.1). It can be a straight line with a different angle of inclination (2), square or cubic parabola (1), or any other type (3).

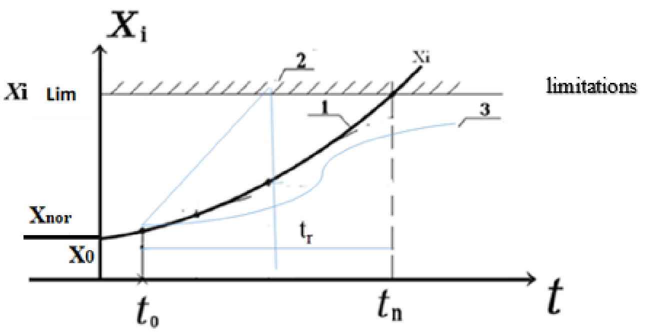


Fig. 5.1. Possible change options of parameter X_i for failure status display.

The possibility of parameter correction depends on the type of failure, flight conditions, pilot qualification and training, or automated system capabilities, etc. One of the decisive conditions for this is the ratio of the transition time of the parameters outside the limits, which depends on the speed of their change and the time required for correction, i.e., the available time t_r.

Let us examine in more detail the development of the change of parameter *Xi* and the possibilities of the pilots to correct such changes under the influence of unfavorable factors (Fig. 5.2).

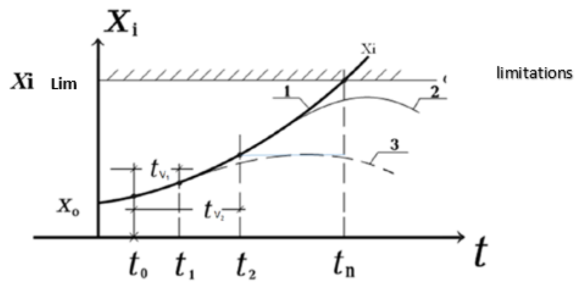


Fig. 5.2. Curve 1 –the curve of the parameter X_i change at the failure effect; Curves 2 and 3 – parameter change when the pilot (autopilot) reacts and corrects the situation (reaction of the aircraft at different times).

During flight time t_0 (normal flight), an abandonment situation occurs on board the aircraft. As a result of the failure, at least one of flight parameters X_i starts to change from a certain parameter value X_0, approaching the operating limit area from the beginning. This will be a situation with difficult flight conditions. If the pilot does not respond, the parameter at time t_n will go out of the limits of the restriction (flight recommended modes) and the further development of the process situation moves to another level – to a complicated failure situation. If the pilot (autopilot) fails to prevent further changes in the parameters, then the parameter will reach the maximum allowable limit – the situation will change to an emergency failure situation. Thus, the time of development of the situation is

$$t = t_n - t_0 \tag{5.11.}$$

It depends, on the one hand, on the nature of the failure and the flight mode, and on the other hand, on the time of change and the rate of change of the parameter X_i itself. In this case, the rate of convergence of the parameter with its limitation can be evaluated by the change in the first derivative of the function describing the change in parameter X_i. Time t_r, in Fig. 5.2, determines the possibilities for correcting the consequences of the waiver. Obviously, the higher the rate of parameter change, the less t_r, and the higher is the probability of a failure situation moving to a more dangerous area. If the start time of the pilot's intervention in the control of the aircraft to correct the situation in order to exclude the negative consequences is denoted by t_1, then the actual start time of the pilot's intervention in the control will be equal to

$$t_v = t_1 - t_0 \tag{5.12.}$$

This includes the time and action on aircraft control to prevent adverse effects, i.e., this is the time for decision. It is regulated by normative documents, although in reality it is an approximate variable that depends on many circumstances, including the pilot's psychophysiological state, which is also one of the signs of a failure situation. As the parameter cannot return to its original value immediately, the maximum possible pilot intervention moment will be controlled when the parameter change curve touches the boundary line. If the parameter changes according to a controlled law, the inflection point, i.e., the tangent to the limitation line, will be determined by the zero value of the first derivative of the function describing this change. The maximum available decision time t_{rmax} will always be less than t_{vmax}.

If $t_v > t_{vmax}$, then the pilot does not have time to change the increase of the parameter and the parameter will exceed the limits, and the situation of failure from less dangerous will become more dangerous. Obviously, these values can be determined based on the crew training on flight simulators or decoders of flight recorders, or by other means [51].

5.3. Assessing the impact of aircraft maintenance on operational safety

We will assume that aircraft maintenance is performed by a maintenance organization, meaning an organization certified in accordance with EASA Part-145, or an airline technical center. The task of the maintenance organization is to ensure the operational safety (airworthiness) of the airline's aircraft. Flight safety and airworthiness are quite close to each other. The transition from airworthiness assessment to flight safety assessment shall take into account in-flight denials and/or malfunctions during maintenance by dividing them into separate groups and defining ICAO accepted safety indicators for each of them. Thus, for the purposes of the analysis, two indicators are introduced.

- Statistic indicator at time, KT_{ij}:

$$KT_{ij} = \frac{n_{ij}}{T_{ij}} 10^5 , \tag{5.13.}$$

where n_{ij} failures and malfunctions detected in the airline fleet airline j for the analyzed period i , on the airline fleet of the flying hours T_{ij}.

- Statistic index per landings, KN_{ij}:

$$KN_{ij} = \frac{n_{ij}}{N_{ij}} 10^5, \tag{5.14.}$$

where n_{ij} is the number of failures and malfunctions detected in the aircraft fleet airlines j for the analyzed period i at the number of landings for the same period N_{ij}.

The classification of risk factors into three categories that is generally accepted in flight safety theory has been used:

A – the human factor associated with technical personnel;

B – technical factors related to aircraft failures and malfunctions;

C – environmental factor.

In this case, in the array for the relevant time period the operational safety statistics for period i for a given aircraft fleet should include the following parameters:

$$KT_{ij}(A),\ KT_{ij}(B),\ KT_{ij}(C),\ KN_{ij}(A),\ KN_{ij}(B),\ KN_{ij}(C) \tag{5.15.}$$

In this case, the analysis is performed of accidental failures that occur during normal operation, when the initial operating equipment phase (adaptation) has passed and intensive wear has not yet begun. When compiling statistics, a time series of indicators is obtained; in order to study the nature of its course over time, it is necessary to know the form of the basic function, which can be constructed using regression analysis methods. The base function $\tilde{K}_{ij}$ will differ from the initial function with a random total error S_{Σ}:

$$K_{ij} = \widetilde{K_{ij}} + S_{\Sigma} \tag{5.16.}$$

Based on the basic function $\tilde{K}_{ij}$, is possible to perform the development trends of service indicators θ_{ij}, which will be the first derivatives of the basic function over time:

$$\theta_{ij} = \frac{\mathrm{d}\widetilde{K_{ij}}}{\mathrm{d}t} \tag{5.17.}$$

The development of operational indicators over a period of time characterizes the impact of long-term large-scale measures aimed at improving the level of flight safety. However, as the analysis shows, the basic function of safety performance and its trends must depend on the level of trends over time:

$$\dot{\theta}_{ij} = \frac{\mathrm{d}\theta_{ij}}{\mathrm{d}t} = \frac{\mathrm{d}^2\,\theta_{ij}}{\mathrm{d}t} = \frac{\mathrm{d}^2\,\widetilde{K_{ij}}}{\mathrm{d}t^2} \tag{5.18.}$$

For further analysis we denote any of the basic functions of time series $y = f(t)$ and with this dependence will be sought in the form of independent variable t polynomial n-degree:

$$y = b_0 + b_1 t + b_2 t^2 + \dots b_n t^n \tag{5.19.}$$

So, the first derivative of the base functions at a time period will be the base function's θ change in trend lines of type:

$$\theta = \frac{\mathrm{d}y}{\mathrm{d}t} = b_1 + 2b_2 t + 3b_3 t^2 + \dots + n b_n t^{n-1} \tag{5.20.}$$

The second derivative of the basic function, or the rate of change of the trend, will be the time series of the form:

$$\dot{\theta} = \frac{\mathrm{d}\theta}{\mathrm{d}t} = \frac{\mathrm{d}^2 y}{\mathrm{d}t^2} = 2b_2 + 6b_3 t + \dots + n(n-1) b_n t^{n-2} \tag{5.21.}$$

The rate of change, trend or acceleration of the time series of the basic function allows the behavioral dynamics of the initial dataset to be done only by correctly selecting the degree of the approximate polynomial and determining the values of the coefficients of the polynomial of the chosen degree. A fairly complete analysis of the whole array of safety performance can then be performed. Firstly, in order to obtain effective organizational and technical measures to improve flight safety when the organisation's management staff carries out an engineering and social analysis of the causes of changes in the trend of flight safety indicators for the aircraft maintenance organization subsystem, it needs to know not only time function θ (its sign), but also the rate of its change $\dot{\theta}$.That is the point in time function changes θ and $\dot{\theta}$ that the management and control of staff should pay attention to as well as to certain developments in the process of change causes – social, technical, economic or other, both negative and positive. Secondly, it will allow to predict the behavior of such a time series for the next phase of the operation, which will allow management staff to draw appropriate conclusions and take the necessary measures to prevent the development of undesirable trends in the near future. Thus, the interaction between the links of the "aircraft-maintenance organization" subsystem needs to be ergonomically considered in order to anticipate and prevent adverse developments that will lead to a deterioration in the change of basic functions from the technical factor of the aircraft fleet. This means that during a given cycle, information should be collected on accidental aircraft denials and those resulting from human activity through further mathematical processing of the resulting statistics. When creating failure indicator *KT(A)*, the basic function of *KN(A)* allows to assess the development trend by performing regression analysis $\theta(A)$. However, when studying the impact of maintenance operators on the safety performance of air transport, this approach is not sufficient, as in the ergonomic subsystem "aircraft-maintenance organization" the change in operator organization leading to deterioration of safety indicators and changes in speed is inevitable with a delay over time; this will affect the aircraft fleet, worsening the technical factor. To find trend parameters $\theta(A)$ and the rate of change $\dot{\theta}$ it is necessary to move square, cubic or higher degree of approximation, only then investigated parameters θ and $\dot{\theta}$ will become an essential function of time and will be subject to detailed study. The use of a cubic approximation makes it possible not only to obtain functions of time $\theta(A,t)$ and $\dot{\theta}(A,t)$ but also to determine the fourth regression coefficient and acceleration, the knowledge of which will be very useful in particularly complex cases. Thus, the task is set as follows: in order to predict the trend of changes in safety performance by technical factor, considering random failures, in the previous time cycle it is necessary to study the behavior of trend parameters and their speed for safety performance determined by the human factor – maintenance operator. To determine the reliability of the accepted connection between the links of the aircraft maintenance organization subsystem, a mathematical experiment should be performed over two time cycles: a mathematical model of the process should be constructed using available statistical materials and the results obtained with the proposed initial scheme should be compared. If the presence of the combinations described above is confirmed, it is recommended that an analysis be performed to predict trend $\theta(B)$ and the rate of change $\dot{\theta}(B)$ of the technical factor $KT(B)$ and factor $KN(B)$ for the intended operating cycle.

5.4. Quadratic approximation of the basic functions of Aviation Technical safety indicators

Final results of function K_T in the graphical form and its change trends θ_T by factors *A, B, C* are shown in Section 6. However, these types of laws do not allow to obtain both parameters $\theta(t)$ and $\dot{\theta}(t)$ describing the trend and the change in the speed expressed in a function of *t* time. As a result, a more accurate analysis of events (failures) is needed, using mathematical modeling for the basic functions of Aviation Technical safety indicators in the form of cubic dependence.

6. Approbation of the Results Obtained in the Doctoral Thesis

The objects of the examination of the results obtained in the dissertation were Latvian airlines with small and medium air traffic. According to the methodology used by the author, the probability of failure of the technical components of the aircraft of unfavorable factors was calculated at different levels of the multi-level structure.

6.1. Calculation of the reliability of the cabin air conditioning system

Figures 6.1–6.9 show the rejection frequency of elements (individual factors) in the analyzed period. The components whose failure creates a dangerous failure situation in flight and certain non-hazardous failures that lead to failure situations without complicating the flight conditions are highlighted. Figure 6.4 shows the results of calculating the probability of trouble-free operation of these units.

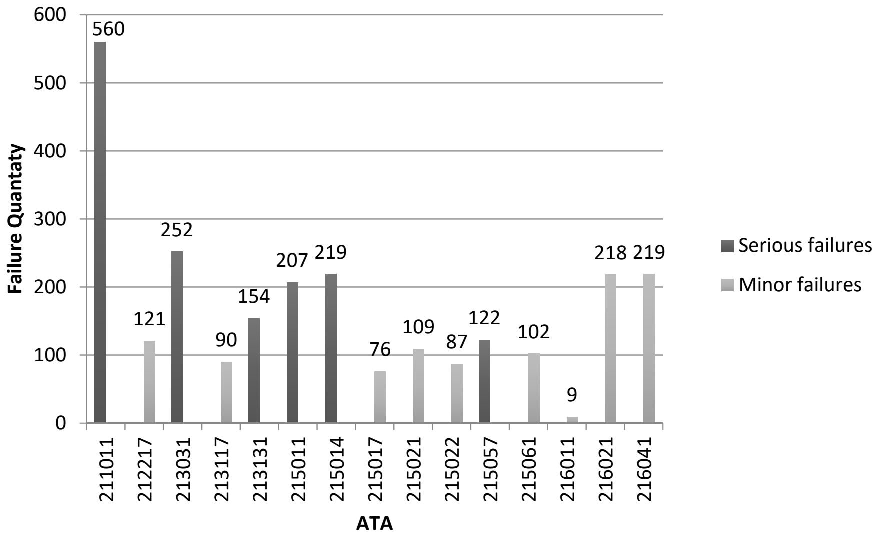


Fig. 6.1. Number of failures of air conditioning system elements during the study period.

In order to assess the possibility of safe operation of the system units, the units with the highest absolute number of failures were selected. The components highlighted in the figure are the units whose failures in flight create a complicated failure situation.

Probabilities of operation of all components of the above functional systems without failures were calculated in the same way:

21 – conditioning system;
27 – management system;
28 – fuel supply system;
29 – hydraulic system;
30 – anti-icing system.

The results of the calculations showed and identified the least reliable of them. They are shown graphically in Figs. 6.3 and 6.4.

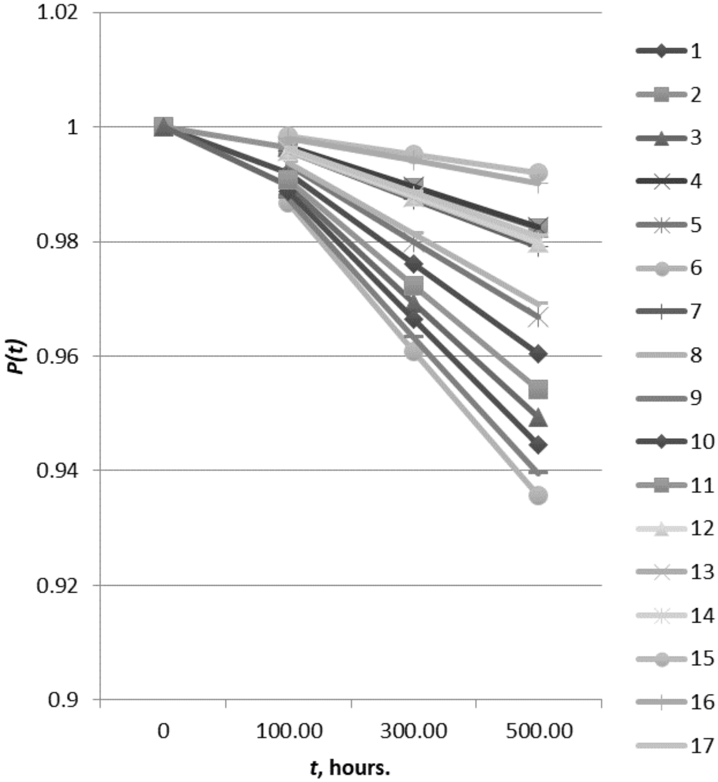


Fig. 6.2. Probability of failure of individual components of an air conditioning system.

Similar probabilities of fail-safe operation were performed during the study period for 5 functional systems in Fig. 6.3. Summarized results are shown in Figs. 6.4 and 6.5.

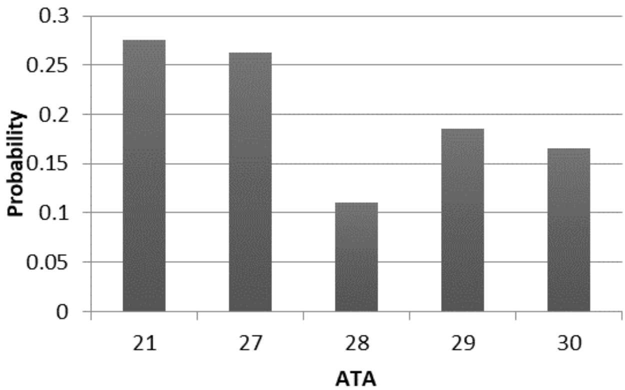


Fig. 6.3. Probability of airplane deflection systems.

21– conditioning system;
27– management system;
28 – fuel supply system;
29 – hydraulic system;
30 – anti-icing system.

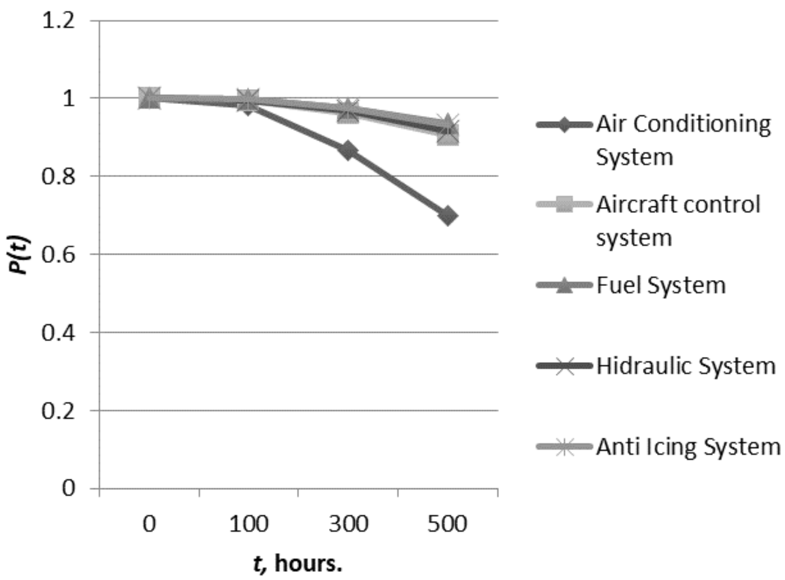


Fig. 6.4. Probability of fail-safe operation of *AVRO-RJ70* functional systems.

The graph shows that the most unsafe system is (in order of increasing safety):

- air conditioning system;
- aircraft control system;
- hydraulic system;
- anti-icing system;
- fuel supply system.

Based on the performed research, the least reliable components of the studied systems were identified. According to the standards, an individual failure that is not highlighted in dark color causes a failure situation without complicating the flight conditions (ASBLAS), the failure marked with the darkest color leads to a failure situation with flight difficulties (ASLAS). Simultaneous failures of two or more components lead to emergency failure situations (AAS).

The performed calculations are the basis for estimating the overall risk of an airplane being terminated in the event of an in-flight technical occurrence.

6.2. Regression (correlation) analysis of the airworthiness reliability of the aircraft operated by the airline

Based on the calculations of the airworthiness reliability of the aircraft air conditioning system described above, their regression (correlation) analysis was also performed.

This required finding function $K(t_i)$ to approximate the set of numerical values. Usually the smoothing function is characterized by a m polynomial of degree:

$$K_t = a_0 + b_1 t + b_2 t^2 + \ldots + b_m t^m, \qquad (6.1.)$$

where a and b are coefficients of the smoothing function.

As described in the previous section, the mathematical apparatus of regression (correlation) analysis, *a* and *b* coefficients of the smoothing function were obtained, which determine the linear approximation function for the case under study. The total number of failures components, $y = K(t_i)$, has been calculated, with the air conditioning system performing statistical data processing for the whole fleet as per months (Fig. 6.5). According to the described methodology and graph, the smoothing functions $K(t_i)$ are denoted by quarters and years. As can be seen from the graph, the smoothing function decreases monotonically during year $K(t)$. This indicates a favorable development of the changing trend $K(t)$. However, the quarterly analysis shows that this view is unrealistic, as $K(t)$ declined in the second quarter but rose sharply in the third quarter, and in particular in the first and fourth quarters. The results confirm that it is possible to take timely measures to improve the quality of aircraft maintenance and flight safety using this methodology.

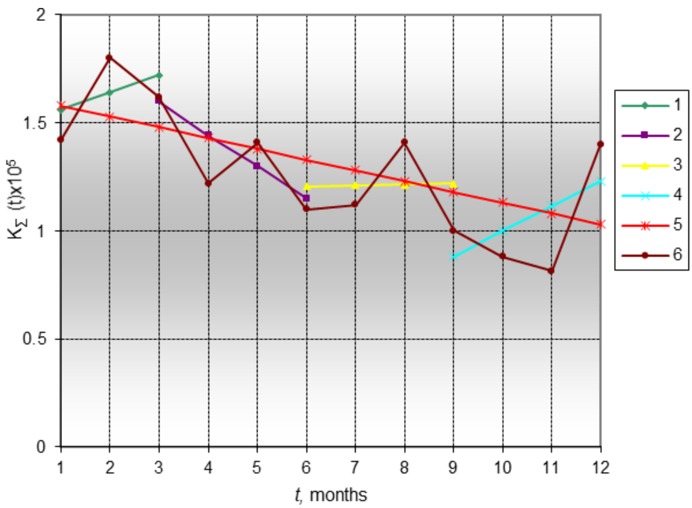


Fig. 6.5. Changes in the number of air conditioning system failures after maintenance periods.

$$
\begin{aligned}
&1 - K_{1\ \mathrm{qua}}(t) = 1.48 + 0.08\,t;\\
&2 - K_{2\ \mathrm{qua}}(t) = 1.59 - 0.15\,t;\\
&3 - K_{3\ \mathrm{qua}}(t) = 1.2 + 0.002\,t;\\
&4 - K_{4\ \mathrm{qua}}(t) = 0.89 + 0.12\,t;\\
&5 - K_{\Sigma\ \mathrm{year}}(t) = 1.63 - 0.05\,t;\\
&6 - K_\Sigma;
\end{aligned}
\qquad (6.2.)
$$

6.3. Assessment of the severity of a missed flight with the risk of an unfavorable termination

The risk of an abort will be equal to

$$R = \sum \eta_i \frac{n_i}{T_i} \qquad (6.3.)$$

Algorithm for estimating the risk of terminating a flight with an unfavorable outcome R.
All data necessary to be included in to table.

Table 6.1

i, serial number	Event type (failure situation type)	ρ_i disaster probability	n_i, controlled events *i* type	*T*
1	ASBLAS	$\eta T_{ASBLAS} = 10^{-5}$	n_{ASBLAS} – number of events ASBLAS	Flight hours during safety control period
2	ASLAS	$\eta T_{ASLAS} = 10^{-4}$	n_{ASLAS} – number of events, ASLAS	
3	SAS	$\eta T_{SAS} = 10^{-3}$	n_{SAS} – number of events, SAS	
4	AAS	$\eta T_{AAS} = 10^{-1}$	n_{AAS} – number of events, AAS	
5	KAS	$\eta T_{KAS} = 10^{0}$	n_{KAS} – number of events, KAS	

The number of controlled failure situations at different hazard levels is determined on the basis of the failure situation criteria specified in the regulatory documents and the analyses of the consequences of specific levels of different failures specified in the technical documentation of this aircraft (Table 6.1). By analyzing each failure of any aircraft component on the basis of the technical documentation, it is possible to identify the failure situations and estimate their number for a certain period of time *T* (flight hours in the safety control interval).

Let us show this using the example of an aircraft air conditioning system discussed above. This functional system provides the aircraft consumer with vital functions for passengers and crew during the flight.

So, the consumer is an important life support system. In our case, the functional system is air conditioning system (ACS). The regulatory requirements specified in the operating instructions for this system are as follows:

a. Cockpit and cabin air pressure $P_к$ relation to the permissible pressure values $P_к$. Allowed to be: $P_к > P_{norm.}$ (overpressure). According to the flight manual, an increase in cabin pressure (air pressure circulating compressor) must be excluded in such cases, an emergency altitude reduction must be performed and, if the aircraft does not provide cabin ventilation at low altitudes, landing at the nearest alternate aerodrome. According to the standardized features, (Table 5.1) this will be **an emergency failure situation (AAS)**.
b. $P_к < P_{к.norm.}$ (depressurisation). It is not necessary to switch on the pressure in this position, so the crew that has reached the flight level at a safe altitude in terms of the allowable pressure can continue the flight for as long as needed. Accordingly, with standardized features, this will be **a difficult failure situation (SAS)**.
c. $(dP_к / d\tilde{\imath}) > (dP_к / d\tilde{\imath})$ allowed. Usually, this condition also leads to a reduction in pressure, which means leading to **an emergency failure situation (AAS)**.

According to the statistics from 15 failure conditions associated with this functional system during the monitored period, an increase in pressure in the pressurized cabin and system normalization of the system were observed in 9 cases. Out-of-standard pressure cab parameters are usually raised by control valves failure and left in open position. As a result, the aircraft were forced to make an unscheduled landing, which is an emergency failure situation (AAS) according to the criteria for a failure situation. In the other 5 cases, the cause of exposure to high temperature sensors was air radiator failure, damage to hot air ducts. In four of the above cases, the crew was forced to cut off the air supply from the engines, which corresponded to a difficult failure situation (SAS).

Thus, knowing the number and quality of failures and the corresponding flight hours, we can estimate the frequency of each failure condition ρ_i per flight hour:

$$\rho_i = \frac{n_i}{T_{li}}, \qquad (6.4.)$$

where n_i is the number of appropriate failure situations in flight;
T_i is flight hours.

6.4. Pyramid method for the quantitative assessment of the severity of failure situations where technically unfavorable factors appear in flight

To practically assess the level of flight safety using group C safety performance indicators related to aircraft operations, the author used the pyramid method described in the Chapter 1 to quantify the severity of failure situations when in-flight adverse events occur using the aviation adverse event classification.

Where n_K is the number of catastrophe; n_A is the number of emergency situations; n_{SI} is the number of serious aviation incidents; n_i is the number of aviation incidents, according to the generally accepted ratio

$$n_k : n_A : n_{si} : n_i = 1 : 10 : 30 : 600, \qquad (6.5.)$$

Analyzing this ratio in Figs. 6.5 and 6.6, it can be concluded:

- The severity of the consequences of much higher-level events is always higher than the lower level of severity of events.
- The process of developing an adverse event most often occurs from less dangerous events to more dangerous events.
- In each of the most dangerous events, less dangerous events had occurred with a high probability – examples (precursors).

In the pyramid model (Fig. 6.6) for assessing the level of flight safety it is represented rather as an underlying adverse events ratio, not as the failure of the flight situation frequency and the severity in the estimated period .

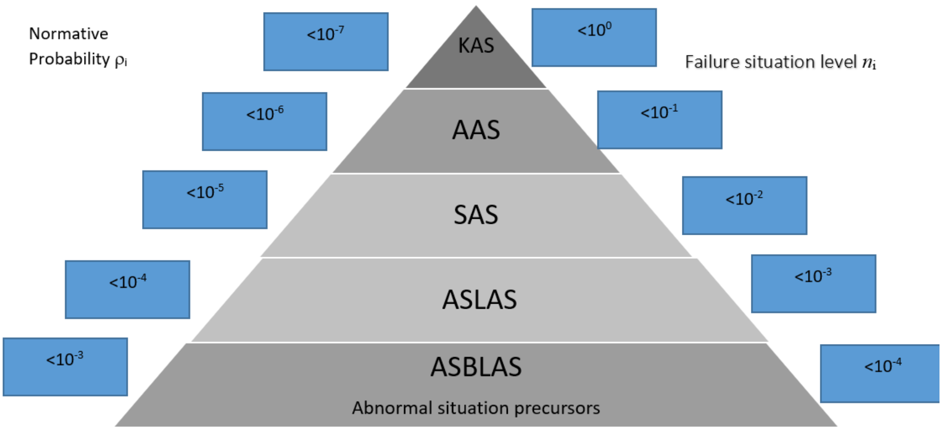


Fig. 6.6. Pyramid of possible development of failure situations in flight.

$$N_{KAS} : N_{AAS} : N_{SAS} : N_{ASLAS} : N_{ASBLAS} = 10^0 : 10^{-1} : 10^{-2} : 10^{-3} : 10^{-4}, \qquad (6.6.)$$

where N_{KAS} – number of catastrophic failure situations;

N_{AAS} – number of emergency failure situations;

N_{SAS} – number of complicated failure situations;

N_{ASLAS} – number of cases of failure situations with complicated flight conditions;

N_{ASBLAS} – number of cases of failure situations without complicated flight conditions.

Thus, we move from the flight safety level determined by the number of adverse events during the reporting period to overall risk probability R that is determined by an integrated assessment of the sum of all risk-failure situations during the flight.

Then, from the relation (6.6), assuming numerical values and showing that the weighting factors λ_i, which determine the investment in each risk situation, risk R is directly derived for the determined flight:

λ_{KAS} – catastrophic failure situation weight factor – 10^0;
λ_{AAS} – emergency failure situation weight factor – 10^{-1};
λ_{SAS} - complicated failure situation weight factor – 10^{-2};
λ_{ASLAS} – failure situation with complicated flight conditions weight factor – 10^{-3};
λ_{ASBLAS} – failure situation without complicated flight conditions weight factor – 10^{-4}.

Numerical values of λ_i can be determined using mathematical methods. However, the most appropriate way to quantify is a statistical estimate. This is done by determining the frequency of the transition from emergency to complicated situations or from complicated flight conditions to catastrophic situations. To do this, it is necessary to know the absolute values of the number of different types of failure that have occurred in a given period, as well as the number of failures that have caused the failure.

The general risk level, flight risk level R as an integral failure situation risk assessment per flight hour is determined by Formula (6.7):

$$R = N_{\mathrm{KAS}}\lambda_{\mathrm{KAS}} + N_{\mathrm{AAS}}\lambda_{\mathrm{AAS}} + N_{\mathrm{SAS}}\lambda_{\mathrm{SAS}} + N_{\mathrm{ASLAS}}\lambda_{\mathrm{ASLAS}} + N_{\mathrm{ASBLAS}}\lambda_{\mathrm{ASBLAS}} = \sum_{i=1}^{5} N_i\lambda_i \qquad (6.7.)$$

or

$$R = \sum_{i=1}^{5} N_i\lambda_i \qquad (6.8.)$$

The formula is used to estimate the probability of transition from an abnormal situation to a catastrophic situation due to a failure per flight hour. Information on specific situations for risk assessment in an airline allows to create a risk scale. When creating the risk scale, it is assumed that all its possible values are in the range from “0” to “1”, which means the lower and upper limits. Such a scale can be used to assess a specific situation in the form of a matrix (Table 6.2).

Table 6.2

Risk Matrix

		Failure situation severity				
		Minor (ASBLAS)	Insignificant (ASLAS)	Significant (SAS)	Hazardous (AAS)	Catastrophic (KAS)
Event probability	Frequent $\rho_i \leq 10^{-3}$	Subject to analysis	Not acceptable	Not acceptable	Not acceptable	Not acceptable
	Probable $\rho_i \leq 10^{-4}$	Subject to analysis	Subject to analysis	Not acceptable	Not acceptable	Not acceptable
	Low probability $\rho_i \leq 10^{-5}$	Acceptable	Subject to analysis	Subject to analysis	Not acceptable	Not acceptable
	Very low probability $\rho_i \leq 10^{-6}$	Acceptable	Acceptable	Subject to analysis	Subject to analysis	Not acceptable
	Practically impossible $\rho_i \leq 10^{-7}$	Acceptable	Acceptable	Subject to analysis	Subject to analysis	Subject to analysis

However, such a risk scale must be reclassified periodically because the actual values of λ_i are determined by the level of flight safety achieved over time, which changes over time.

In research is assumed that for an airline with an average air transport volume that is the subject of this study, the relative safety performance can be calculated with sufficient accuracy in the form of a relative safety index for the period analyzed using Formula (6.9) and (6.10):

$$K = \frac{1 - N_{NG}}{A} \cdot 100\ \% \qquad (6.9.)$$

$$K = \frac{N}{N_{NG}}, \qquad (6.10.)$$

where N_{NG} – total number of negative events classified in regulatory documents, as well as existing non-compliances and violations of standard (specified) parameters, equipment malfunctions and other events not included in Fig. 6.6);

A – airline flight of the airline for the study period.

The coefficient condition is $K : K < 1$.

In order to increase the relative level of flight safety, a scale factor of the criterion is introduced:

$$M = 10^5. \qquad (6.11)$$

N_{NG} is calculated by the following formula:

$$N_{NG} = K_1 N_{KAS} + K_2 N_{AAS} + K_3 N_{SAS} + K_4 N_{ASLAS} + K_5 N_{ASBLAS} = \sum N_i K_i, \qquad (6.12.)$$

where K_1, K_2, K_3, K_4, K_5 are the weighting factors of negative events.

The weighting factors (K_1, K_2, K_3, K_4, K_5) are determined according to the expert method described in Chapter 3. The following values are intended to be used for practical application:

$$K_1 = 0.5;\ K_2 = 0.3;\ K_3 = 0.1;\ K_4 = 0.05;\ K_5 = 0.005 \qquad (6.13.)$$

Substituting the value from Equations (6.13) and (6.12) and placing in Equation (6.9), we obtain the following:

$$K = (0.5N_{KAS} + 0.3N_{AAS} + 0.1N_{SAS} + 0.05N_{ASLAS} + 0.005N_{ASBLAS}) \times 10^5 / A \qquad (6.14)$$

The relative flight safety index over the analyzed period is determined by the following formula:

$$K = \frac{1 - N_{NG}}{A} \cdot 100\ \% \qquad (6.15.)$$

Relative flight safety index K over time is simple and straightforward.

This index takes into account the airline's load, all adverse events in the airline and reflects the level of flight safety [36], [40], [47], [48].

6.5. Impact of aircraft maintenance assessment on operational safety performance

As outlined in Chapter 4, in order to move from the airworthiness assessment to the safety assessment, it is necessary to take into account in-flight failures and/or malfunctions during maintenance, dividing them into separate groups (A, B, C) and determining the impact of each on the safety indicators. Calculations were obtained according to the methodology described in research and the following data were obtained: quarterly regression coefficients (A, B, C; A+B+C); annual regression coefficients; variances and standard deviations per year; quarterly figures; quarterly trends; the pace of change in quarterly trends; annual indicators and their forecast; annual trends and their forecast; annual trend change rates and their forecast. Based on the obtained graphs they will be analyzed more detailed.

6.6. Analysis of the schedule of changes in the basic functions of afety indicators

Figures 6.7 and 6.8 show the graphs of changes in basic functions depending on the indicators by quarters, based on the rolling indicator method, which means taking into account the events of the previous quarter. The data set will then cover the events (failures) that occurred in the entire fleet of this type of aircraft in days 182–184, taking into account the denials of all 22 technical systems and components of each aircraft (aircraft, engine, chassis, fuel in aeronautical radio equipment and navigation equipment, etc.).

The presence of such a large amount of data for six months actually allows the use of conventional distribution laws and standard methods to study the case value.

The presence of moving indicators is required to calculate regression coefficients for the quarter under review. Therefore, the actual change in parameters $K_T(A)$, $K_T(C)$, $K_T(B)$ and $K_T(A,B,C)$ in the charts only for this quarter (excluding the values for the previous quarter).

Total schedule $K_T(A, B, C)$ for the year gives a fairly clear picture of the failures of aircraft from January to September, with a slight increase again at the end of the year. However, the role of the individual in these failures is ambiguous. According to human factor *A*, the change in the $K_T(A)$ parameter deteriorates until May, after which it improves until the autumn, after which the presence of factor A and the increase in component failures increase again.

Thus, it is necessary to perform an engineering and social analysis of the reasons for the deterioration of the work of technical staff in these periods, which can be done quite completely, if we use the graphs of changes in indicators, the rate of change, as well as data from other sections.

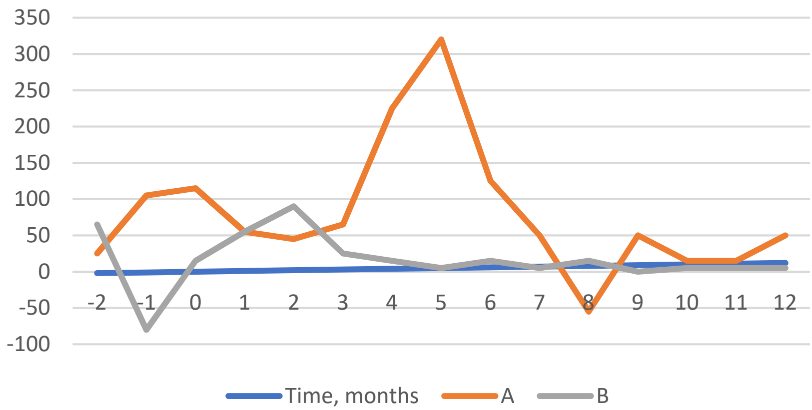


Fig. 6.7. Graph of changes in quarterly indicators by factors *A* and *B*.

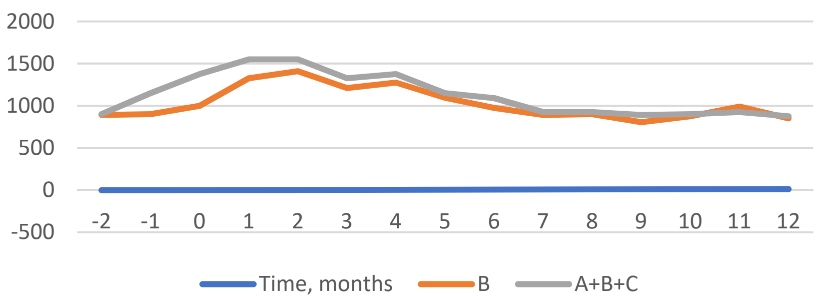


Fig. 6.8. K_T graph of changes in quarterly indicators by factors B and A + B + C.

From graph θ(*A*, *t*) in Fig. 6.9 it follows that from January to the end of April the trend was positive and the most negative work results were in March, when the acceleration of the maximum deterioration of the trend was achieved, as can be seen from $\dot{\theta}(A,t)$ in Fig. 6.10. After 7 months, the indicator continued to decline, but this downward trend deteriorated, leading to an increase in θ(*A*, *t*) with a smaller acceleration $\dot{\theta}(A,t)$, which again showed a sharp decline after 9 months. A similar justification should be provided when analyzing the results of the processing of statistical material on aircraft failures and malfunctions performed on individual aircraft systems and equipment.

Figure 6.11 shows an example of the change in the flight safety schedule indicator and its parameters according to coefficients A and B for the electrical equipment of the aircraft fleet. From the graphs, as well as from the view of the schedule it can be seen in advance (see. Figs. 6.7 and 6.8) that important interrelated causal trends and changes in the rate take place on a quarterly basis, depending on factors A and B. Trends θ(A, *t*) and θ(B , *t*) and speeds $\dot{\theta}(A,t)$ and $\dot{\theta}(B,t)$ change according to an approximately periodic law with phase shift trends θ(A, *t*) and θ(B, *t*), as well as trend rates $\dot{\theta}(A,t)$ and $\dot{\theta}(B,t)$, may in some cases reach *P/2* and *P*, respectively. These data indicate that the deterioration of staff quality later leads to equipment failures. Thus, the non-monophonic nature of the change of flight safety parameters θ(A, *t*) and $\dot{\theta}(A,t)$ under the influence of factor A has been identified. Roughly it can be considered as a quasi-periodic process. Moreover, even one type of monthly production task does not lead to a transition to a quasi-monotonic flow.

It also follows from the given graphs that the process of changing the parameters of the basic functions of the safety indicators of technical coefficient *B* is not monotonic. This process also describes the trends in quasi-periodical function parameter θ(B, *t*) and speed $\dot{\theta}(B,t)$. However, these curves are phase shifted with respect to similar curves describing parameters *θ*(A, *t*) and $\dot{\theta}(A,t)$ under the influence of factor A. The phase shift is negative: there are delays and changes in parameter functions θ(B, *t*) and $\dot{\theta}(B,t)$, by factor B compared to similar functions θ(A, *t*) and $\dot{\theta}(A,t)$ by factor A, which indicates the link between the maintenance organization and the aircraft, directly in the subsystem "aircraft in the maintenance organization". Thus, if the management of the maintenance organization were able to use the proposed methodology on an ongoing basis and perform a timely engineering and social analysis to assess the causes of such a trend change, it would be possible to influence the production process to prevent uncontrolled changes in aviation technology safety indicators that are currently underway.

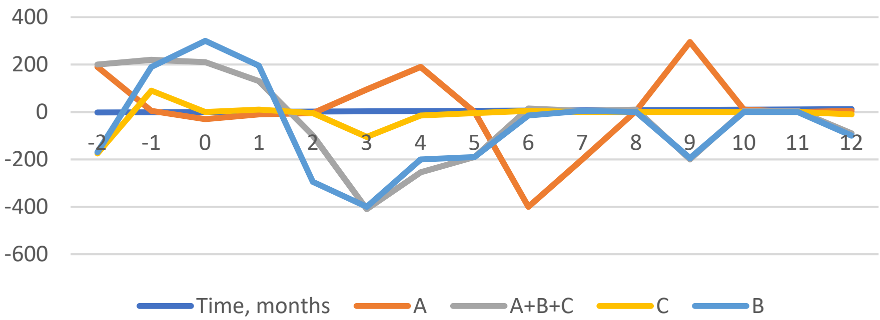


Fig. 6.9. Quarterly graph of changes in speed trend indicators by factors A, B, C; A + B + C.

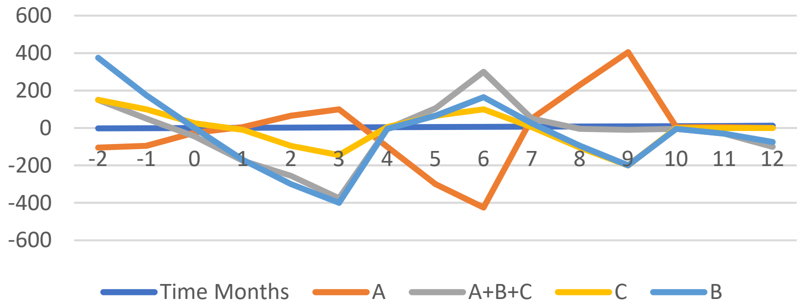


Fig. 6.10. Factor trends $\dot{\theta}$

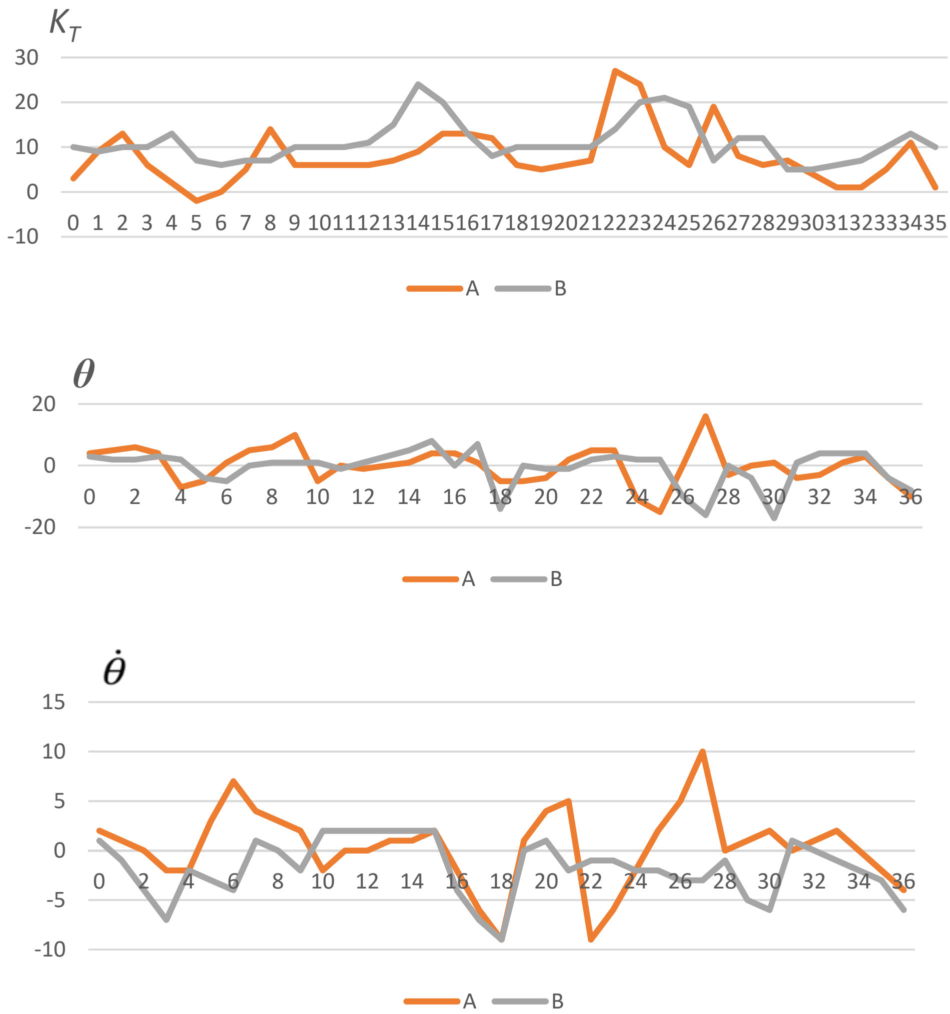


Fig. 6.11. Graphs of flight safety indicator and parameter changes by coefficients A and B of aircraft electrical equipment

Summary

The developed system for the identification, collection, processing, analysis and use of risk data arising directly from deviations from the standards in the operation of various airline structures and personnel can be considered as the basis for the joint management of an airline. It is based on a quality system as an integral part of the airline's integrated management system.

In the analyzed airline, the quality system was developed and implemented in accordance with the requirements of *ISO 9001: 2008*, based on the overall quality management system. It is a one-size-fits-all model that best meets the requirements of all stakeholders (shareholders, management, staff, consumers) and thus allows both the overall transmission and the focus to meet the individual requirements of the situation. The safety management system has also been implemented and is operating successfully in accordance with *ICAO* and *EASA* requirements, building on existing resources, and assessing the company's current capabilities in the field of safety management (including experience, knowledge, processes, procedures, resources, etc.)

The functions of the departments and decision-makers are assigned to both the flight safety department and the quality control department, which coordinate functions with each other and with the heads of the departments, facilitating their safety and quality management functions. The creation of the information base in the proposed form allowed:

- to expand the "geography" of airline systems management, thus contributing to its improvement;
- to ensure greater coordination of activities within the airline, thus reinforcing the synergy effect; the result of coordinated practices is greater than the simple sum of the individual results;
- to reduce functional inconsistencies in the airline resulting from the development of autonomous management systems;
- it is much less labor intensive to manage than several parallel systems;
- introduction of this system increases the corporate culture, in which quality and safety are considered to be the same core values, which meet the requirements of *ICAO* in this area, given that 2021 has been declared the *ICAO* Year of Aviation Safety Culture.

Conclusions

1. An information database model has been developed for the airline to identify, process and provide information in a timely manner, allow the airline and decision-makers to provide objective information on areas at risk of adverse events, and identify trends in safety performance based on information flows from the various areas of the airline's operations with an integrated management system that allows the expected level of safety to be determined in a timely and reasonable manner. This makes it possible to minimize the risk and thus maintain an acceptable level of safety for the airline, as well as to forecast the safety performance for the next period. This approach can be seen as a transition to a new level of safety management at airline level.
2. An algorithm has been developed for the detection and analysis of irregularities of departments and errors of airline personnel under conditions of uncertainty, which allows the analysis of safety aspects based on factual information coming from various sources to airline information on the basis of which it is collected, classified, stored and analyzed using analytical methods and techniques. Based on this algorithm, software for automated information processing and analysis has been developed.
3. A system of indicators has been developed for the assessment of flight safety (6 groups of indicators for the general directions of the airline's operations), each of which will include a specific set of indicators, as well as the methodology for their assessment.
4. A methodology has been developed to determine the level of flight safety using Group *C* indicators related to the aircraft and its operation by assessing that the multi-level functional system takes into account the probability of failure of each level and the severity of the consequences.
5. The developed methodology was tested on the basis of the airline's performance, the results of which show that the implementation of this system in the airline's practice will allow timely provision of the necessary information to the airline's bodies and decision-makers in those areas where the risk of adverse events is highest, as well as allow the identification of trends in safety performance based on information flows from different areas of the airline's business, with an integrated management system that allows timely determination of expected level of flight safety in a reasonable manner.

This approach can be seen as a transition to a new concept of safety management at airline level.

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