MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
EDUCATIONAL AND RESERCH FACULTY OF AIR NAVIGATION,
ELECTRONICS AND TELECOMMUNICATIONS
AIR NAVIGATION SYSTEMS DEPARTMENT

PERMISSION FOR DEFENCE

Head of the Department
Doctor of Sciences (Engineering), prof.
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"_____" ______ 2020

MASTER’S THESIS
ON THE EDUCATIONAL PROFESSIONAL PROGRAM "SYSTEMS OF AIR NAVIGATION SERVICE"
(EXPLANOTARY NOTE)

Theme: " Aircraft incident and accident investigation techniques with the help of proactive measures"

Performed by: _______________________________**B.V. Bas**

Supervisor: Doctor of Sciences, associated prof. _______**V.P. Kharchenko**

Standard inspector __________________________ **G.F. Argunov**

KYIV 2020

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

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д-р техн. наук, проф.
___________В.Ю. Ларін
«__»_________2020 р.

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)
ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА
ЗА ОСВІТНЬО-ПРОФЕСІЙНОЮ ПРОГРАМОЮ
«СИСТЕМИ АЕРОНАВІГАЦІЙНОГО ОБСЛУГОВУВАННЯ»

Тема: "Розслідування авіаційних подій та катастроф за допомогою проактивних заходів"

Виконав: __________ **Б.В.Бас**

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Київ 2020

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AI NAVIATION, ELECTONIC AND TELECOMMUNICATION
AIR NAVIGATION DEPARTMENT
SPECIALTY 272 “AVIATION TRANSPORT”

APPROVED BY

Head of the Department
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«…» …………… 2020

Graduate Student’s Degree Thesis Assignment

Bohdan Bas

1. The Thesis topic: «Aircraft incident and accident investigation techniques with the help of proactive measures » approved by the Rector’s order of 29.09.2020 №1815/ст.

2. The Thesis to be completed between з 05.10.2020 - 13.12.2020.

3. Initial data to the thesis (project): ICAO Safety Management Manual Doc 9859, Annex 19, ICAO.

4. The content of the explanatory note (the list of problems to consider): analysis of international safety management documents, methodical approaches to risk control, procedures for the identification and assessment of risks in the safety management system with fuzzy measures of hazard factors.

5. The list of mandatory graphic (illustrated) materials: 23 figures of explanatory material, 7 tables.

6. Calendar timetable

№	**Completion stages of Degree Thesis**	**Stage completion dates**	**Remarks**
1.	Preparation of chapter 1	05.10.20 - 23.10.20	complete
2.	Preparation of chapter 2	24.10.20 - 11.11.20	complete
3.	Preparation of chapter 3	12.11.20 - 30.11.20	complete
4.	Preparation of chapter 4	01.12.20 - 11.12.20	complete
5.	Preparation of report and graphic materials	05.10.20 - 23.10.20	complete

7. Assignment accepted for completion: «__ » ____________ 2020

Supervisor of graduate work ___________________________. Kharchenko V.P.

(supervisor`s signature) (name, surname)

The task is obtained for fulfillment by____________________ Bas B.V.

(student`s signature) (name, surname)

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
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КАФЕДРА АЕРОНАВІГАЦІЙНИХ СИСТЕМ

СПЕЦІАЛЬНІСТЬ 272 «АВІАЦІЙНИЙ ТРАНСПОРТ»

ЗАТВЕРДЖУЮ
Завідувач кафедри
Ларін В.Ю.
………………………
«…» …………... 2020 р.

ЗАВДАННЯ

на виконання дипломної роботи магістра

Баса Богдана Валерійович

1. Тема дипломної роботи: «Розслідування авіаційних подій та катастроф за допомогою проактивних заходів» затверджена наказом ректора від 29.09.2020 №1815/ст..

2. Термін виконання роботи (проекту): 05.10.2020 –13.12.2020.

3. Вихідні дані до роботи: додаток 19 до Міжнародної конвенції цивільної авіації, ICAO, ICAO Safety Management Manual Doc 9859.

4. Зміст пояснювальної записки: аналіз міжнародних документів з управління безпекою, методичні підходи до контролю ризиків, процедури виявлення та оцінки ризиків у системі управління безпекою з нечіткими показниками факторів небезпеки.

5. Перелік обов'язкового графічного (ілюстративного) матеріалу: 23 рисунки результатів проведених досліджень,7 таблиць.

6. Календарний план-графік

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1.	Підготовка та написання 1 розділу	05.10.20 - 23.10.20	виконано
2.	Підготовка та написання 2 розділу	24.10.20 - 11.11.20	виконано
3.	Підготовка та написання 3 розділу	12.11.20 - 30.11.20	виконано
4.	Підготовка та написання 4 розділу	01.12.20 - 11.12.20	виконано
5.	Підготовка презентації та доповіді	05.10.20 - 23.10.20	виконано

7. Дата видачі завдання: «__ » ____________ 2020 р.

Керівник дипломної роботи ___________________ Харченко В.П.

(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання __________________Бас Б.В.

(підпис випускника) (П.І.Б.)

ABSTRACT

Explanatory note to the thesis "Aircraft incident and accident investigation techniques with the help of proactive measures": 90 pages, 23 figures, 7 tables, 38 sources.

Purpose of the work — creation of methods for a flight safety control in the civil aviation taking into account a calculus of risks of hazard factors in a flight.

Research method — automata theory and fuzzy logic usage for methods of statistical processing of results.

Relevance — aviation system consists of plenty of parts which collaborate with each other. It leads to risk and, consequently, possible incidentents at any moment and place. Even though the safety level in aviation is maintained at the high level, some incidents occure. It is impossible to identify them taking into account previous experience only but possible if we will learn to predict these events.

Investigation object — the process of flight safety management in the aviation industry and within flight operations worldwide.

Projection according the research object — method of forming control corrective actions on the aviation system based on the analysis of fuzzy implications of a risk value in rare events.

FUZZY SETS, RISK, INCIDENT, INVESTIGATION, SAFETY, HUMAN FACTOR, MODEL, METHOD OF MODELLING, ANNEX 19

РЕФЕРАТ

Пояснювальна записка до дипломної роботи "Розслідування авіаційних подій та катастроф за допомогою проактивних заходів": 90 сторінки, 23 рисунки, 7 таблиць, 38 використаних джерел.

Мета дипломної роботи — створення методів контролю безпеки польотів у цивільній авіації з урахуванням кількості ризиків небезпечних факторів в польоті..

Методи дослідження — теорія автоматів та використання нечіткої логіки для методів статистичної обробки результатів..

Актуальність — авіаційна система складається з безлічі частин, які співпрацюють між собою. Це призводить до ризику і, як наслідок, можливих інциндентів у будь-який момент часу і в будь-якому місці. Незважаючи на те, що рівень безпеки в авіації підтримується на високому рівні, деякі інциденти трапляються. Ідентифікувати їх неможливо лише з урахуванням попереднього досвіду, але можливо, якщо ми навчимося передбачати ці події.

Об'єкт дослідження — процес управління безпекою польотів в авіаційній сфері та при польотів світі.

Прогнозовані припущення щодо розвитку об'єкта дослідження — спосіб формування коригуючих дій в авіації на основі аналізу нечітких наслідків ризику в нечастих випадках.

НЕЧІТКІ МНОЖИНИ, РИЗИК, ІНЦИДЕНТ, РОЗСЛІДУВАННЯ, БЕЗПЕКА, ЛЮДСЬКИЙ АКТОР, МОДЕЛЬ, МЕТОД МОДЕЛЮВАННЯ, ANNEX 19

LIST OF REMARKS

CONTENT

LIST OF ABBREVIATIONS AND TERMS

PIC – pilot in command

NASA – National Aeronautics and Space Administration

ICAO – International Civil Aviation Organization

CNS – Communication, Navigation, Surveillance

ATM – Air Traffic Management

SMS – Safety Management System

ECAST – European Commercial Aviation Safety Team

CVR – Cockpit Voice Recorder

ILS – Instrument Landing System

RWY – runway

ATC – Air Traffic Control

ACC – Area Control Center

GPWS – Ground proximity warning syseem

UTC – Universal Coordinated Time

QMS – Quality Management System

LOSA - Line Operations Safety Audit

QNH (Height Above Sea Level) is a pressure setting you dial into your altimeter to produce the height above sea level.

METAR (Meteorological Aerodrome Report) is a format for reporting weather information.

TAF (Terminal Aerodrome Forecast) is a concise statement of the expected meteorological conditions at an airport during a specified period.

NOTAM (notice to airmen) is a notice filed with an aviation authority to alert aircraft pilots of potential hazards along a flight route or at a location that could affect the safety of the flight.

SPECI (Aviation selected SPECIal Weather Report) is a Aerodrome special meteorological report.

TREND is a professionally considered forecast for weather over a two-hour period, and is based on an actual weather report, such as a METAR or SPECI and appended to the end of it.

UKKK – Kyiv Zhuliany International Airport

LTAI – Antalya International Airport

INTRODUCTION

Civil aviation is a strategic priority of geopolitical, social and economic development of Ukraine and an important part of production and social infrastructure. Its sustainable, efficient operation is a necessary condition for national security, sustainable economic growth and improving living standards.

With the beginning of the restructuring of economic relations, the volume of aviation activity in Ukraine has decreased significantly. The financial situation of aviation enterprises has become more complicated. It has led to a reduction in the development and improvement of civil aviation, and led not only to a slowdown in scientific and technological progress, but also to a deterioration in its technical condition.

The fashion for the creation of "independent structural units" within enterprises and the industry as a whole in search of economic benefit has pushed to the background the issue of flight safety. Annual, long-term structural reorganizations with the Aviation Administration of Ukraine do not allow effective and efficient management. The predominant interests of "commerce" lead to the widespread use of strictly prohibited methods: the irreversible process of deconstruction aircraft and rearranging units, engines and equipment from one aircraft to another, extending the resources of aircraft without a proper assessment of its condition which inevitably leads to complete lack of control on the part of the Aviation Administration of Ukraine. It indicates that the level of flight safety in the air navigation system of Ukraine is not provided [1].

A number of problems in safety theory are caused by imperfect methods of scientific research, in particular, when planning airspace.

The basis of the new approach is the principle of structural and logical analysis of scenarios for the development of events.

The scenario approach is currently the only promising method of proactive system control with information uncertainty.

CHAPTER 1

THE PRINCIPLE OF CREATING SAFETY MANAGEMENT SYSTEM FOR CIVIL AVIATION ON A GLOBAL CSALE BASED ON REQUIREMENTS OF ICAO

1.1. SMS functional purpose that implements ICAO's safety strategy

Chicago convention contracted states realized necessity to create Quality Management System based on international standards [23].

There are indicate stages for national SMS which must be as a part QMS in ICAO's program of SMS creation [23, 24].

The fundamental result is that SMS, as an element of a general integrated management system of the type Integrated Management System (IMS) should contain two subsystems that meet the requirements of two (or more) international standards and function as a whole. This idea was presented by ICAO council in 2012 with the name “10 things you know about SMS” and published in SMM document (Manual – for SMS) that was created by FAA.

1.1.1 Analysis of international safety management documents

Ensuring flight safety is a priority of air transport and an integral part of national security. According to [2], as a member of the International Civil Aviation Organization (ICAO), Ukraine must strictly adhere to the standards established by this organization, according to which each ICAO member state is obliged to develop and implement a national safety program, and aviation entities - to implement flight SMS [3].

It is important to note that in the 1980s, the concept of "flight safety" was seen as a property of the air transport system, which is the ability to carry out air transportation without endangering human life and health [4, 5]

Today, the inability to approach the issue of flight safety in the aviation system has been proven solely from the standpoint of comprehensive counteraction to the negative impact of the environment on flight safety. [6] provides the following definition of security, namely: security is a condition in which the risk of harm to persons or damage to property is reduced to an acceptable level and maintained at this or lower level through a continuous process of identifying sources of danger and controlling risk factors . Thus, one of the current areas of improvement of safety management methods is risk identification, assessment and management.

That is why international aviation organizations such as Eurocontrol and ICAO have proposed a new model of flight safety, which provides a proactive method and consists in the active collection of information on events from various sources (voluntary notification system; objective control materials; results of aviation accident and incident investigations active exchange of information [7, 8].

The safety management system is a set of measures to apply a unified approach to safety management that involves optimizing the organizational structure, the division of responsibilities between public authorities and aviation entities, defining policies and operational procedures to ensure safety.

Safety management is based on a systematic approach to identifying and eliminating sources of danger and risk control to ensure safety in order to minimize human loss, material, financial, environmental and social damage.

Based on a systematic approach to safety management, it is possible to use the characteristic points of its assessment function, which determines the attitude to risk in the decision-making process to resolve a conflict and dangerous situation, to differentiate the levels of the risk triangle. Using such a classification of risks by quantitative calculation, there is an opportunity to improve the information and methodological content of the already proposed decision support systems by flight safety experts [9,10].

In all cases where the risk factor does not meet the pre-established eligibility criteria, an attempt should be made to reduce it to an acceptable level, using appropriate means to reduce the risk. Before a risk can be classified as acceptable or acceptable, the following conditions must be met [9,10]:

- this risk is below the established limit of unacceptable level;
- this risk was reduced to the lowest possible level;

- The benefits of the proposed system are significant enough to accept this risk.

Obtaining quantitative assessments for experts who carry out PR will allow to obtain a quantitative assessment of current risk, and thus, to evaluate the results of risk management measures and attitudes to it.

To increase the level of flight safety, public authorities and aviation entities must take effective measures to implement a flight safety management system in accordance with the requirements of ICAO, the European Aviation Safety Agency and the European Organization for the Safety of Air Navigation (Eurocontrol) [3]. In preparation for the conclusion of the Agreement between Ukraine and the EU on a common aviation area, solving safety problems, will increase the attractiveness of Ukrainian airspace and the competitiveness of domestic aircraft operators. Security is a relative concept, and assumes the presence of natural risk factors in a "safe" system.

That is why safety management is considered as control over risk factors and risk management, allows forecasting the occurrence of hazards within the functioning of the safety management system [12, 13].

It should be noted that the adoption of modern and effective management decisions largely depends on the understanding of the nature of danger, threat and risk, as well as the attitude to them by the subjects of aviation. The main provisions contained in the guidance documents on flight safety are shown in figure 1.1 - 1.5. It is necessary that the subjects of aviation activities have an unambiguous understanding of the essence of such a category as "risk" and related categories of "threat" and "danger". Risk is defined as a measure of uncertainty about a future event, as a possible danger [14, 15, 16].

The principles of flight safety management are shown in figure 1.1 - 1.5. Danger can be described as the possibility of any misfortune, as a result of the action of systemically interconnected objective and subjective factors, some of which can be observed, and others can be hidden. The most common approach to the definition of danger is defined in [17, 18, 19] where only the concept of "security threat" is used, and then lists its types depending on the area to which the document relates.

Often concepts such as "risk" and "danger" are identified. It should be noted that the threat arises in the case of refusal to take into account when modeling and analyzing the situation a set of systemic and unique risks, which can be both predictable and partially unpredictable. At a time when the danger arises directly at the decision-making stage, taking into account the possible risks.

Among a number of destabilizing factors for aviation entities (risk, danger or threat), the primary risk is risk, and danger and threat are types of situations that lead to flight safety violations if risks are ignored, ie act as secondary factors. Therefore, the set of parameters that pose a danger or threat to flight safety can be classified as a set of risk factors, the detection and counteraction of which should be engaged in all personnel of the aviation entity in the functioning of the safety management system. The level of acceptable risk depends to a greater extent on the degree of usefulness for the decision-maker, the ultimate goal of its activities, as well as the usefulness of intermediate results that it can achieve by implementing a particular action.

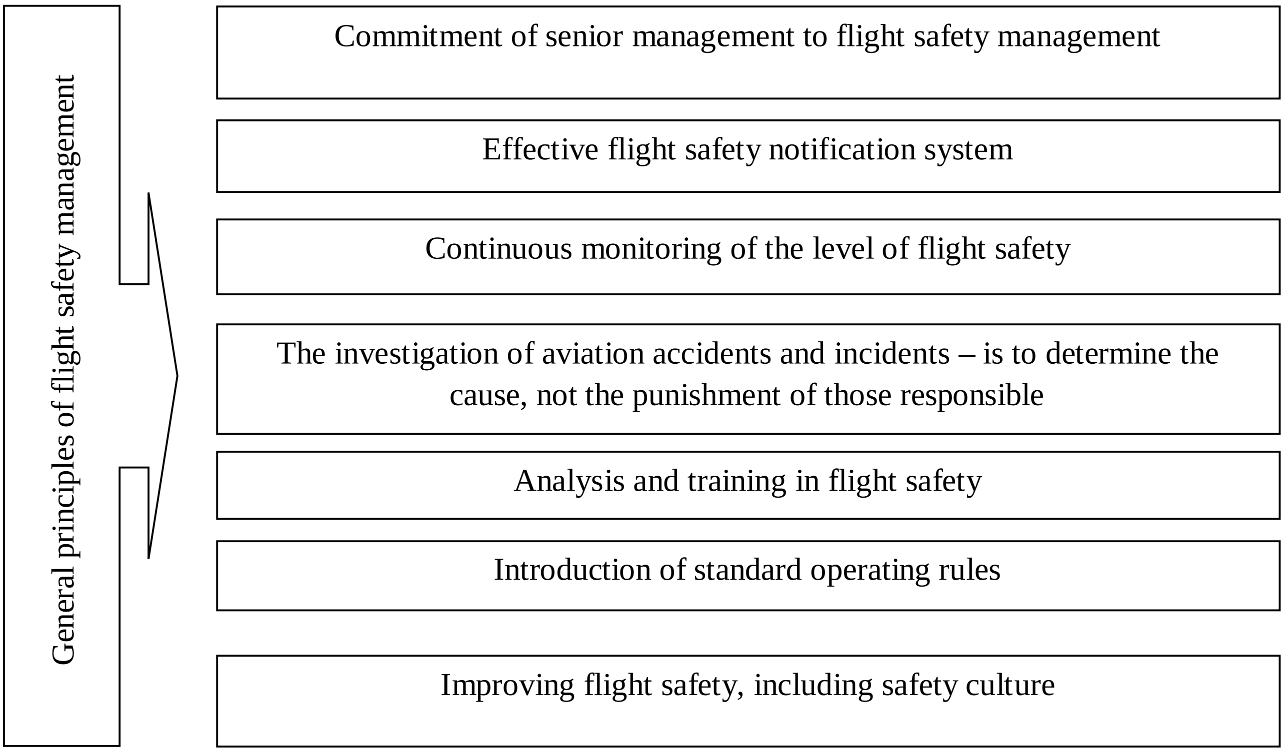


Figure. 1.1 – General principles of flight safety management

The concept of risk can be characterized only as a qualitative category that is not quantified by direct measurements. This means that the risk should be assessed by some qualitative signs of the state of the studied system, and in the presence of qualitative signs to find a quantitative equivalent that will help determine the level of risk. It is important to know this level in order to obtain methodologies for proper training of specialists in crisis situations in the process of management.

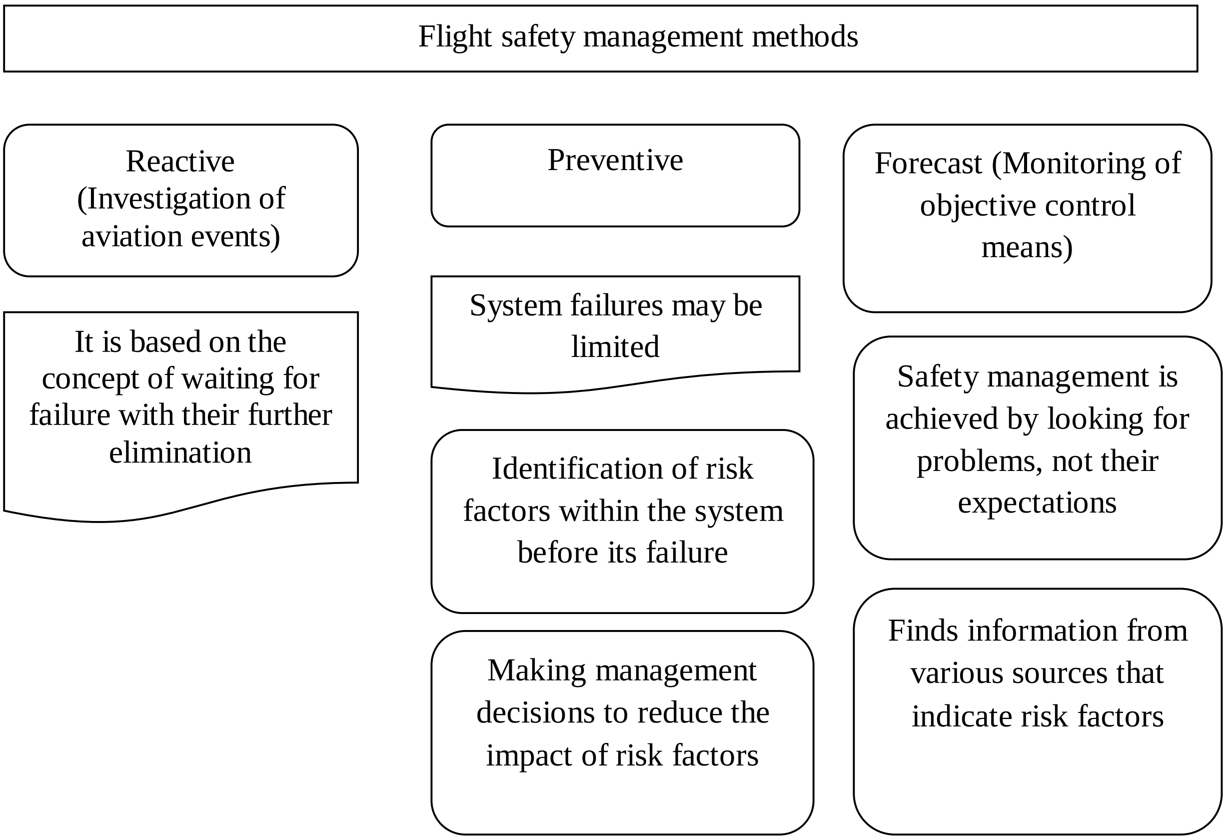


Figure. 1.2 – Principles of the area of responsibility in the process of flight safety management

Risk identification and assessment provides the information needed to make decisions about risk management methods. Thus, risk assessment is the basis for developing risk management measures.

The final phase of the risk assessment procedure is also the first part of the risk management procedure, ie the risk analysis reveals a picture of possible risk events, the probability of their occurrence and consequences. After comparing the obtained values of risks with the maximum allowable, a risk management strategy is developed, and on this basis - measures to prevent and reduce them [20-21]. On this basis, a methodology [3] is proposed, which is based on the generalization of the experience of the three main schools of operation:

- Soviet school of aircraft operation, which operates on the basis of national aviation rules (instructions for the production of flights, etc.);
- European School of Operation, governed by a system of European mandatory rules: JAR-OPS-1 (commercial aircraft); JAR-OPS-3 (commercial helicopters); PART-M, PART-145, regulating the preservation of the airworthiness of aircraft; JAR-OPS-2, JAR-FCL, etc.
- Schools based on compliance with standards and recommended practices, ICAO (SARPs), primarily Annexes 1, 6, 8 and 16, taking into account the best practices of the global aviation community.

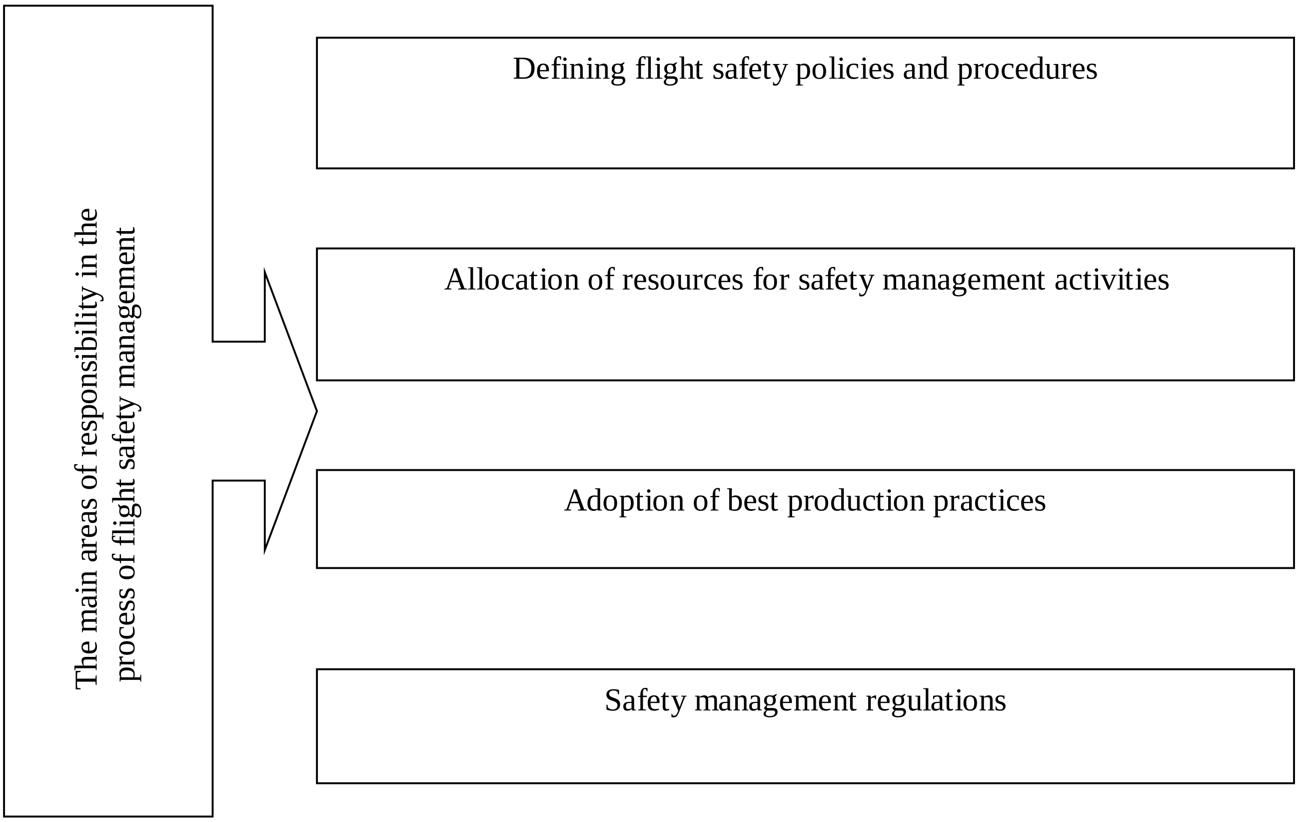


Figure 1.3– Flight safety management methods

Safety is a condition in which the risk of harm or damage does not exceed an acceptable level.

Risk is a combination of the probable frequency of the risk of harm and the severity of the consequences.

*Risk = probability of occurrence * Severity of consequences*

Risk is inevitable in any human activity.

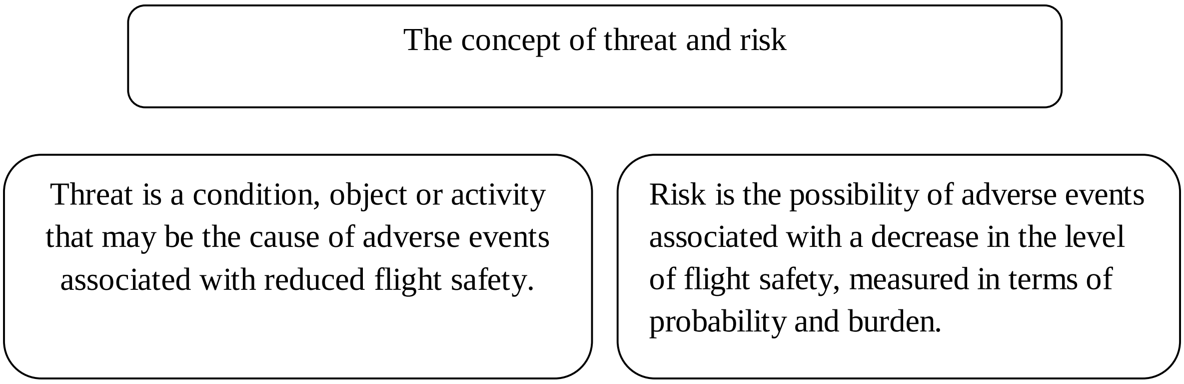
Learning to manage risk is the best solution in ensuring flight safety.

Figure 1.4 – The concept of safety and risk

The developed methodology takes into account the existence of three types of property - public, private, private-public, while reflecting the peculiarities of the operation of the three states of the fleet: the development of Soviet-Russian production; western production and mixed park (partly Soviet and partly western production).

National aviation rules can be represented as a three-level hierarchical system:

- Level I - Standard Air Code, the basic law governing the activities of civil aviation in all its areas, taking into account all international conventions ratified by the state.
- Level II - aviation rules, which include state requirements for all operators, aviation personnel and centers for maintenance and repair of aircraft (developed by the Aviation Administration).
- Level III - aviation rules are the development of level II rules in terms of a particular airline, airport, etc. (developed by airlines, airports, etc.).



The concept of threat and risk

Threat is a condition, object or activity that may be the cause of adverse events associated with reduced flight safety.

Risk is the possibility of adverse events associated with a decrease in the level of flight safety, measured in terms of probability and burden.

Figure. 1.5 – The concept of threat and risk

Currently, in accordance with the requirements of ICAO and the EU, a modern approach to flight safety management is being implemented as the most effective form of state regulation of civil aviation by conducting ongoing work to identify and eliminate risks to flight safety.

Improving the level of flight safety is expected to be achieved through the introduction of all subjects of aviation and the gradual modernization of the infrastructure of the air navigation system [3].

1.1.2 Methods for assessing the risks of emergencies during the flights of civil aviation which are based on risk models

Risk management in SMS is a strategy for the assistance to managers in decision making in conditions of uncertainty to ensure flight safety based on:

- Compliance with the principles and goals of the state in the field of aviation safety;
- State management of risks affecting flight operations;
- Safety support of aviation transportation system;
- Government promotion of flight safety;
- Enforcement of amendment 33 of ICAO.

That amendment defines the functions and objectives of the state, which must be reflected in the structure of SMS and include technical and legal norms on the acceptable level of flight safety established by the state.

1.2. Integrated Management System

The system in question is a combination of at least two subsystems in the general management system based on two or more standards for systems that function as a whole.

The difference between SMS and QM is described below.

Safety Management System (Doc. ICAO 9859) is based on the use of necessary organizational structures that focus on security. So, the purpose of SMS is to meet security requirements.

Quality Management System (QMS ISO 9000:2005) is a set of interrelated elements that are used to develop policies and goals in order to achieve these goals for guiding the organization in relation to quality. QMS focuses on the product, that is, “customer satisfaction”.

Management System of civil aviation may include:

- Safety Management System (SMS);
- Security Management System (SeMS);
- Quality Management System (QMS);
- Enterprise Risk Management (ERP);
- Supplier Management System (SUMS);
- Environmental Safety Management System (ESMS);
- Occupational Health and Safety Management System (OHSMS).

1.3. Problems of assessing safety levels in civil aviation based on the ICAO risk concept and categories of rare events

The methodology for calculating risks according to ICAO provides solutions only at the level of experimental methods, which also requires its additional justification.

The global statics of accident analysis over a long period of time confirms that undesirable events rarely occur but entail unjustified losses. Therefore, the issues of ensuring flight safety should be investigated quite deeply within the framework of the "rare events" problem.

The progress of changes in the global accident rate in the period from 1970 to 2020 is presented in the Figure.1.6 below. It can be seen from this graph that after 2006 there was some improvement flight safety.

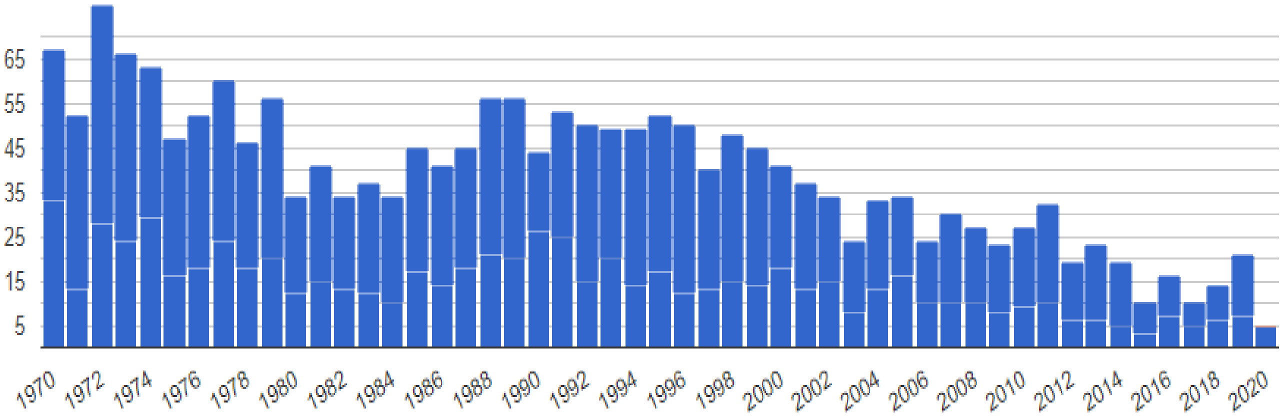


Figure.1.6 – Number of fatalities per year involving commercial (passenger or cargo) flights of aircraft certified for 14+ passengers.

1.4. Analysis of trends in the change of flight safety indicators depending on the types of risk factors

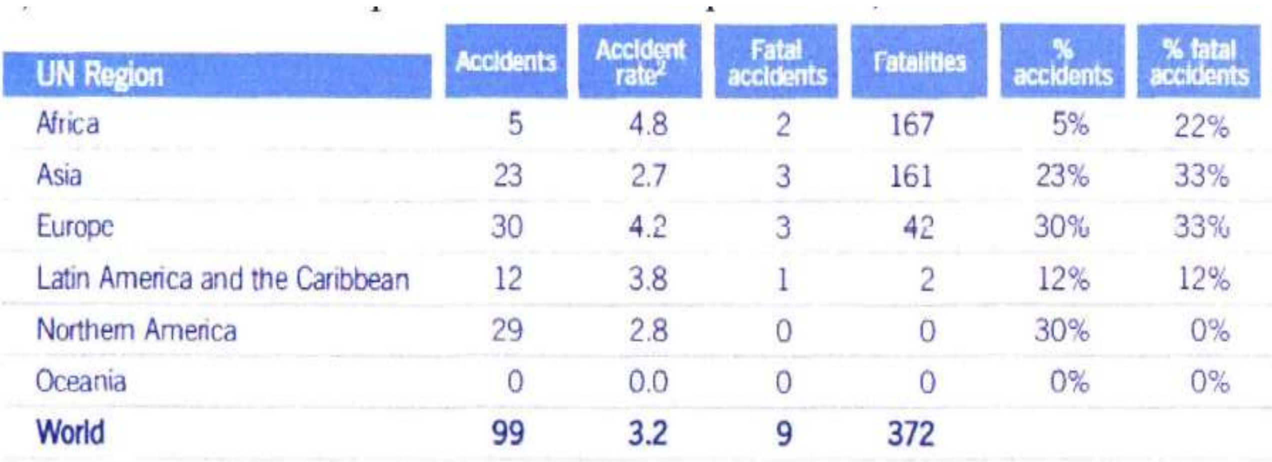
There is an analyzed change of some indicators of flight safety in civil aviation on a global scale below. This provides grounds for developing a scenario approach to determining the level of risks and the level of safety.

Repeated errors in piloting are not detected in a timely manner and are not properly analyzed, the processing of information of flight recorders of flight flights in airlines is carried out formally, without serious and responsible approach to it. Some airline flight specialists do not give a proper assessment of the quality of flight performance, which ultimately leads to massive violations of the requirements of the flight operations management. The figure 1.7 describes it.

A system, activity, action or procedure that is put in place to reduce the risks associated with a

- hazard. Mitigation may include:
- elimination of the hazard (preferred),

- reduction in the frequency of the hazard (barriers),
- reduction in the likelihood of the outcomes of the hazard,
- reduction of the severity of the outcomes of the hazard



UN Region	Accidents	Accident rate^2	Fatal accidents	Fatalities	% accidents	% fatal accidents
Africa	5	4.8	2	167	5%	22%
Asia	23	2.7	3	161	23%	33%
Europe	30	4.2	3	42	30%	33%
Latin America and the Caribbean	12	3.8	1	2	12%	12%
Northern America	29	2.8	0	0	30%	0%
Oceania	0	0.0	0	0	0%	0%
World	**99**	**3.2**	**9**	**372**		

Figure 1.7 – The statistic of accidents in 2012

On the figure 1.8 the risk distribution is presented by such categories:

- Runway safety related (RS)
- Loss of control if-flight (LOC-l)
- Controlled flight into terrain (CFIT)

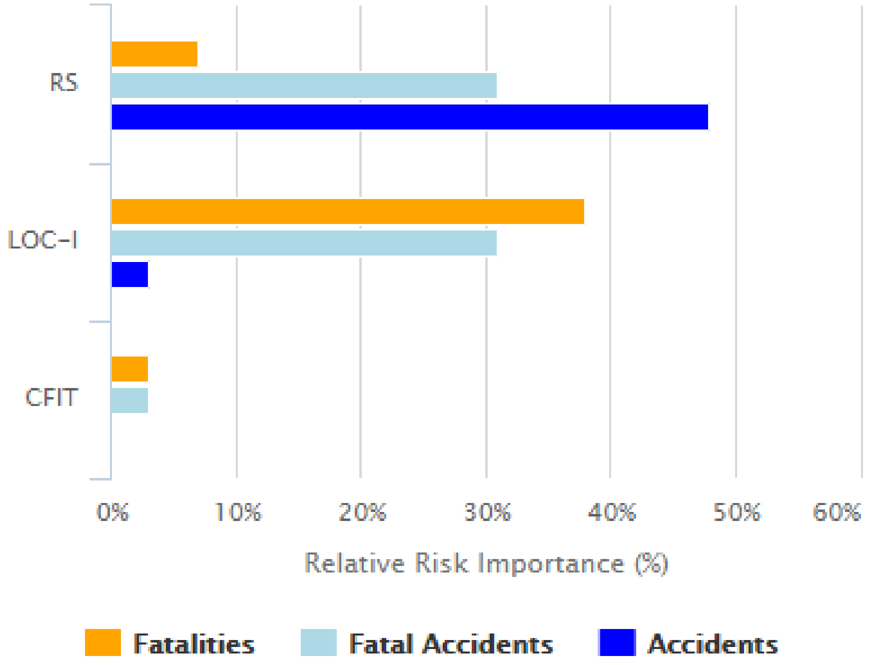


Figure 1.8 – The risk distribution 2010 – 2019

1.4.1. Indicators of flight safety

The main feature of the indicators of negative consequences that arise during flight operations is that all of them characterize rare but very significant damage to airlines. This determined the need to develop in ICAO the methodology for assessing risks in civil viation on a global scale.

According to the analysis of global aviation safety statistics concerning commercial aircraft with a maximum take-off weight of over 2250 kg., there were 135 accidents when performing regular flights in 2010. This is 19.4% more than in 2009 when there were 113 incidents. The number of deaths among passengers on scheduled flights worldwide increased to 767, which is 25.7% more than in 2009 (610 people).

Though the year 2010 was noted with the increasing number of accidents due to a common raise of flight operations worldwide, the global level of the accident rate remained unchanged and amounts to approximately 4 accidents per 1 million of regular flights.

Exactly in this period the intensive SMS implementation into the processes of activities of aviation service providers began. Annex-19 strengthened the position of ICAO in the development of risk theory and the creation of standard SMS. Details of the trend are given in the figure 1.9.

A new interpretation according to Annex-19 is used in this work - the concept of flight safety through "acceptable risk".

A description of the general picture for assessing the safety of flights in the global aviation is presented by Boeing below in the figure 1.9.

Safety risk assessment can be performed on steady-state operations to provide assurance that the risks associated with day-to-day operations remain tolerably safe. It can also be performed on proposed changes to a system or operation to ensure that the risks from any additional hazards or any impacts on existing hazards, introduced by the change remain acceptably safe.

The most significant causes of disasters that must be taken into account when creating databases in standard SMS modules is listed in table 1.1.

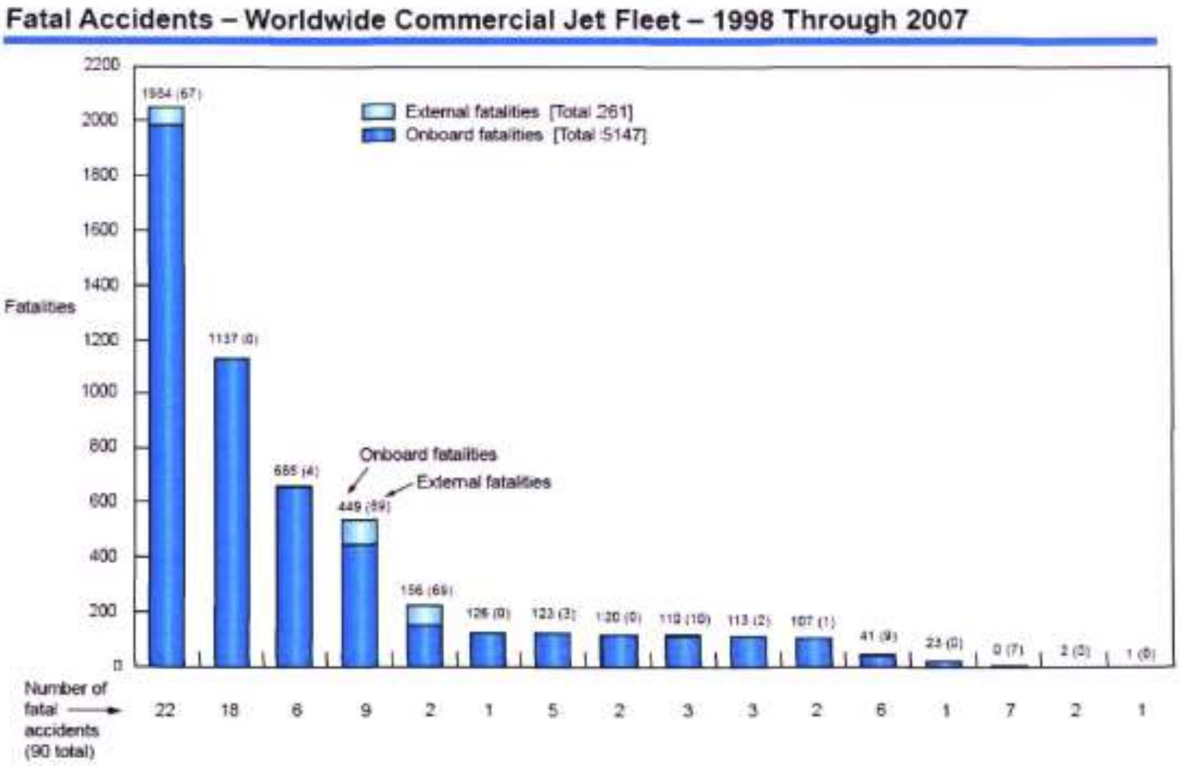


Figure 1.9 – Fatal accidents worldwide for commercial jet fleet during the period of 1998 – 2007

Table 1.1 – Causes of fatal disasters worldwide for commercial jet fleet

- Abnormal runway contact
- Controlled flight over some terrain
- Fire
- Smoke
- Fuel system
- Loss of control on the ground
- Loss of Control in Flight
- Aircraft collision
- Ground handling
- Runway overrun
- Uncontrolled movement on runway - "car, aircraft or people"

Table 1.1– Causes of fatal disasters worldwide for commercial jet fleet:

- System failure or unit malfunction
- Unknown or undefined failure
- Wind shear
- Tunderstorm
- Unpredictable maneuvers
- Aerodrome
- ATC / Communication, Navigation, Surveillance
- Safety relating events in the cabin
- Evacuation
- Ground collision
- Icing
- Operations at low altitudes
- Animals on runway
- Factors concerning aviation security
- Turbulence

There were 137 aviation accidents were noted (including 29 with deaths fatal outcome) within non-scheduled commercial passenger service sector in 2010 year, versus 145 incidents in 2009.

The number of casualties among passengers of non-scheduled flights fell from 200 in 2009 to 154 people in 2010.

It is not possible to estimate the accident rate for irregular air transportation due to the lack of a comprehensive statistics on this type of service.

Information about air accidents of types different shows that meteorological conditions and flight operation violations are dangerous factors that can turn into threats and cause an incident. Also, the statistics says the number of accidents at different stages of flight depends on different types of aircraft as in table 1.2.

Table 1.2 – Statistics of fatalities by aircraft type

Airbus A300	1436 Fatalities
Airbus A310	700 Fatalities
Airbus A320	1014 Fatalities
Airbus A321	377 Fatalities
Airbus A330	338 Fatalities
ATR 42/72	675 Fatalities
Boeing 737	4298 Fatalities
Boeing 737 NG / Max	937 Fatalities
Boeing 747	3713 Fatalities
Boeing 757	572 Fatalities
Boeing 767	854 Fatalities
Boeing 777	540 Fatalities
BAe 146 / Avro RJ	298 Fatalities
Canadair Regional Jet	164 Fatalities
DC-10	780 Fatalities
Dash 8	130 Fatalities
Embraer 120 Brasilia	55 Fatalities
Embraer 135/145	22 Fatalities
Embraer 190/195	75 Fatalities
Fokker 70/100	179 Fatalities
Fokker 50	7 Fatalities
Lockheed L-1011	233 Fatalities
MD-11	237 Fatalities
MD-80/90	1266 Fatalities
Sukhoi SuperJet 100	116 Fatalities

1.4.2. Safety performance monitoring

Aircraft accidents and incidents are classified as rare events in aviation, therefore the use of statistical indicators of rare events does not provide a reliable forecast of the level of safety in terms of reliability indicators. It is necessary to proceed with the calculation of a risk level during flight operations and ATM.

1.4.3. Analysis of RVSM concept impact on safety ensuring elements of ATM

The basis in solving the problem of introducing new CNS / ATM systems is to reach agreement in the development of standards for these new means and procedures for their use to ensure the required level of flight safety.

The second basis is the construction of the required infrastructure in accordance with Article 28 of the Chicago Convention. Each state is responsible for bringing its own funds and infrastructure services in full compliance with the ICAO. The third foundation is to ensure the provision of the new CNS/ATM systems which are developed and approved by ICAO standards and recommended practices (SARPS) for CNS/ATM system elements.

The problem of transition to a new system of air traffic service. Full integration of ground-based ATC systems and airborne facilities is the main technical challenge in the development of the ATM system, especially in connection with the need for optimal use "common human resources" and resources in the form of "skills of pilots and controllers" as professional operators.

Combining and harmonizing human skills and automated systems through effective human-machine interfaces is probably the most difficult technical challenge in the detailed design of future systems.

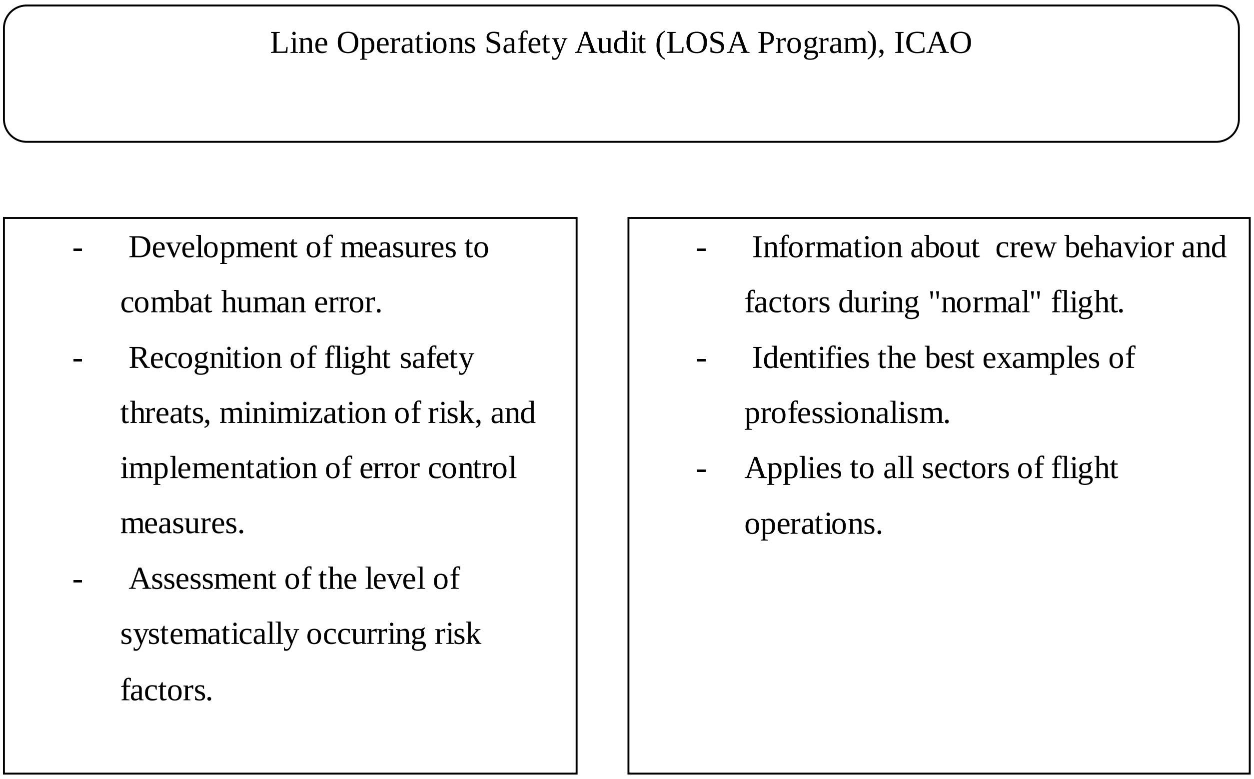
Airspace management is based on expected demands of air traffic. It is foreseen that with increasing complexity of system elements, more global analytic tool will be required. The approach is based on determination of collision risk (CRM). Then, CRM is to be compared to the risk level that is considered as acceptable and is called target level of safety (TLS).

As a result, it is determined what CNS/ATM facilities and the characteristics of the onboard equipment are required to achieve these operational goals.

1.4.4. Analysis of existing automated flight safety management systems

The appearance of new, highly efficient and at the same time increasingly complex aircraft on the air lines naturally causes an increase in the amount of information, the processing of which is necessary for a correct and timely assessment of the level of flight safety. Due to the significant amount of information needed to reliably assess trends in flight safety, even in one airline, not to mention the industry as a whole, the collection of this information, and in the future to make recommendations for management decisions, should be automated modern means of electronic computing [24, 25]. The basic principles of existing automated systems are shown in the Figure. 1.10 - 1.13.

Understanding the impact of the human factor on the temperament and failure of aviation can be better ensured by monitoring the actions of the crew in normal conditions than by investigating aviation events and incidents [26].



Line Operations Safety Audit (LOSA Program), ICAO

- Development of measures to combat human error.
- Recognition of flight safety threats, minimization of risk, and implementation of error control measures.
- Assessment of the level of systematically occurring risk factors.

- Information about crew behavior and factors during "normal" flight.
- Identifies the best examples of professionalism.
- Applies to all sectors of flight operations.

Figure 1.10 – Airline flight safety verification program

Line Operations Safety Audit is seen as an important way to help develop countermeasures to operational errors. It involves a structured programme of observation of front line activities built around the Threat and Error Management (TEM) concept. It aims to identify threats to operational safety, identify and minimise the risks which are the origin of such threats and implement measures to manage the human error aspects of the residual risk. LOSA provides a way to assess the level of organisational resilience to systemic threats in accordance with the principles of a data-driven approach.

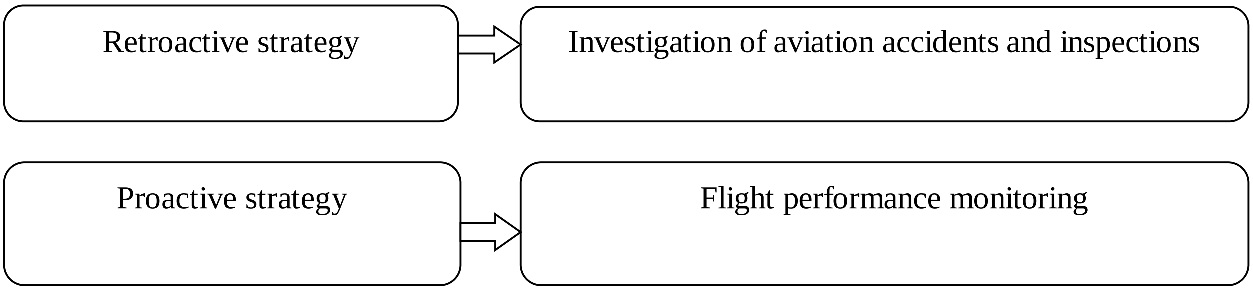


Figure 1.11 – Flight safety management strategies based on various sources of information

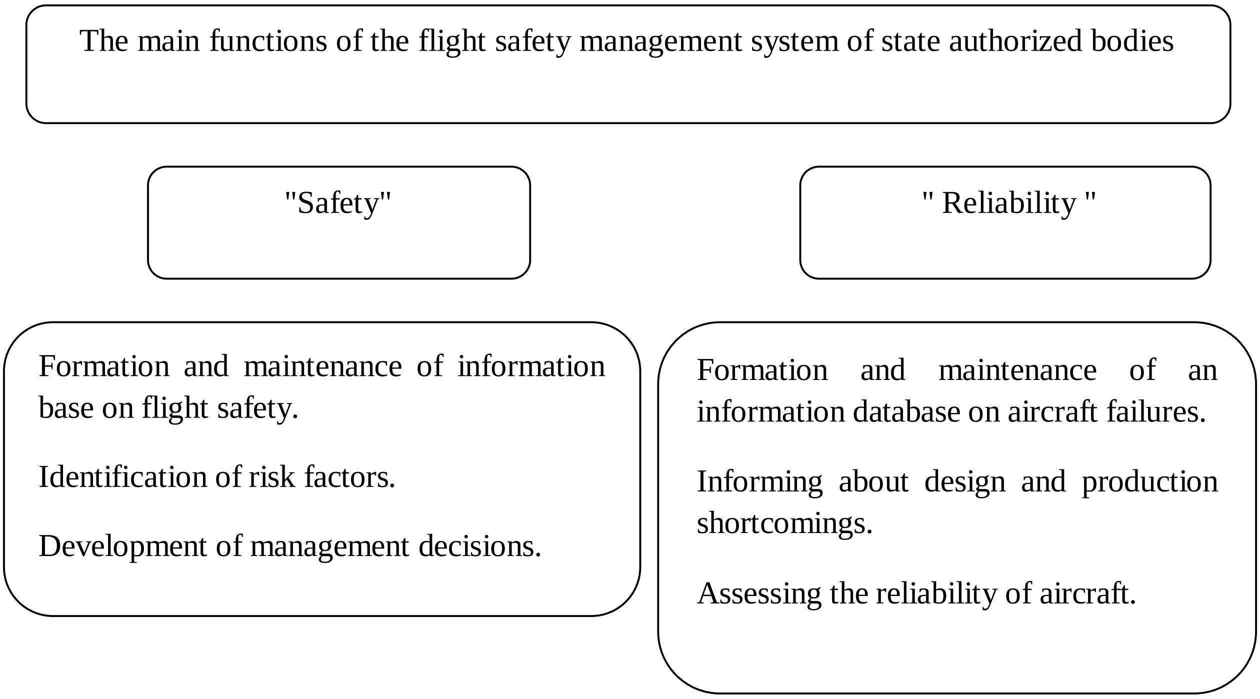


Figure 1.12 – The main functions of the flight safety management system of state authorized bodies

Taking into account the new conditions of aviation activity and considering the existing automated safety management systems, there arises the task of developing subsystems of sectoral and territorial levels that allow the accumulation of static information in the industry as a whole.

Operator-level subsystems will be designed for the purpose of sound solution of problems related to flight safety [27,28].

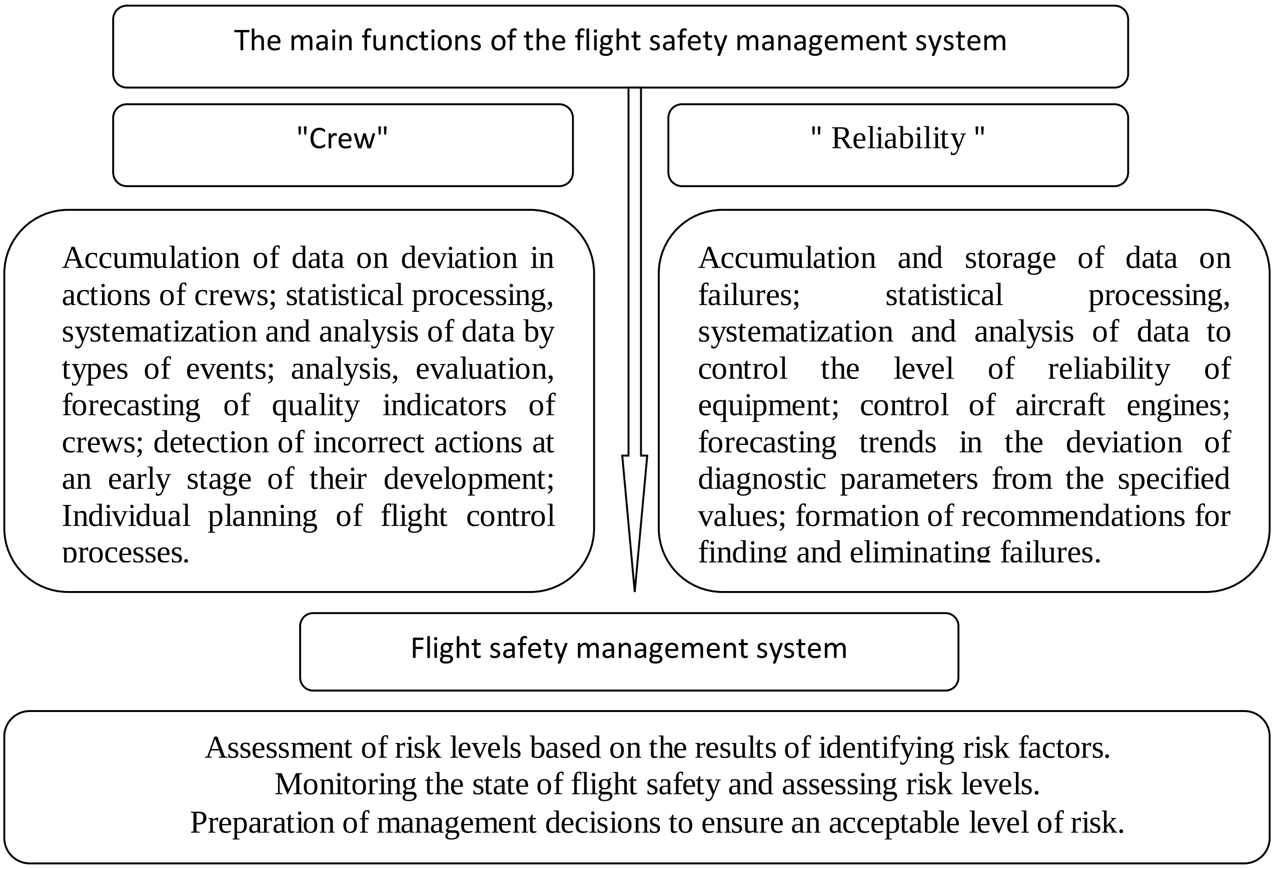
When building a safety management system based on the use of information and control systems, there is a problem of developing its optimal structure, and the criterion of optimality can be taken as an indicator such as the amount of information received.

This decomposition makes it possible to consistently develop and put into operation fragments of an automated flight safety management system that closes the control circuit and turns the entire system into a feedback control system [28,29,13]. Information support for the operation of the safety management system should include the creation of databases on aviation events, including the causes and risk factors identified by the investigation, the results of analysis of flight recorders and other flight information, mandatory and voluntary notifications of aviation personnel about aviation events, incidents and risks, remarks of the inspection staff of aviation authorities [13,31,32].

1.4.5. Formulation of the problem of assessing errors of objects tracking in the SNS / ATM system

The criteria of flight safety during RVSM implementation is TLS equal to such number of accidents as 2.5×10^{-9} per one flight hour.

Assessment of flight safety is impossible without statistics on rare events at ATM and if the possibility of risk occurrence in this system exists. Thus, it is necessary to improve flight safety support systems and move to new risk models at RVSM.



Accumulation of data on deviation in actions of crews; statistical processing, systematization and analysis of data by types of events; analysis, evaluation, forecasting of quality indicators of crews; detection of incorrect actions at an early stage of their development; Individual planning of flight control processes.

Accumulation and storage of data on failures; statistical processing, systematization and analysis of data to control the level of reliability of equipment; control of aircraft engines; forecasting trends in the deviation of diagnostic parameters from the specified values; formation of recommendations for finding and eliminating failures.

Assessment of risk levels based on the results of identifying risk factors.
Monitoring the state of flight safety and assessing risk levels.
Preparation of management decisions to ensure an acceptable level of risk.

Figure 1.13 –The main functions of the flight safety management system of state authorized bodies

CONCLUSION TO CHAPTER 1

The issues of determining the significance of the risk of occurrence of possible rare dangerous events according to Annex 19 in the analysis of general approaches to the construction of SMS have not been considered before.

Previous studies confirm the importance of theoretical developments to substantiate the objective reasons for the lack of statistical data on rare hazardous events in highly reliable aircraft systems.

The first chapter solves the problem of analysis, systematization and generalization of problems and methods of flight safety management in the aviation industry.

The results of the analysis of the causes of aviation events and incidents over the last ten years show that approximately 80% of such events occurred due to erroneous actions and violations of the rules of operation by human crews (human factor);

The classical methods of decision-making are considered and analyzed, which allow to make reasonable decisions in case of uncertainty of data and situations, lack of factual information and its perspective changes. However, developed ways to solve problems in conditions of risk and uncertainty are not limited to these methods. Depending on the specific circumstances, other methods can be used in the analysis process to help solve problems related to risk minimization. From the analysis of existing automated flight safety management systems, it can be noted that their main position is focused on the accumulation of statistical information, but there are no methods of analysis, forecasting and management decisions aimed at eliminating risk factors before an accident or incident.

CHAPTER 2

STUDY OF THE FUNCTIONAL RELIABILIY OF THE AVIATION EQUIPMENT SAFETY MANAGEENT SYSTEM USING THE RESULTS OF AIRCRAFT FLIGHT MONITIRING

2.1. Application of the scenario approach and new risks in the theory of flight safety in civil aviation

Methods for assessing the importance of risk management processes according to ICAO and Appeh-19 for ensuring the safety of flights are considered. One of challenges is to create a database structure and monitor hazardous events in civil aviation.

Four results will are presented in this chapter:

- General problem statement of the SMS creation;
- General scheme for solving the problem of establishing the SMS structure;
- Statement of the general principle of assessing the negative risks events in the SMS according to ICAO. This makes it possible to find the safety indicators of systems without probabilistic characteristics;
- Substantiation of an experimental method for testing the validity of the hypothesis about the possibility of interpreting real aviation systems as highly reliable, in which incidents arise with a probability close to zero.

2.1.1. General problem statement of the SMS creation

The task is to find a generalizing formula for determining a set of questions which will help to construct a typical flight safety control system in the form of SMS taking into account the SMS requirements of Annex 19.

2.1.2. General scheme for solving the problem of establishing the SMS structure

The general scheme defines the principles and provisions of the problem of a scenario approach implementation into the risk management and some options as hypothesis. The solution scheme is given in the figure 2.1 – 2.2.

SMS method: the risk control of possible accidents by factors.

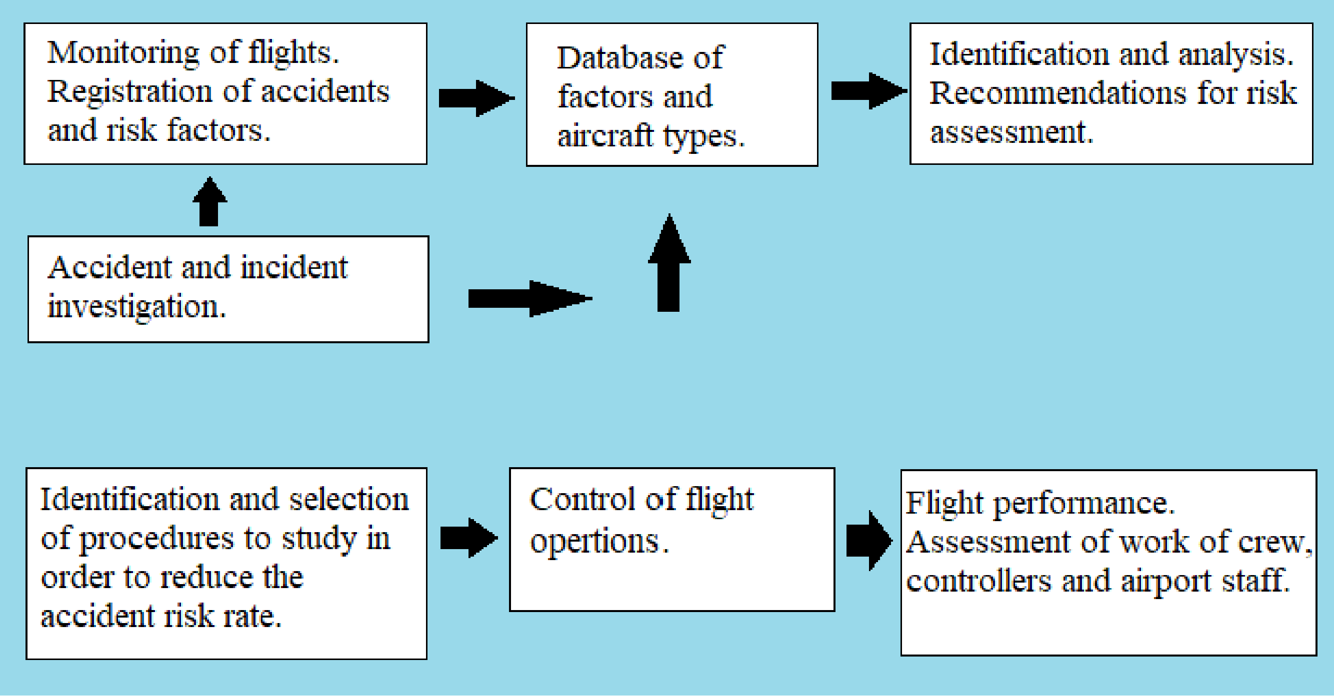


Figure 2.2. The solution scheme

It is known that the scenario of events and threats leads to the occurrence of a special condition. Analysis of the structure of scenarios for the hazard events development determines the path to disaster.

Figure 2.1 – Functional diagram of stages of goal achievement

Based on insufficient statistic data, hazard assessment is incorrect and should be done, for example, with the help of the fuzzy sets.

A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function which assigns to each object a grade of membership ranging between zero and one.

The accepted hypotheses are as follows:

- HYPOTHESIS 1 – high reliability of the system (checked by monitoring of flights).
- HYPOTHESIS 2 – usage of fuzzy sets.
- HYPOTHESIS 3 – risk management by factors according to ICAO (Annex-19).
- HYPOTHESIS 4 – usage of Failure Mode and Effects Analysis (FMEA).

These hypotheses must be checked before being accepted as a work instrument.

2.1.3. Conditions for rare events existence

Nowadays, only 2 types of disasters can be clearly observed in science and technology:

- Type 1 - " disasters in synergetic systems", manifested in the form of bifurcations of processes in homeostatic structures. This type is studied to be applied in respect of small systems.

- Type 2 - "disasters in technical systems", when its functional properties are lost as a result of failures due to outer factors. This type is studied to be applied in respect of multidimensional systems.

The fundamental difference between mathematical objects in safety support systems is that rare events of $\tilde{A}$ type are inverse events to A instead of events A which are considered in the theory of reliability. This means that we are studying events additional to A with a binary of outcome:

$$\tilde{A} = 1 - A$$

It can be assumed that in a technical system with normal quality indicators, which are guaranteed using the methods of the theory of reliability, there are studied random events of the "non-failure type" ~ A.

The quality of such systems is defined by the initial A event with properties which are indicated as P_A. For example, the "probability" of an event:

$$P_A = P\{A \mid \Sigma_0\},$$

P_A – nonrandom measure of such event.

P_A indicates a property of the object within some multiplicity $\{A \mid \Sigma_0\}$ if Σ_0.

The P_A indicator determines the measurability of a random event and is a non-random measure of the "amount of randomness" in the specified set. In highly reliable systems, these indicators are large in value and close to one:

$$P_A \sim 1.$$

It should always be kept in mind that P_A is a real nonrandom clear number that can be found analytically (in ideal or approximately ideal conditions) or even based on some reliable statistics from experiments.

"Safety" is assessed in the corresponding "state" by the "level" of the severity of the consequences but always only on the opposite, additional to A, events Ã - of the "failure" type.

These events are inconsistent and form a general population like binary space of outcomes Ω for a binary partition:

$$\Omega = A \cup \bar{A} \cup \varnothing \text{(inconsistent A and Ã).}$$

Ø is an “emptiness” element.

Thus, the objects that are used to evaluate some properties are different and opposite, always inconsistent and setting different mismatched properties.

It is possible to admit that "safety" is assessed through "danger". For these, additional characteristics such as "consequences of some failures" are used in the form of "criticality" of failures. Therefore it is necessary to introduce the concept of "dangerous" $A_* \equiv \tilde{A}_*$ or "risk event" - R which makes this event A_* entail negative consequences. Thus, A_* is not always a trivial refusal of Ã with not serious consequences but critical with a sign ($_*$):

$$R \equiv \bar{A}_* = \bar{A}_*(\omega_{\xi*} \,|\, H_R),$$

where:

- H_R is indication of negative result as a some damage,
- $\omega_{\xi*}$ is a primary occasional event,
- Ã is a class of the event.

2.1.4. Functional reliability assessment scheme

The indicator of the functional reliability of the ATC can be assessed by the flight regularity index and its variations due to flight delays because of system element failures and other certain violations. In addition, it is necessary to take into account the delays of flights by Minimal Equipment List program (MEL). There are rules for replacing failed elements based on the criterion of "minimal risk" according to MEL.

Thus, if there is standard base B_F of failures (F) as risk factors for aircraft, it is possible to define the indicator of functional reliability K_R (R – reliability) for the aircraft which is a subsystem of ATC and may be seen as:

$$B_F \Rightarrow K_R \cong \frac{m_F(t)}{N_R} \Leftrightarrow \frac{\Sigma \Delta t_i}{\Sigma T_j} \qquad (2.1)$$

Where $m_F(t)$, N_R, Δt_i, T_j are multiplicity of failures and durations Δt_i of flight delays in relation to flight hours T_j after operating cycles i, j. Indication (2.1) may assessed with examples of aircraft operation in air transportation system.

2.2. Scheme for solving the problem of assessing the aviation safety systems based on the theory of system safety

2.2.1. Theoretical and methodological foundations of system safety

The provisions of the theory of system security are as follows:

- Disasters (and serious accidents) in highly reliable systems are considered as rare events with a near-zero probability of occurrence.
- The main safety characteristics must be consistent with ISO with the basic provisions of the theory of reliability.

2.2.2. Risk definitions and a systematic approach to risk assessment according to ICAO

There are two definitions as below:

- Risk is the expected possible danger in the system from the moment a certain threat (source of danger) appears with certain negative factors. This definition reflects in practice "common sense" which makes to assume the occurrence of a dangerous event, which can be harmful. From this point of view, all assumptions are fuzzy. This requires to perform fuzzy calculations.
- Dangerous or risky situations are the state of the system in which a risk event R is possible.

Since the level of security is determined through the level of harm when the properties of system functionality are violated, this leads to difficult solutions in the problem of rare events.

Thus, it is necessary to use approaches based on Fuzzy Sets with fuzzy indicators of randomness and uncertainty of consequences from rare events.

So, as some conclusion, it is possible to say that there is no concept of “randomness” of rare event in high reliability systems. There are “uncertainty” and “fuzziness” only.

2.3. Formulas for assessing the integral significance of risks

2.3.1. Risk Significance Criteria

With known probabilities of hazardous events, the criterion is the value of the average risk $\underset{\cdot}{\bar{R}}\ (\tilde{A}_*)$ on the set of hazardous events as below:

$$\bar{A}_* = \left\{ \bar{A}_{i*} \middle| H_{i*}, i = 1, 2, \dots m_* \right\}$$

This value is defined as:

$$\bar{R} \equiv \bar{R}_{\bar{A}*} = H_* \cdot P_{\bar{A}*} \approx \sum H_{i*} \cdot P_{A*i}$$

Where $\tilde{A}_*$ is some class of $\tilde{A}_{i*}$ events, (*) is a criticality sign of damage value, H_* is a total damage, $P_{\tilde{A}*}$ is a probability of events $\tilde{A}_*$ of some class if all events of this class are incompatible.

Obviously, it is necessary to solve the problem of rare events on the basis of different approaches and a different concept of risk. In this case, it is necessary to introduce a different, more general, definition and formula for assessing risk, which is also suitable for "stable statistics".

2.3.2. Methodical approaches to risk control

The high reliability of technical systems, in terms of probability, does not mean the safety of the system, since in any highly reliable system a "residual risk" is embedded in a latent form. This means that there is a possibility of a very rare event with very large damage if measures have not been taken to manage the state of this system.

"Residual non-zero risk" exists due to features of design and technology. It is a sign that a incident may occur (an event from the class of rare) which can be easily analyzed basing on a scenario approach and dynamic modeling.

When solving problems of assessing the safety of technical systems with complex structural schemes for elements of reliability connection (elements providing functional properties), it is necessary to apply alternative methods of calculating risks and to abandon the use of probabilistic indicators of the properties of "rare events".

Initially, fuzzy sets of undesirable events are studied, which entail negative consequences of certain damages in highly reliable systems. Further, the methodology of safety analysis is refined with the transition to the assessment of indicator risks (according to ICAO).

The main task arising from the presented scheme is included in the confirmation of principles for identifying the essence and significance of the "residual risk", which characterizes the possibility of a hazard in systems during their operation.

2.3.3. Risk assessment according to ICAO concept

The ratios for assessing the level of safety are established by comparing the potential risk $\tilde{R}$, $\hat{\tilde{R}}$ with the level of acceptable risk $\tilde{R}_*$, $\hat{\tilde{R}}_*$ through the predicted consequences $\tilde{H}_R$:

$$\tilde{R} = \left(\mu_1, \tilde{H}_R \middle| \Sigma_0\right), \quad \hat{\tilde{R}} = \hat{f}\left(\tilde{R} \middle| \Sigma_0\right),$$

Where μ_1 is measure of risk denoting uncertainty or occurrence of a risk event R with negative result $\tilde{H}_R$. Thus, $\tilde{H}_R$ is measure of consequences. $\sum_0$ is a conditions of the experiment. $\bar{R}$ is a risk at fuzzy assessment (quantity of danger).

The scientific problem is a synthesis of functions for current quality assessments from a set of elements in the formula above for given systems at proactive threats.

The average risk $\bar{R}$ is a scalar, but with $\bar{R} \to \hat{\bar{R}} \equiv \bar{\bar{R}}$ it is impossible to determine in problems with an assessment of the probability of a risk event "almost zero”.

In the same way, the risk assessment $\bar{R}$ is a set of two fuzzy elements $\left(\mu_1, H_R\right)$, which set the predicted "amount of danger".

The new result of this work is that discrete states are definite attributes from the set, but any estimates of risks are not definite.

The final result of this topic is a recommendation on the need to develop schemes for constructing hazard models according to ICAO in situations arising from changes in discrete states of the system.

2.4. Principles of factorial risk management according to ICAO

ICAO principles highlight the stages and methods of influencing on the state of systems:

- Proactive (and predictive) management with a forecast of consequences from the manifestation of assumed external and internal influences.
- Active or a posteriori assessment of possible harmful consequences when searching for sources of danger (threats).

2.4.1. Maintaining and ensuring flight safety through factorial management of the state of the system by risk indicators

Assessment of the significance of risk in a predicted hazardous event with a fuzzy set of factors can be carried out using the Fuzzy Sets methods.

This is proved by the fact that with practically zero probability it is impossible to calculate the average risk.

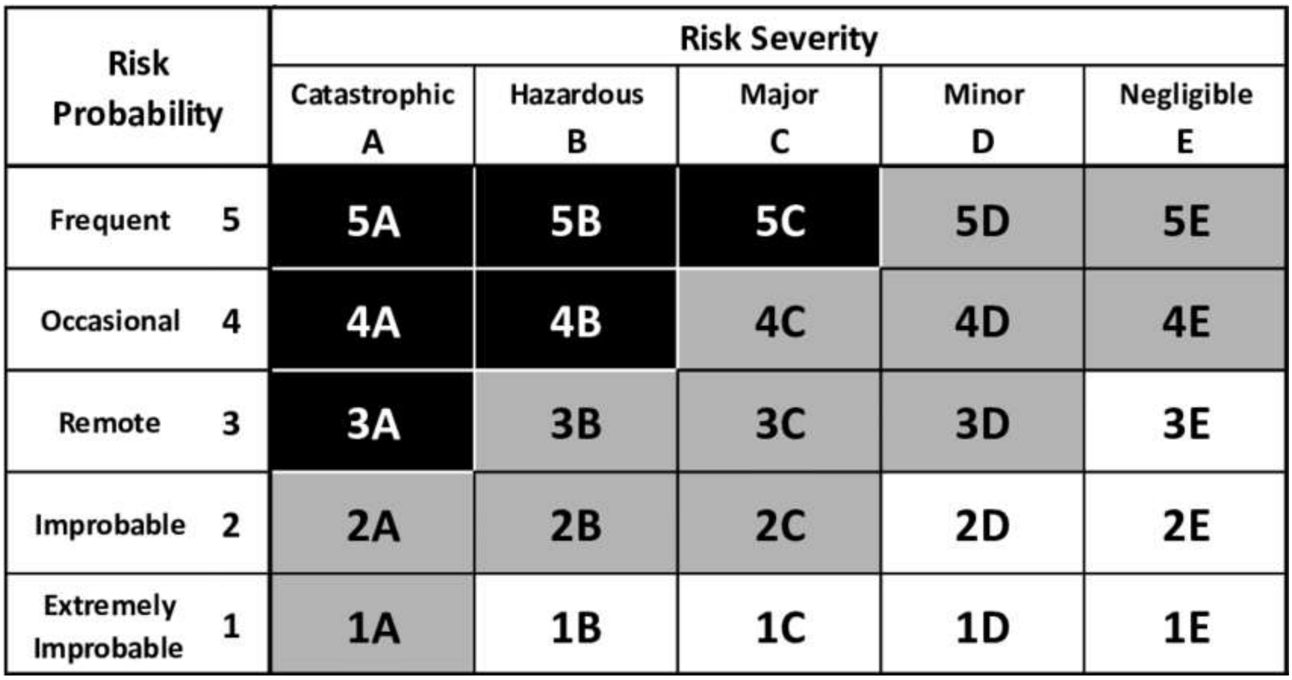
2.5. Determination of fuzzy sets uncertainty degree of risk actors, which are analyzed by using risk matrices according to ICAO

ICAO provides us with the table of the significance of risk factors for many elements as on Figure 2.3 and table 2.1.

This is confirmed on the basis of Fuzzy Sets procedures using fuzzy implication operations. But in this matrix, the designation in the risk probability has been introduced alternatively, but incorrectly, in addition to the fuzzy index in ICAO.

The ICAO materials offer free interpretations of the process assessing the possibility of occurrence or manifestation of risk factors for flight safety and the degree of their severity. These estimates are used in calculating the safety risk alternatively through the concept of probability in the ICAO matrix (in Fig. 2.3) and the "capability" from Table 2.2. However, it is calculated basing on the methodology described above and is a combination of alphanumeric symbols that show the cumulative results of the possibility and the severity of the factors. Various combinations of pairs of severity elements and possibilities presented in each cell of the matrix.

The new result in this work is an improvement in the application of the matrix.



Risk Probability		Risk Severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely Improbable	1	1A	1B	1C	1D	1E

Figure 2.3 - Safety risk assessment matrix

In the problem under consideration, the main stage of the process is to determine the acceptability of risk factors for flight safety through indices. For example, the probability of a safety risk is given through the possibility of "sometimes" occurring. But in fact, the two-dimensional risk severity index will be assessed as dangerous (4B).

The index obtained in this way from the risk assessment matrix is now need to be transferred to the safety risk acceptability matrix using the "acceptability" criterion for a particular organizations. A safety risk criterion rated 4B is not acceptable under the circumstances. In this case, the index of the consequences of factors safety risk is unacceptable and therefore the organization must develop controls for its operations:

a) take measures to reduce the organization's exposure certain risk, i.e. reduce the fuzzy component of the risk index;
b) take measures to reduce the severity of the consequences dangerous factors, i.e. reduce the severity of damage from the risk index;
c) stop the activity if the risk reduction impossible.

Table 2.1 - Severity of risk factors

Severity of event	Meaning	Degree
Significant	• A significant decrease in the acceptable level of safety. Operators are unable to cope with adverse conditions due to high load. • Serious incident. • Human injuries. • Emergence situation rules should be applied. • Significant damage.	C
Small	• Inconvenience. • Operational limitations. • Not serious incident. • No significant damage.	D
Tiny	• Minor consequences. • No injuries. • No serious damage.	E

The remark following from the performed analysis boils down to the fact that it is incorrect to interpret the measure of the factor's possibility in the form of “probability” as in figure 2.2.

Table 2.2 - Probability of factors of risk to happen

Probability of occurrence	Description	Significance
Often	It happens often	5
Sometimes	It may happen from time to time	4
Rarely	Unlikely but may happen	3
Almost impossible	No evidence that it has happened ever	2
Close-to-zero probability	Practically unreal event	1

The index obtained in this way from the risk assessment matrix is now need to be transferred to the safety risk acceptability matrix using the "acceptability" criterion for a particular organizations. A safety risk criterion rated 4B is not acceptable under the circumstances. In this case, the index of the consequences of factors safety risk is unacceptable and therefore the organization must develop controls for its operations:

d) take measures to reduce the organization's exposure certain risk, i.e. reduce the fuzzy component of the risk index;
e) take measures to reduce the severity of the consequences dangerous factors, i.e. reduce the severity of damage from the risk index;
f) stop the activity if the risk reduction impossible.

The remark following from the performed analysis boils down to the fact that it is incorrect to interpret the measure of the factor's possibility in the form of “probability”.

2.6. Types of uncertainty in safety theory

Uncertainty is the absence or incomplete information about events and processes.

Uncertainty is measured through various species indicators of the following form:

a) Randomness, when probabilities and probability distribution functions are known;
b) "Minimax" uncertainty (a decision rule used in artificial intelligence, decision theory, game theory, statistics, and philosophy for minimizing the possible loss);
c) fuzziness - all calculations are done through membership functions.

The word "possibility" cannot be replaced by the word "probability", since “opportunity” is a vague concept, and “probability” is a clear one, i.e. a calculated value that characterizes the "amount of randomness".

The fuzzy characteristics are as follows:

a) The essence of the concept of fuzziness of elements of technical systems means fuzziness of properties (physical or mathematical) for selected elements from sets.
b) Fuzziness is expressed in two ways:
    - through membership functions;
    - through colloquial words such as: “more”, “less”, “rare”, “frequently”, “very rarely”, “not dangerous”, “insecure”, “probable”, “possible”, “impossible” and so on.

c) Currently, all theories of safety in civil aviation are based on the concept of "randomness" and indicators of "probability".

However, all elements of the system of rare events such as "events", "factors", "parameters" are undefined or fuzzy since the probability of these events are very small and it is difficult to find this probability when any statistics are absent.

Small probabilities objectively appear because many technical systems are highly reliable and the probability of failure is not significant .

However, according to ICAO and Annex-19, the safety assessment is based on such failures.

This gives the problem of "rare events", which obviously needs to be solved taking into account the objective properties of such events.

So, a solution can be found with the help of Fuzzy Sets because the probability of such events is small due to the absence of statistics.

CONCLUSION TO CHAPTER 2

It is necessary to initially investigate using the methods of clear logic, scenarios for the development of events in the aviation system in the form of accidents, incidents and air crashes, but not to take into account the measure of the possibility of these events, the probability of which is close to zero.

In this section, the modeling of the occurrence of special situations in flight was modernized, which leads to the refinement of the simulation results of the probability of such a situation. It is used to solve problems of analysis and synthesis of systems to ensure the appropriate level of safety of rafts and allows to take into account all essential for solving problems of connections, analysis of complex processes in parts, its synthesis and development of models without additional experiments.

1.2. The developed multifactor model of risk of occurrence of aviation events allows to execute:

- risk monitoring for each type of aircraft, taking into account the number of flights performed during the estimated period;

- based on the results of flight work, or after each investigation of an aviation accident, assesing the degree of change in the risk of an aviation accident;
- forecasting the risk of an aviation accident;
- time to time updating of the results of forecasting the risk of an aviation event during operation as new statistics accumulate or after each aviation event.

CHAPTER 3

AUTOMATED SMS MODELS FOR EXPERT RISK PREDICTION BASED ON CHAINS OF RANDOM EVENTS AND DYNAMIC MODELING METHOD

3.1. The principle of finding the shortest path to disaster when assessing the criticality of event scenarios through the risks of damage

The concept of "Dynamic Method" of modeling was introduced by the European Association ECAST (Component of European Strategic Safety Initiative: Guidelines for hazard identification), but only in the form of an "idea" to solve complex problems of risk identification.

In this work, this idea has received a new development as a tool for finding conditions for the occurrence of functional failures in systems.

It is proposed to study the aviation system using scenarios of communication of elementary events without using the values of probabilities when assessing criticality of scenarios. The shortest paths to a disaster have been identified as clear attributes - chains in the space of discrete states of the system. These chains are proactively assigned with fuzzy assessments of significance and criticality.

3.1.1. Method of dynamic modeling of processes with rare events

A method and an algorithm for digital modeling of processes of changing discrete states of the system are being developed.

Scenarios are created automatically by the method of enumerating combinations of system elements in accordance with the numbers of the listed properties and qualities of system elements.

This method is physically equivalent to the Failure Modes and Effects Analysis (FMEA) method known in reliability theory. This allows the study of risk management processes in systems with specified functional properties.

Failure Mode and Effects Analysis (FMEA) is a structured approach to discovering potential failures that may exist within the design of a product or process.

Failure modes are the ways in which a process can fail. Effects are the ways that these failures can lead to waste, defects or harmful outcomes for the customer. Failure Mode and Effects Analysis is designed to identify, prioritize and limit these failure modes.

At the same time, to assess the criticality at the point of the final (emergency) state, it is enough to assess the consequences or damage in each such simulated scenario. This method and the corresponding algorithm make it possible to solve the main problem of the theory of risks with their new definition and concept: to find a way and discover the conditions and the possibility of the existence paths and events mud "catastrophe". Obviously, if the measure of opportunity is insignificant, i.e. the probability of an event is "almost zero", then it is possible only with this approach to study processes with rare events.

The aviation system S with discrete states $q_i \in Q$ is studied.

It is proved that such a system can be investigated using a scenario of events without the use of probabilistic indicators and without the Monte Carlo method, when analyzing chains of events using a tool in the form of a dynamic modeling method of European Commercial Aviation Safety Team (ECAST) in the form of automata models.

Monte Carlo methods, or Monte Carlo experiments, are a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. The underlying concept is to use randomness to solve problems that might be deterministic in principle. They are often used in physical and mathematical problems and are most useful when it is difficult or impossible to use other approaches.

Launched in October 2006, ECAST was the European equivalent of Commercial Aviation Safety Team (CAST) in the US. In March 2016, the initiative was discontinued and ECAST functions and resources were transferred to the other teams involved in the European Safety Risk Management (SRM) system.

When assessing the level of predicted hazard in the system, with an uncertainty in the value of the risk measure, it is only necessary to find the quality functions of the system on the set of elements of the system with a given structure that determines the deterministic discrete automaton.

3.1.2. The basic principle of constructing event scenarios

Scenarios in the form of J. Reason's chains (The Swiss cheese model) are considered. It was found that: "The catastrophe is inherent in the system and is just waiting for its manifestation." This is also announced in the ICAO documents.

The Swiss cheese model of accident causation is a model used in risk analysis and risk management, including aviation safety, engineering, healthcare, emergency service organizations, and as the principle behind layered security, as used in computer security and defense in depth. It likens human systems to multiple slices of swiss cheese, stacked side by side, in which the risk of a threat becoming a reality is mitigated by the differing layers and types of defenses which are "layered" behind each othe as in figure 3.1. Therefore, in theory, lapses and weaknesses in one defense do not allow a risk to materialize, since other defenses also exist, to prevent a single point of failure. The model was originally formally propounded by Dante Orlandella and James T. Reason of the University of Manchester and has since gained widespread acceptance. It is sometimes called the "cumulative act effect".

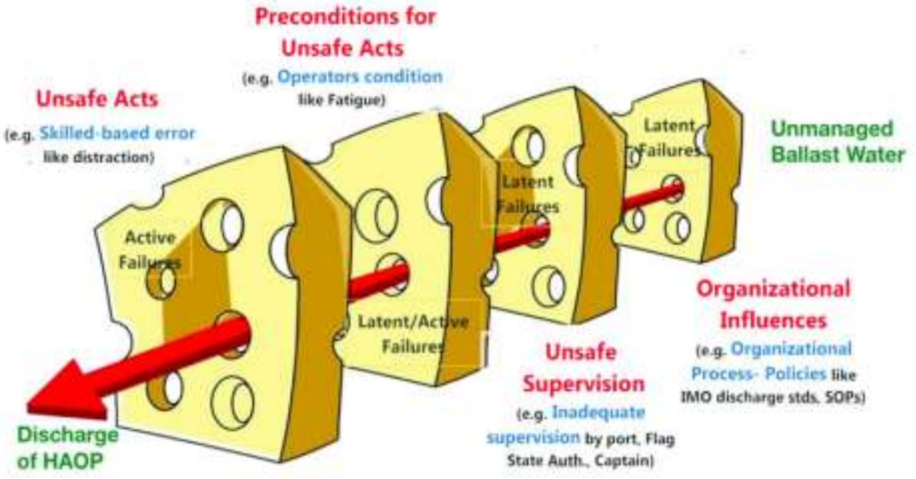


Figure 3.1 - The Swiss cheese model of accident causation

According to the Safe Management Manual (SMM) guidelines, it is necessary to identify threats and formulate corrective controls in advance to prevent disasters.

ICAO proposes to assess the significance of risk in detectable scenarios using risk analysis tables.

According to the SMM manual, it is necessary to identify threats and formulate pre-correcting controls to prevent disasters in the system. ICAO has proposed to evaluate the significance of risk in detectable scenarios using ICAO risk analysis tables.

The solution of these issues is possible on the basis of Fuzzy Sets.

State sequences in dynamic modeling are:

$$(q_0 \in \{Q) \rightarrow \Gamma Q\} \Rightarrow (q_0 \rightarrow \{q_{0i}\} \ldots \rightarrow \{q_{ij}\}),$$

where sequences of indices are given as: $i = 1, 2, \ldots, m_i$; $j = 1, 2, \ldots, m_j$; ΓQ is a representation of $Q \rightarrow Q$; Q is some space of discrete states; q_0 is an initial state.

On this topic, the following issues of this study were considered in the section "Scenario approach" and "Dynamic modeling":

- Principles of building hazard models according to ICAO, characterizing the processes of changing discrete states on the basis of the scenario approach.
- Correction of the risk analysis matrices taking into account the ICAO algorithm to predict possible hazards in the system.
- A method of dynamically modeling hazard scenarios in systems and assessing the risks of "harm to the system" without probabilistic indicators, but only on fuzzy subsets of risk factors included in a clear universal set of system and environmental parameters.
- An automaton model of SMS as a deterministic tool for processing data on the state of systems and implementing a method of dynamic modeling according to the ACARS principle.

ACARS is a digital data link system for the transmission of messages between aircraft and ground stations. Modern ACARS equipment now includes the facility for automatic as well as manual initiation of messaging.

3.2. Solving the problem of rare events based on the Fuzzy Sets method

3.2.1. Fuzzy Sets transition scheme

The purpose of this chapter is to create a universal common approach to assessing the safety of complex systems through the concept of risk according to ICAO, but using a new interpretation of risk (”not in terms of probability”) and Fuzzy Sets tools.

The problem is that the concept of "risk", as it is shown in Chapter 2, determines the integral indicator in the form "quantity" of danger. The basis for this amount of risk is characteristic of safety or danger in the system "through the level of possible harm". Therefore, it is necessary to find ways to measure risk (as predictable measure of hazard) without probabilistic indicators.

This is the essence of one of the new results of this work.

The task as a whole was solved earlier by NASA. The method is based on methods and algorithms for proactive risk management (and the state of systems), taking into account the set of risk factors and risk assessment matrices. The theoretical basis of this NASA method is defined, by default, in Fuzzy Sets. But this was not formulated at NASA.

3.2.2. The principle of fuzzy implication in the analysis of fuzzy statements

Fuzzy statements are explained by the uncertainty of the descriptions of objects for various reasons, for example, due to the lack of information about an object or phenomenon.

So, in the method of confidence intervals, it is not possible to predict specific values measured values. There is a duality in the designation of the boundaries of the intervals. The question is to check the degree of the truth of unclear conclusions, for example, the significance of the integral risk level in fuzzy terms: "more", "less", etc., although these fuzzy levels are indicated in the ICAO matrices.

The solution of such problems is presented in the class of fuzzy implications of the set of fuzzy statements in an arbitrary set *V*. In this case, V is represented in the form of 2 subsets: P - conditions and Q - results, in the sense of selected $Q < V$ statements, the truth of which is established with a certain measure μ but in relation to P. In fuzzy logic (with fuzzy implications), the set P is not a cause, but Q is a consequence, in contrast to implications in a clear logic. With fuzzy implications $(P\supset Q)$, the elements P and Q are chosen completely arbitrarily and the truth of the compositions of statements in the set V is checked as below:

$$V=\{P,Q\,|\,P\supset Q\}.$$

This set is mapped using the operator T into the segment [0, 1). The result of the check is given by the formula for the selected criteria:

$$T:V\rightarrow[0,1]\Rightarrow T(P\supset Q)\rightarrow[0,1)\ .$$

The simplest fuzzy implication $(P\supset Q)$ from V will find a solution:

$$T(P\supset Q)=max\{min\{T(P),T(Q)\},1-T(P)\}\ .$$

The classical fuzzy implication, in contrast to clear logic, denotes the result of a binary logical operation in the form of a fuzzy statement with some measure of truth $(P\supset Q)$.

Thus, in the NASA matrices, the measurable clear values of the probabilities P were first replaced by fuzzy linguistic variables. The damage was also entered as fuzzy. The result of the fuzzy implication is the elements in the cells of the matrix.

The "safe corridors" on the matrix were found using the fuzzy implication formula (3.1). But this was not indicated in the risk assessment matrices.

Assessment of the degree of failure of fuzzy solutions has forms like : "large risk", "at least some chance", etc. In reality, in highly reliable systems the values of the "probabilities of rare negative events" do not make sense because they are small. However, in ATM, these values are specified as 10^{-12}, 10^{-8}.

A practical way of solving such questions is given in the method of Fuzzy Sets. Thus, in manuals for flight operations, PIC’s actions are mainly formulated in clear logical implications. The "fuzziness of behavior" of the PIC during the flight safety assessment is compensated by "Aircraft-PIC" system based on the methods of proactive and predictive state control according to the NASA algorithm.

3.3. Application of the dynamic modeling method to predict the potential disasters

3.3.1. Theoretical provisions in the formula for determining the significance of risk

In this subsection, physical interpretations of the concepts of risk from Chapter 2 are formalized within the framework of the theory of discrete states. Unity of interpretations is achieved by studying hazardous phenomena based on the description below.

In this case, the most important in the proposed method is the identification and analysis of possible conditions for the occurrence of "catastrophes" as rare events (according to ICAO), with a low probability of occurrence. So, we have to switch to the "fuzzy subsets" method instead of using the clear methods of probability theory and clear logic.

The main phases of the algorithms are below.

Phase 1 is based on the analysis of the structure of clear (measurable) random events in stages:

- Identification of risk factors, list of "hazards";
- Construction of hazard models;
- Determination of scenarios for the occurrence of accidents using the PMEA method. That is, the definition of events such as scenarios, but with an assessment of criticality without "probabilities", but only in terms of damage to the system.

Phase 2 - the transition from clear assessments of modeled circuits to fuzzy ones is carried out using risk assessment procedures as a hazard measure for comparison with the acceptable risk which is specified in modified matrix (Fig. 2.3). Then, corrective actions on the system are formed ("risk mitigation" taking into account the "residual risk" and ICAO recommendations, etc.).

3.3.2. Proactive methods of influencing on the risks of negative results in flight operations

The term "safety flight management" denotes the accepted methods of influencing the state of the system proactively, just as it is done in the classical theory of controlled systems.

Possible predictive or terminal controls are well known.

In the general theory of control systems, approaches are developed to the formation of controls with the definition of the mismatch according to the "future result", for example, for the final moment of the total control time interval. This is the proactive management found at the current moment in time to achieve the predicted "expected" results. Essentially the same thing happens with factorial risk management.

3.4. Methodological procedures for the identification and assessment of risks in the safety management system with fuzzy measures of hazard factors

With the new approach, calculation procedures should be developed using information uncertainty indicators - not statistics. The traditional fuzzy interpretation of risks in SMS is not adapted to the correct application of traditional procedures for assessing the hazard of systems on unstable statistics.

The relationship between the concepts of risks and threats in the previous methods has not been established, the concept of a latent threat in scenarios and in the structures of J. Reason's chains has not been developed.

3.5. An automaton model in the method of dynamic modeling of the airport aviation security service in countering acts of unlawful interference

An important component of SMS is considered, which provides the solution of problems such as "security" at the airport. But the results obtained in this case are also important for ensuring flight safety.

It is proposed to interpret the system of ensuring the aviation security of the airport complex in the form of a certain converter of information flows, including information on passenger flows, a set of characteristics and indicators necessary for the implementation of procedures for preventing acts of unlawful interference in the activity of the airport.

A compromise solution to separate the areas of application of traditional probabilistic approaches and new methods for assessing the effectiveness of the aviation security system, which propose methods for combinatorial analysis of integral indicators of the significance of risks without using the parameters of the probability of critical events in possible dangerous situations. The reason for this is the validity of the hypothesis about the high reliability of the structures of the aviation security system, and the rarity (in terms of probability) of risk events that determine the severity of acts of unlawful interference.

Reliability is ensured by a high level of personnel of the aviation security system of the airport, the presence of high-quality equipment for screening passengers, for identifying items prohibited for air transportation, high mobility of security services, etc. With this order of things, the main thing is not to assess the likelihood of a rare event, but to determine the severity of the consequences of acts of unlawful interference, if we assume that they can arise as accidental events with a probability of "almost zero". This value for the randomness of a rare event means that the “residual risk” in the systems is irreparable and a serious tampering or other incident could occur. Therefore, it is necessary to provide for measures to eliminate possible consequences, but this is already the ideology of ICAO, that is set out in documents such as The Safety Management Manual (SMM) and is currently being implemented as a module for SMS systems.

Thus, the structure of the aviation security system essentially ensures the precise functioning of the hardware ergatic complex in the "standby for a disaster" mode and for the immediate suppression of unlawful interference on the basis of the current regulations. The aviation security system information complex has almost all necessary databases to build predictive scenarios for the development of various unlawful interferences including the possibility of terrorist threats.

The idea of essence of the aviation security system function presented here gives reason to consider this entire protective complex as some kind of converter of "inputs" into "outputs".

Such a converter, which is constantly being improved, can be most fully described in the framework of the theory of discrete automata. The automaton model makes it possible to provide the most complete assessment of risks of unlawful interference occurrence and the chances of its successful termination with optimal compensation of consequences and losses, as required by proactive methods according to ICAO.

3.5.1. Formulation of the problem

It is proposed to create (or upgrade) of the aviation security system to prevent possible unlawful interferences on the basis of two principles:

- preservation, without change of the airport's sucurity system which is functioning in normal modes with the same set of technical means of control, observation and registration of signs of possible unlawful interferences for a given number of defense lines;
- creation of a special computer module and program for processing all the aviation security system data to assess current situation and danger based on methods of recognition of crisis situations.

This module ensures that a decision is made on the use of countermeasures against acts of unlawful interference in accordance with the most plausible scenario of events.

In addition, special processing of data arrays is carried out in the existing aviation security systems built on traditional schemes, and the creation of a variety of possible options for environmental models and options for the system's behavior (response to external influences) in the form of synthesized scenarios for the development of events based on the method of constructing chains of random events.

The novelty of the proposed approach lies in the implementation of the principle of information processing and recognition of hazardous situations when making decisions in the aviation security systems in crisis situations. However, in the current aviation security systems, the priority is the expert categorization of hazard levels. The fact is that an automated operational forecast of many alternative scenarios for the development of events in the form of some chains of cause-and-effect events is difficult to implement due to the lack of appropriate models for assessing the level of danger.

One of the ways to overcome the noted difficulties is to use schemes for predicting chains of events using the dynamic modeling method. The characteristics of risk situations are pre-structured on the basis of a combinatorial analysis of interconnected flows of input and output parameters with fuzzy measures of the relationship between the analyzed variables.

3.5.2. Analysis of risk criteria in the aviation security system

To ensure the operation of the aviation security system computer module which implements the principle of situation recognition, it is necessary to create a certain information-factor basis in the system. However, to assess the risks of occurrence of prerequisites for hazardous situations in complex systems, there should created the multiparametric basis. Then it is possible to assess the integral risks and compare them with those acceptable according to the methodology on the basis of the sequential implementation of a number of procedures of the iterative process proposed by ICAO.

However, in the case under consideration, for events with a probability of "almost zero" it is difficult to apply an integral risk R_{ij} assessment:

$$R_u = \sum P_{ji} \left(\sum U_{hji} \right),$$

Where R_{ij}, U_{hji} – probability and damage from event $A \sim (ji)$. However, the required probabilities for this scheme cannot be determined. Further, the most realistic scheme of occurrence of accidents in the form of chains of events with a description of the occurrence of discrete states of a certain $q_i \in Q$ type in the system should be considered.

The concept of a discrete state $q_i \in Q$ is necessary because the occurrence of an incident is always an event A_i or B_i, at a random moment of time $\tau_i \tau_j \in [t_0,T)$ on the interval of system functioning. The process of changing discrete states in the aviation security system can become the basis for analyzing the properties of anti-terrorist stability of systems.

Fundamentally important in the presented scheme is the proposed transition from risk assessment through probability to its fuzzy measure in terms of integral damage.

3.5.3. Information and factor basis of the system

The introduction of such a basis is necessary to establish a correspondence between the factors of damage to the system S' and its responses Y to impacts, taking into account the combinatorics of possible connections and alternative results that ultimately coincide with the occurrence of a risk event of R type. In this case, a set of C_R undesirable outcomes arising under the influence of factors V in the protected system is determined:

$$V \to S \Rightarrow C_R = \{C_r \mid r = 1,2,\dots,n_R\},$$

Where C_r are elements of the set C_R (consequences or type of incident). For example “fire”, “explosion” etc; (→), (=>) are symbols of operations (impact and transition). Actually, C_r is a designation of numbered signs of physical influences x_i making up the set of $X_v \ni x_i$, so that:

$$X_v = \{x_i \mid i = 1,2,\dots,n_R\},$$

Taking into account above, we can write:

$$X_v \equiv X(V),$$

And following from that, we can write the same with (⇔) sign (equivalence of operation):

$$(V \to S) \Leftrightarrow (X(V) \to S), X_v \equiv X(V).$$

According to the physical meaning, $X(V)$ is a certain stream of input influences on the system with signs of influences from V. Each of the results $C_r \epsilon C_R$ can be associated with a measure of randomness μ and a measure of undesirable consequences H. The fact is that $C_r \epsilon C_R$ is a designation of $C_r \sim C_R$ type of events for which, in the future, there is an assessment of damage or losses in the form C_r for each risk event R_r:

$$C_r = \left(\mu_r, H_r \mid S, V\right).$$

With this in mind, it is possible to enter into consideration the output stream of Y_V events or results related to the characteristics of the output functions Y in the form as:

$$Y_v \equiv Y(V) = f_y\left(C_r \mid X_v, S\right),$$

$$Y_v = \left\{Y_{v1}, Y_{v2}, \dots, Y_{vny}\right\}.$$

The number of $n_R \sim C_r$ factors does not match the number of output response functions. Therefore, it is possible to establish a correspondence between V, C_r taking into account the degree of reactivity of the S system to X_v, based on the relationship between $F = F(C_r, V)$ in the form of $v_j \epsilon V$ for exposure factors V and the sensitivity function F_D to X_v factors.

As a result, the introduced basis B can be described as a set:

$$B = \left\{V, F\left(X_V, Y_V\right), F_D\left(X_V, Y_V\right), C_R, L_R, \tilde{R}_*\right\}.$$

It is also necessary to determine the set of $\tilde{R}_* \equiv \tilde{R}_*\left(C_R \mid V\right)$ symbols, which define the set (in the form of matrices) of values of acceptable risk levels using two elements - the frequency of the possibility and the frequency of damage. In this case, L_R are the functions of losses, taking into account the degree of damage to the system, taking into account some of its vulnerability and the amount of damage in case of outcomes C_R. In this case, the losses of the system can also be estimated, depending on the combination of factors in the system through the characteristics of the interrelation of elements. Accordingly, the interconnection matrices M_{ij} can be introduced in a fuzzy measure:

$$F\left(X_V,Y_V\right)=\left\{M_{VX},M_{VR},M_{XL},M_{YL},M_{VC_R},M_{YC_R}\,|\,V,L_R,U_R\right\}.$$

$$L_R=f_L\left(C_R,X_V,H_R\right),$$

Where U_R is a level and a type of a threat generating reactions V, X_v and functions of losses $H \sim C_R$.

Based of the introduced basis *B*, a description of *S* (aviation security systems) can be created in the form of a discrete automaton *W* that converts input actions $\{X_v, V \mid U_R\}$ at threat V_R into output results Y_v:

$$Y_V=f_Y\left(C_r\,|\,X_V,V,U_R,S\right).$$

3.6. Automatic procedures for converting data streams in systems such as Safety Management System and Aviation Security System

Graph theory is the study of graphs, which are mathematical structures used to model pairwise relations between objects.

Automata theory is the study of abstract machines and automata. An automaton is a relatively self-operating machine, or a machine or control mechanism designed to automatically follow a predetermined sequence of operations, or respond to predetermined instructions.

The graph *G* of transitions of the system from one discrete state to another $q_i \in Q$ is determined based on the theory of graphs and automata:

$$G=(Q,\Gamma Q),\Gamma Q:Q\rightarrow Q,$$

Where ΓQ is an operation of displaying the space of *Q* discrete states $\{q_i\}$ into itself, which is equivalent to the set of arcs connecting the vertices of the graph.

The *W* automaton has many symbols denoting the functions of the automaton devices, which provide the transformation of inputs into outputs of the form:

$$W=\left\{X_V,T_V,\Psi,\Phi,Q\,|\,G,F_V,\mu_R,B\right\},$$

Where Ψ, Φ are functions of transition from the state $q_i \rightarrow q_j$ by outputs Y_v:

$$\Psi:\left(X_V,Q\,|\,C_R\xrightarrow{F_V}Q;\Phi=\left(Q,X_V\,|\,C_r\right)\xrightarrow{F_D}Y_V\left(V,C_R\,|\,U_R,S_u\right)\right),$$

Where S_u is a mean of protection which is used in each situation (resources). Among the resources S_u, there are regular S_0 and additional ΔS which are necessary to resolve critical situations.

In this case, the system model can also be described by a set of elements, taking into account the intervals (or cycles) of the operating time and observation of the system:

$$S =< X_V, Y_V, W \mid B, U_R, N, S_U >,$$

Thus, the solution of problems can be presented in a unified form, in particular, in the form of an automaton model. The task is to use the automaton (3.14) to quickly find in the aviation security system all possible "paths-chains of events" leading to a disaster, and to assess the hazard measure using risk models, but not "by probability".

The new result is that the refusal to use probabilistic values is justified, since in real time (at objects in reality - at airfields, at enterprises), information is being processed in the current technological process. At the same time, we have to make decisions on each fact of incoming signals about threats.

3.7. Algorithms for building a system of automated diagnostics and forecasting the level of flight safety

One of the ways to increase and control the level of flight safety is the integration of all means and forms of complex automated systems [14,33]. The proposed approaches to the diagnosis and prediction of risk factors should be implemented with the following advantages: logical flexibility, versatility, accuracy, stability and high speed [34], in-depth analysis of the results of aviation investigations and forecasting the level of flight safety.

The use of automation allows you to solve the following interrelated problems:

- Automated diagnostics of flight safety management - obtaining a set of quantitative and qualitative criteria of RBP.

- Automated flight safety level forecasting. - detection of the dynamics of changes in the level of flight safety

The structure of the system allows to refer it to the class of software packages with "open" architecture [35], which has a number of positive qualities: flexible debugging and modification of modules, connection, removal and extension of functions, information and software compatibility, expansion of repair, testing and system administration.

An important qualitative characteristic of the system is the integrity, which is the determinism and balance of the behavior of the system, embedded in the algorithm of integration and interaction of its individual elements.

The automatic flight safety management system is a human-machine complex that includes a set of software, information and hardware that can automate this process.

This system consists of a subsystem of professional training and a subsystem of risk factors management, which includes a set of blocks, grouped and organized on the principle of functional purpose. As part of the automatic flight safety management system, the individual units operate independently of each other and perform specific goals and algorithms embedded in them. Information exchange, synchronization and interaction between units are organized by means of a centralized database and is a distributed two-tier system, providing communication between aviation authorities and operators of all forms of ownership by means of information flows from aviation authorities to the operator.

The upper level is a single complex, within which the collection, processing, in-depth analysis, interpretation and storage of information about risk factors, the development of effective management solutions to prevent aviation accidents. This component of the subsystem performs the functions of forming / restoring safety management to the target values (Y_{CT}) by assigning the optimal content, length and frequency of measures to prevent aviation accidents.

The lower level of the subsystem is the units installed in the safety oversight body and in the operator's enterprises to ensure the functions of the system to maintain the level of safety in the specified range of values. The diagnostic procedure at the lower level of the system allows the introduction in quantitative form of the identified risk factors, errors, comments and identified occupational hazards. The result is an array of data that characterizes the willingness of the operator to carry out professional activities in real conditions.

The implementation of the guaranteed interval of the management decision is carried out during the periodic management of groups and individual factors, in which the periodic management decisions ensure the maintenance of the level of flight safety for all factors at the regulatory level.

The level of flight safety is considered as a time series, which is a set of values of some value in successive moments of time:

$$\{\{a_t\} = a_{t_1}; a_{t_2}; \ldots a_{(t_{i-1})}; a_{(t_i)}; a_{(t+1)}) \ldots\}$$

The use of a neural network is due to the presence in most of the time series of complex patterns that are not calculated by linear methods. One of the most important stages in solving the problem of neural network forecasting is the formation of a training sample. It is the composition, completeness, quality of the training sample that significantly determines the training time of the neural network and the reliability of the results obtained.

Time series forecasting - calculating the value of its future values or characteristics that allow to determine this value, based on the analysis of known values. When forecasting, it is assumed that the value of the forecast value depends on the determining factors. One of the approaches to the forecasting problem is based on the assumption of the dependence of the forecast value on the previous values of the time series, the theoretical justification for this approach is Takens' theorem [36, 37].

If a time series is generated by a dynamic system, thus the value *{a (t)}* is an arbitrary function of the state of such a system, there is such a number *d* (approximately equal to the effective number of degrees of freedom of this dynamic system) that *d* of previous values of the time series uniquely determine the next value.

Let's define the scheme of the decision of a problem of forecasting:

1. In practice, most of the predicted time series are generated by complex dynamical systems, with many degrees of freedom. In addition, a random component may be present in the time series itself. Therefore, at this stage, preliminary transformations of the initial data are performed, allowing to reduce the prediction error as shown in figure 3.1.

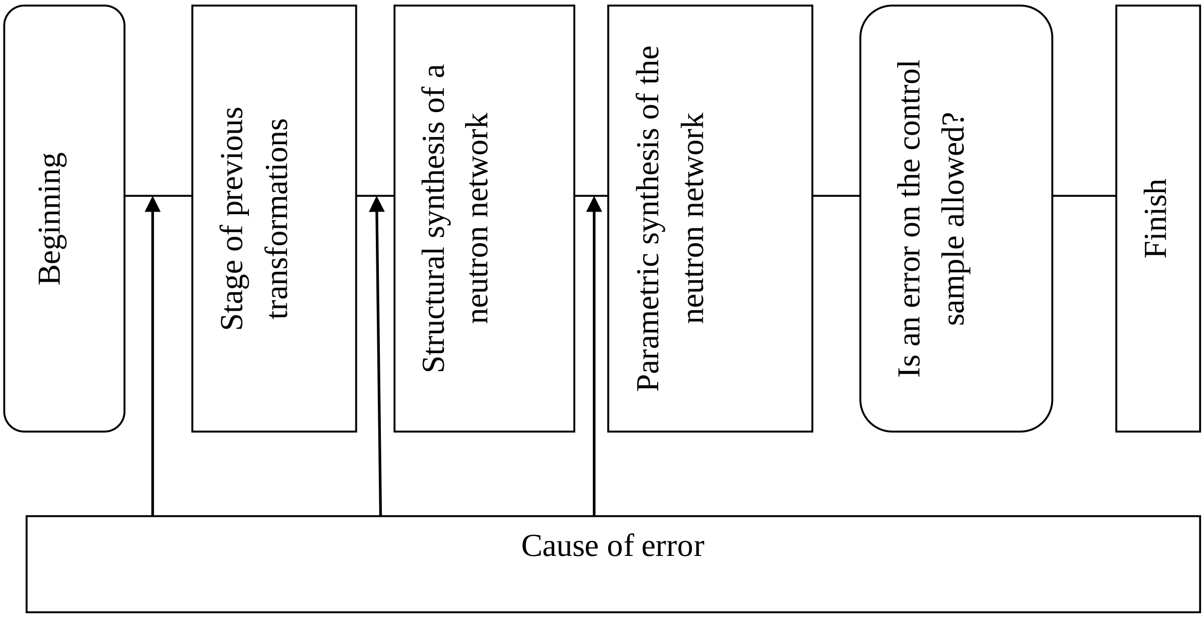


Figure 3.1 - The existing scheme for solving the forecasting problem

After performing the previous transformations for different points in time *t*, the time series appear as a set of values of the function depending on the forecast value on the determining factors (or in the form of a set of sets). Next, from the set of sets obtained, two disparate subsets are distinguished (usually chronologically following one another). One of them is a training sample on which neural network training is performed. Another subset is a control sample, which is not presented by the neural network in the learning process and is used to check the quality of the forecast. Thus, time series prediction is reduced to the problem of interpolation of the function of many variables. The neural network is used to restore this function to many sets that are part of the training sample.

2. Stage of structural synthesis of the neural network. At this stage, the choice of neuron architecture and the structure of connections between neurons.

3. Parametric synthesis of the neural network. Neural network training is performed. As a rule, gradient descent methods are used, in particular, the algorithm of error back propagation and its modification [38, 39]. It should be noted that this stage is the most demanding of computing resources and takes 50-90% of the time to solve the problem.

4. Check of the forecast error for the control sample. If the error value is within acceptable limits, the problem is considered as solved, and the trained neural network is used to obtain a prediction. Otherwise, depending on the presumed cause of the error, a return to steps 1, 2 or 3 is performed.

5. Stage of previous transformations. As a rule, a description of a certain type of previous transformations and the results obtained from its use in a particular area, and a comparative analysis with other types of previous transformations and the criteria by which they could be compared, is not given. However, the stage of pre-transformations affects the result of solving the prediction problem no less than the structure and method of learning the neural network, because the result of pre-transformations are the initial data for these two stages. Therefore, it is advisable to dwell in more detail on the stage of preliminary transformations and try to formulate and justify the basic requirements for previous transformations, necessary to reduce the error of the forecast. The author uses the following requirements implicitly, choosing the types of previous transformations that already satisfy them [24].

The main requirement for the forecast value is the ability to restore future values of the time series with the required accuracy. The use of initial data convolutions as a preliminary transformation allows to describe the situation with fewer features without loss or with a permissible loss of accuracy. This reduces the learning time of the neural network. The interdependence of inputs can lead to a decrease in the informativeness of the description of the situation, and, consequently, to a deterioration in the quality of training. It should be noted that the use of convolutions can partially solve this problem, as most methods of compressing information are based on the elimination of redundancy.

Given the lack of formal criteria for assessing the quality of previous transformations, it is advisable to introduce the requirements necessary to reduce the forecast error, as well as criteria for their implementation.

The proposed scheme for solving the forecasting problem is shown in figure 3.2.

Time series forecasting - calculating the value of its future values or characteristics that allow you to determine this value, based on the analysis of known values. When forecasting, it is assumed that the value of the forecast value depends on the determining factors.

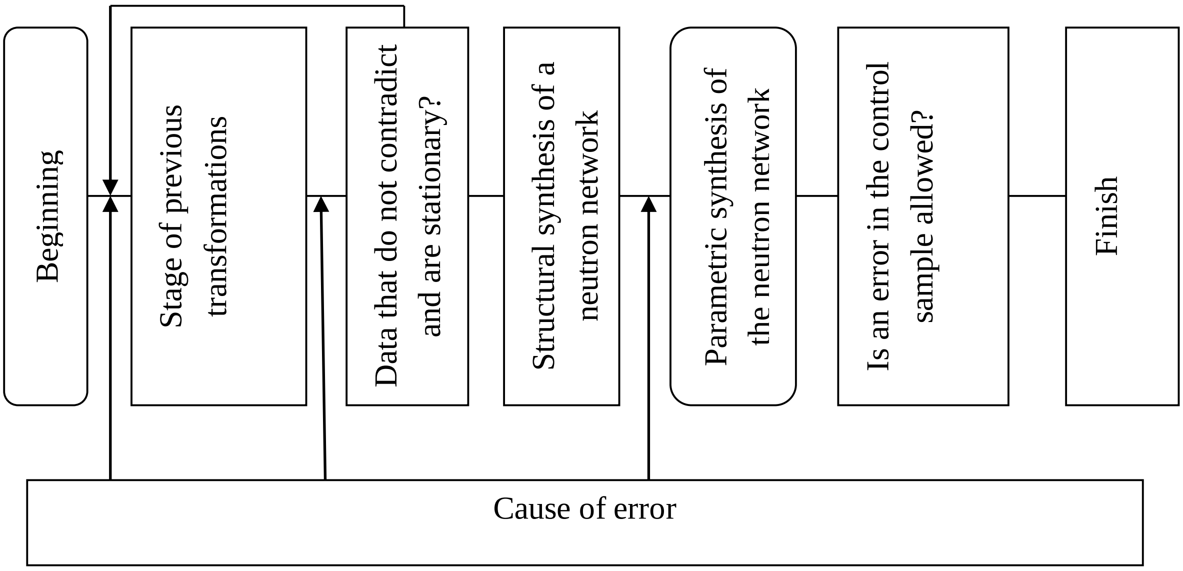


Figure 3.2 - Offered scheme for the decision of a problem of forecasting

Thus, it is necessary to determine the properties of the neural network algorithm, which largely depend on the choice of the parameter, the optimal value of which provides the maximum learning speed.

CONCLUSION TO CHAPTER 3

When monitoring flight safety, it is necessary to record signs of functional failures with a complete list of all units and products reflecting the processes of operation, maintenance and repair. This allows us to create corrective safety management, based on current risk assessments characterizing the operation of aircraft units and other systems in general.

Based on the developed model of the occurrence of a special situation in flight, a method of selecting the volume of the auxiliary sample has been developed, which leads to the refinement of the simulation results of the probable occurrence of a special situation.

Algorithms for building a system of automated diagnostics and forecasting the level of flight safety and management decisions allow to carry out:

- the choice of management decisions aimed at eliminating common mistakes and shortcomings of the work;
- choice of forms of management decisions of professional training aimed at guaranteed achievement of the normative level of flight safety.

CHAPTER 4

ANALYSIS OF THE INCIDENT INVESTIGATION (RUNWAY OVERRUN) WITH MD-83, REGISTRATION NUMBER UR-CPR, ON JUNE 14, 2018 DURING LANDING AT UKKK USING PROACTIVE MEASURES

4.1. Short information about the flight

On June 14, 2018, according to the flight task, it was planned to perform a charter flight BAY 4406 on the route Antalya - Kyiv (Zhulyany) by MD-83 aircraft with a crew of PIC, co-pilot and five flight attendants, state and registration number UR-CPR which belongs to LLC "Bravo Airlines".

Bravo Airlines is the operator of the aircraft and is responsible for the flight and technical operation of the aircraft, maintenance of its airworthiness and flight safety. Accordang to the task of the flight, the PIC trained the co-pilot.

The pre-flight training of the crew, according to their explanations, was carried out an hour and a half before the actual departure at Antalya airport (aeronautical and meteorological information was received by the PIC from a representative of Turkish Ground Services), after which the PIC decided to perform the flight

The climb and enroute flight were performed in the normal mode.

The approach was performed for the ILS of RWY 08 in conditions of thunderstorm activity. At 17:40, during landing at Kyiv (Zhulyany) airfield at a distance of 1260 m from the runway threshold, the aircraft rolled out of the runway to the left on the grass and stopped outside of the runway at a distance of 123 m from the runway axis. It is demonstrated in figure 4.1 As a result of the accident, the aircraft received significant damage, including power elements of the structure. None of the passengers and crew members were seriously injured.

The airport was closed for 3 hours as result of the ocurrence. All 169 passengers of the aircraft were safely evacuated and taken to the terminal [36].

Figure 4.1 - Approximte final position of the aircraft after its overrun

After the incident, 26 passengers complained about their health and medical assistance to the airport medical center. According to an extract from the journal of the medical center, as a result of the incident, 9 passengers received minor injuries (soft tissue bruises, scratches, abrasions), of which 5 passengers suffered during the evacuation, 4 - during the rolling out of the aircraft. Another 17 passengers turned to the medical center with complaints of stress from a nervous breakdown.

4.2. Damage to the aircraft

As a result of the incident, the plane received the following damages:

- broken lower front antenna VHF p / n S65-8262DC10A (destroyed);
- the slat of the right wing was damaged in the end part (significant damage);
- flaps of the right wing are damaged (significant damage);
- flaps of the right wing (significant damage);
- the main right support of the MLG chassis p \ n5930999-5504 s \ n606959 is broken (destructive);
- the landing light p / n 45-0067-9 of the right wing was torn out (destroyed);

- illumination of the airline's emblem on the tail unit (logo light p / n 7910525-505) of the right wing was broken (destroyed);
- fuselage from the emergency door to the rear baggage compartment (significant damage);
- the upper part of the right wing was pierced (significant damage);
- left flashing beacon broken (destroyed);
- the left strut of the main landing gear p \ n5930999-5503 s \ n477753 was broken (destroyed);
- left logo light p / n 7910525-505 (minor damage);
- tail light (AFT position light p / n GE16720-010-6) broken (minor damage);
- the second rail of the left flap was broken (destroyed);
- the upper panels of the left wing are damaged (significant damage);
- damaged brake shield cylinder and shield (significant damage);
- damaged frame of the main left strut of main landing gear (destroyed);
- damaged electrodes and tubes of the hydraulic system (significant damage).

As a result of the rolling out of the aircraft, two side lights of the runway were shot down - № 89 and № 90. The lights were completely destroyed, could not be repaired and were restored by the electrical and lighting support service by replacing them with new ones [36].

4.3. PIC and co-pilot’s main information (table 4.1)

Table 4.1 - Crew information

PIC:

Date of birth:	Nowember 27, 1972
Education:	Balashov Higher Military Aviation School of Pilots
Total flight time:	11548 hours

Table 4.1 - Crew information

PIC:

Flight time as a PIC:	2639 hours
MD-83 flight time:	5580 hours
Flight time on the day of event:	02 hours 00 minutes
Flight time for the last 90 days:	189 hours
Meteominimum:	CAT I ICAO (DH=200ft; RVR=550m; Visibility =800 m)

Co-pilot:

Date of birth:	March 6, 1960
Education:	State Flight Academy of Ukraine
Total flight time:	12514 hours
MD-83 flight time:	3580 hours
Flight time on the day of event:	02 hours 00 minutes
Flight time for the last 90 days:	177 hours
Meteominimum:	Not indicated in the pilot licence

The crew has been used to performing such flights to Kiev (Zhulyany) airport [36].

4.4. Aircraft main information (table 4.2)

It is indicate in [36] that weight and balance calculations were in the operating range and did not exceed the limits. No malfunctions or failures of the aircraft systems and engines were detected.

Table 4.3 - Aircraft information

Aircraft type:	MD-83
State registration number:	UR-CPR
Serial number:	49946
Manufacturer:	McDonnell Douglas-Boeing USA
Date of manufacture:	September 9, 1991
Owner:	«AIR FLEET MANAGEMENT S.A.L.», Lebanon, Beirut.
Operator:	Bravo Airways
Airworthiness review certificate:	№ 0679/1 from 30.11.2017, valid till November 29, 2018.
Total flight time:	43105 hours.
Pre-fllight inspection:	Was completed before departure fron LTAI on June 14, 2018.

4.5. Meteorological information

On the day of departure from Antalya Airport, PIC received a package of meteorological documentation from a representative of Turkish Ground Services, which contained weather forecasts in the TAF code, actual weather in the METAR code at Kyiv (Zhulyany) airport and aeronautical information (NOTAMs and navigation calculations).

The TAF for UKKK was valid from 12.00 UTC on 14.06.2018 to 12.00 UTC on 15.06.2018 as follows:

“Wind 100º 4 m/s gusts up to 9 m/s, visibility more than 10 km; significant clouds 900 m high; maximum air temperature +29° C at 12 UTC on June 14; minimum air temperature +16 ° C at 02 UTC on June 15; between 12.00 and 18.00 UTC on June 14. wind variable 10 m/s gusts up to 17 m/s , visibility 1000 m, moderate rain , thunderstorm, hail, squall; significant clouds 180 m high, significant

cumulonimbus clouds 750 m high; sometimes in the period between 18.00 UTC on June 14 and 03.00 UTC on June 15 wind variable 9 m/s gusts up to 14 m/s, visibility 1500 m, heavy rain, thunderstorm, significant clouds with a height of 150 m, significant cumulonimbus clouds with a height of 750 m; gradually between 03.00 and 05.00 UTC on June 15 wind 130º 3 m/s gusts up to s 8 m/s; time between 05.00 and 12.00 UTC on June 15 wind variable 10 gusts 15 m/s, visibility 1000 m, heavy rain, thunderstorm, hail; significant clouds 210 m high, significant cumulonimbus clouds 750 m high.”

These weather conditions did not prevent the decision to take off, but required increased attention from the crew. At the time of the plane's arrival at UKKK, difficult meteorological conditions were expected (wind of variable directions with gusts up to 17 m/s, moderate rain, thunderstorm, hail, squall).

According to this meteorological data, during the approach and landing of the aircraft, thunderstorm activity was indeed observed at UKKK, as expected.

PIC informed that before comliting the before-landing check-list, he received meteorological information and information about the runway conditions of UKKK while listening to ATIS at 17:00 UTC:

“Aerodrome weather: Wind magnetic: landing area: 080º 7 m/s. Changing from 060 to 120º. Runway threshold: 080º 6 m/s, gusts max 9, min 4 m/s. Changing: from 070 to 130º. Visibility 10 km, thunderstorm with light rain. Cloudiness scattered cumulonimbus, 630 m, significant 1290 m. Temperature: 23, dew point 19. QNH 1007 hPa, QFE 986 hPa.

Landing forecast: occasionally, wind is unstable 10 m/s, gusts maximum 17 m/s. Visibility 1000 m, thunderstorm, with moderate rain, storm. Cloudiness: significant cumulonimbus 750 m.

Ground-based meteorological radar data: thunderstorm, with a squall line. Sector 0 to 360º. Distance 0 to 101 km, moving to the North at the speed of 20 km/h, weakening. After take-off, work immediately with Kyiv Radar 125.3. Confirm receipt *of Hotel information. For arrival: Kyiv Radar 127.72 or 124.67. For departure: Zhulyany-Taxiing 119.0.”*

According to SPECIAL Local Special Report for 17:40 UTC, the weather conditions were as follows:

“Wind in the landing zone 090º 9 m/s, maximum wind speed 13 m/s, minimum wind speed 6 m/s, varies from 060º to 170º, at the end of the runway 130º, 5 m/s, varies from 060º to 200º, landing zone visibility 10 km, weather phenomenon - thunderstorm, light rain, scattered cumulonimbus at 630 m, broken cloudiness at 1230 m, air temperature 22ºC, dew point temperature 19ºC, QNH: 1006 hPa, atmospheric pressure at the level of the runway threshold: 0986 hPa, forecast for landing: occasionally, surface wind direction variable, wind speed 10 m/s with gusts up to 17 m/s, visibility 1000 m, thunderstorm, moderate rain, squall, broken cumulonimbus at 750 m, wind at altitude of 500 m 120º, 13 m/s, thunderstorm, squalls line with azimuth from 071º to 270º, distance 12/96 km, moving to the northeast with 30 km/h, weakening.”

According to the SPECIAL Local Special Report for 17:40:50 UTC (upon the Alarm), the actual meteorological conditions at the aerodrome were as follows:

“Landing zone wind 140º, 9 m/s, maximum wind speed 13 m/s, minimum wind speed 4 m/s, changes from 060º to 250º, at the end of runway 150º, 6 m/s, maximum wind speed 12 m/s, minimum wind speed 3 m/s, varies from 060º to 210º, landing zone visibility 10 km, weather phenomenon - thunderstorm, light rain, scattered cumulonimbus at 630 m, broken clouds at 1230 m, air temperature 22º, dew point temperature 19º, QNH: 1006 hPa, atmospheric pressure at the level of the runway threshold: 986 hPa, landing forecast: occasionally, variable wind direction, wind speed 10 m/s with gusts up to 17 m/s, visibility of 1000 meters, thunderstorm, moderate rain, squall, broken cumulonimbus at 750 m, wind at 500 m altitude: 120º 13 m/s, thunderstorm, line of squalls azimuth sector from 071º to 270º, distance of 12/96 km, moving to the northeast with 30 km/h, weakening.”

In general, the organization of meteorological service of flights at UKKK met the requirements of the Aviation Rules of Ukraine "Meteorological service of civil aviation".

The crew and ATC were provided with timely objective data on meteorological conditions at UKKK.

Information about the state of the runway was recorded in the Airfield Status Journal and passed to the Tower Control Unit and the meteorologist on duty at UKKK meteorological office for further inclusion in the METAR / SPECI weather reports. Than, this information is transmitted to the meteorological technician of the meteorological monitoring body of the Kyiv Air Traffic Control Center for inclusion in the ATIS broadcasting unit.

The PIC’s statement that the weather forecast for Kyiv (Zhulyany) airfield did not indicate the presence of dangerous meteorological phenomena is not true [36].

4.6. Sequence of events

The plane took off from Antalya airport (LTAI) at 15:41 UTC. The flight was delayed for about six hours. The reason for the flight delay was the non-arrival of the plane. There is no information on repeated before-flight check-list caused by a significant flight delay.

The climb and enroute flight before entering the airspace of the Kyiv ACC was performed in the regular mode.

At 17:10 UTC, the MD-83 UR-CPR aircraft entered the Kyiv ACC at FL320. The ATC informed the crew of the standard arrival route and informed about the presence of thunderstorm activity along the flight route of the aircraft.

The pilot confirmed receipt of the standard arrival route and requested shortcut to KK820. A minute later, ATC approved shortcut to KK820.

According to PIC, the crew received information "Bravo" actual from 17:00 UTC.

However, based on the analysis of the crew-controler radio contact records and inside cockpit, the crew did not confirm the receipt of ATIS information when communicating with the ATC [36].

According to information provided by ATIS and the METAR report, at 17:00 ГЕС at UKKK, simple meteorological conditions were observed with a constant wind of up to 8 m/s, visibility of more than 10 km and no clouds. Despite the fact that the meteorological information contained data on the presence of a thunderstorm at a distance of 40 km from the aerodrome, which shifted towards the aerodrome at a speed of 40 km/h and intensified, the landing forecast erroneously informed the crews that weather conditions would not worsen.

Thus, the TREND forecast for the time of landing did not come true.

PIC said that during the before-landing check-list, the crew listened to the weather conditions at Kyiv (Zhulyany) airfield, which were simple. 5 minutes before landing, during the in-cabin communication, the crew is surprised to discuss the weather with the phrase "CAVOK was reported" (at 17:34:39 UTC).

METAR reports at Kyiv (Zhulyany) aerodrome for 15:30 UTC, 16:00 UTC, 16:30 UTC and 17:00 UTC contained information on good weather conditions (CAVOK), and the landing forecast (TREND) for 2 hours did not provide for worsening weather conditions or occurrence of dangerous (NOSIG) [37].

In this part, the forecast did not come true.

UKKK 141700Z 11004MPS CAVOK 25/17 Q1007 R08/CLRD70 NOSIG=
UKKK 141630Z 11005MPS 080V150 CAVOK 25/17 Q1007 R08/CLRD70 NOSIG=
UKKK 141600Z 11006MPS CAVOK 26/17 Q1006 R08/CLRD70 NOSIG=
UKKK 141530Z 11005MPS CAVOK 27/17 Q1006 R08/CLRD70 NOSIG=
UKKK 141500Z 11004MPS CAVOK 27/16 Q1007 R08/CLRD70 NOSIG=

At 17:10:25 UTC the ATC of Kyiv ACC, after establishing contact with the crew, warned them about the thunderstorm activity on the flight route.

At 17:16:44 the PIC requested descending to FL170.

Information about the storm at Kyiv (Zhulyany) airport was indicated in ATIS "Charlie" message at 17:20 UTC.

At 17:28:55 UTC the pilot informed about approaching FL120 and requested for further descent. The ATC reported the atmospheric pressure QNH, the transition level and approved descending to altitude 9000 feet.

At 17:29:47 UTC, the ATC informed the crew about the radar identification of the aircraft, the runway in use at UKKK and approved descending to altitude 5,000 feet and later to altitude of 4,000 feet.

According to ATIS information at 17:21 UTC, a thunderstorm was observed at Kyiv (Zhulyany) airport, which was accompanied by significant changes in wind direction in the sector from 080 to 140º. According to the TREND forecast, an unstable wind with gusts of up to 17 m/s was expected at the aerodrome. The specified information was not transmitted to the aircraft crew.

Due to the fact that controllers did not receive confirmation that ATIS information was received by the crew controllers had to provide the crew with up-to-date meteorological and runway condition information.

At 17:35 UTC the ATC asked if the crew was able to land in a thunderstorm. The crew confirmed their readiness to continue landing and asked about the weather at Kyiv (Zhulyany) airport.

After receiving information about the weather, the PIC decided to continue the approach and informed the ATC accordingly.

According to the PIC, the crew received information from the dispatcher about the surface wind, visibility and lower limit of clouds at the point of landing and thunderstorm at Kyiv (Zhulyany) airport, but at this time the crew had already seen runway lights and informed the ATC about the decision to continue landing.

At 17:37 UTC at a distance of 6 m. to the landing point the crew was informed that the aircraft was to the left of the runway direction and asked if crew would continue to land in such a configuration. To which the crew replied that the runway is being observed and they continue to land.

At 17:38:02, after establishing contact with the crew, the ATC of UKKK Tower informed the crew about the wind (direction 080º, 5 m/ s, gusts 8 m/s), pressure QNH 1007 and gave clearance for landing. After the crew’s readback, at 17:38:30 UTC the ATC provided the crew with information about the state of the runway (wet, covered with a layer of water up to 3 mm, traction coeficient - 0.54, braking action is good) [36].

At 17:39:17 UTC, just before landing at UKKK, the crew asked ATC to clarify the information about the actual wind: "Wind check, please", to which they received the following answer: “Wind 080º 7 gust 11 m /s”.

Aircraft made a touch down of RWY08 at 17:39:53 UTC.

The Tower ATC Supervisor was observing f the aircraft on the runway. After it overran, Tower ATC Supervisor immediately, at 17:40:17 UTC gave the signal "Alarm"[36].

4.7. Approach and landing

The approach was performed for Runway 08 of Kyiv Airport (Zhulyany). Magnetic landing course 79 degrees. The total length of the runway is 2310 m (available landing distance is 2160 m). Width - 45m [38].

The aircraft approached the final turn to the right of the runway axis. During the finl turn (turn to the landing course) the aircraft crossed the landing direction and deviated to the left. The maximum deviation was 730-740 m at a distance from the end of the runway 16 km. It is shown in figure 4.2. Then, the aircraft approached the landing heading, while remaining to the left of the runway axis. At the time of crossing the runway threshold, the lateral deviation was 1 m to the left of the runway axis as in figure 4.3.[36].

At 350 m of height and a distance of 6 km from the end of the runway, the autopilot is switched off and piloting is done manually.

Immediately after the autopilot is switched off, a before-landing check list is completed. The check list was read in full, but the answers are incomprehensible on the CVR.

Fig. 4.2. The scheme of the aircraft movement while approach plotted on a map of the earth's surface

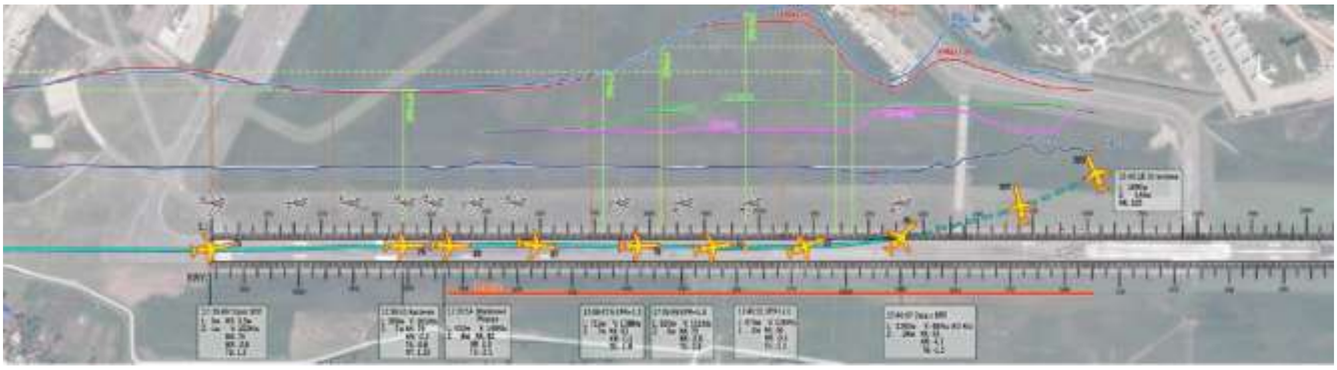


Fig. 4.3. The scheme of the aircraft movement along the runway plotted on a map of the earth's surface

The aircraft was in an unstabilized position with its speed (165 knots) and rate of descend (1150 ft / min.).

The PIC had to make a decision about “Go around” procedure already at this stage (according to paragraph 8.1.3.18 "Criteria for a stabilized measure" of the Operation Manual of the airline "Bravo").

After flying at an altitude of 1000 feet, the aircraft gradually deviates below the glide path, and continues to approach on the left of the axis of the runway. At 17:39:19 UTC, the GPWS "Sink rate" alarm was given due to exceeding the vertical descent rate Vy (Vy = 1200 ft / min.).

At an altitude of 500 feet, the aircraft was also in an unstabilized position.

At altitude 200 feet, speed 168 knots, heaading 79 degrees, distance from the runway 1150 m, deviation to the left of the runway axis was 14 m. On the CVR recording, the voice informant gives a "Minimums" signal. From altitude of 200 to altitude of 100 feet, the pitch gradually increases from -5 to -3 and the true airspeed drops from 168 to 160 knots. After flying at a height of 100 feet, the engine operation mode increases and true airspeed is stabilized at a value of 151 knots.

At the moment of overflying the runway threshold, the aircraft had a significant deviation as shown in table 4.4 an figure 4.4..

Table 4.4 – approach indicators devitions

Parameter	Estimated value	Actual value	Remarks
Height, m (feet)	15 (50)	3,5 (11)	11.5m below (39ft)
True airspeed, knots	133	151-152	18-19 more

After landing, the crew started reverse thrust and increased the mode of operation of the engines. Spoilers in automatic mode after landing were not released, and in manual mode the crew did not release them as well.

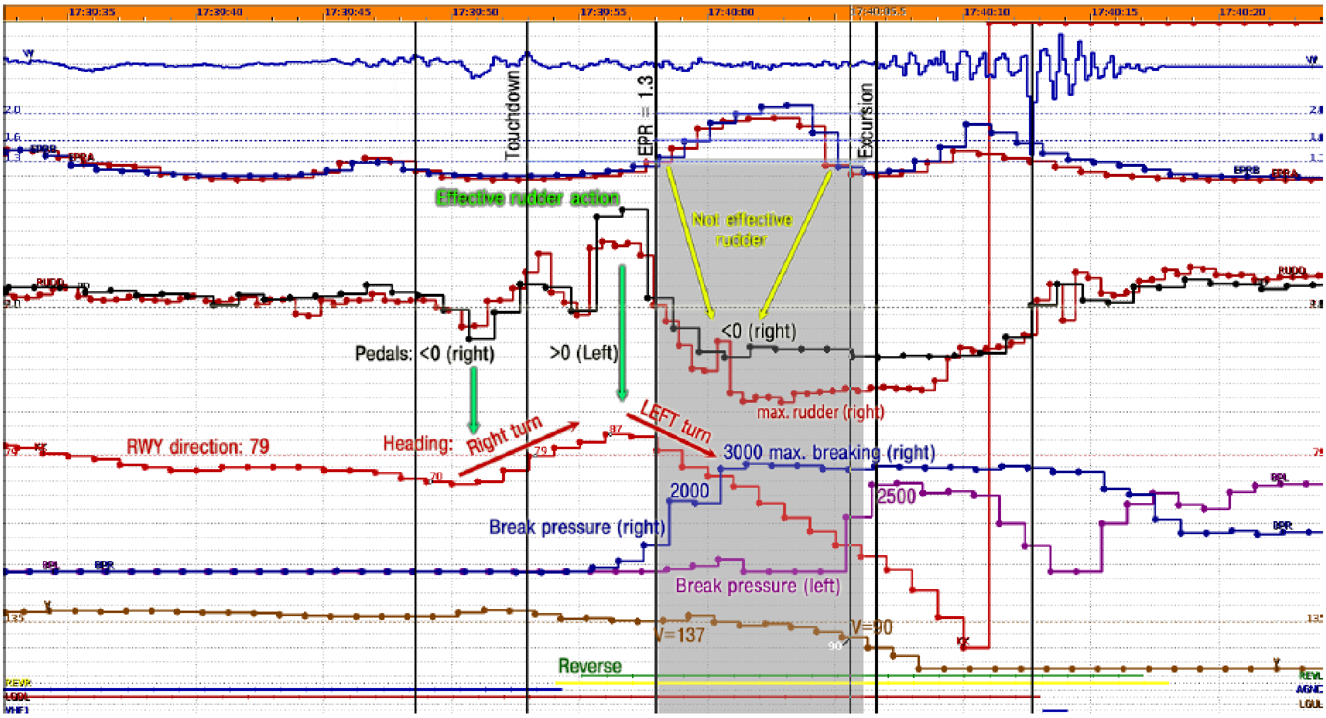


Figure 4.4 - Aircraft movement parameters after touchdown

After increasing the reverse thrust mode, the aircraft did not respond to the control actions of the rudder and moved by inertia under the influence of external forces.

13.5-14 seconds after landing, at a distance of 1260 m from the runway threshold and with the speed of 48 knots, the aircraft went beyond the runway. The aircraft continued to move on the ground outside the runway and stopped at a distance of 1690 m from the end of the runway, 145 m to the left of its axis.

As a result of the accidents, none of the crew members and passengers received serious physical training.

The plane was evacuated from the airfield within a week of the incident, after which the airport resumed operations without restriction [36].

4.8. Reasons of the incident

The cause of the accident - overrun of the aircraft MD-83 UR-CPR of the airline "Bravo", which occurred on June 14, 2018 at the airport Kiev (Zhulyany) during flight BAY 4406 on the route Antalya-Kiev (Zhulyany), was the decision of the PIC to continue landing at the airport Kiev (Zhulyany) in thunderstorm conditions with the following main factors:

- unstabilized approach, starting at an altitude of 1000 feet;
- non-release of spoilers by the crew;
- incorrect actions of the crew with usage of the reverse thrust on a wet runway.

Additional factors are:

- not fully provided to the crew flight information service in the classified airspace of Ukraine;
- varying wind within its strength and direction;
- probably not listened to current ATIS by the crew;
- there are incorrect landing procedures in the Bravo Operation Manual;
- non sufficient pre-flight preparation, reading and execution of the check lists at all stages of the flight.

4.9. Measures to prevent similar incidents according to Chapter 2 and Chapter 3

1. To oblige the operators of civil aviation aerodromes (where ATIS broadcasts are provided) to make appropriate changes in the Flight Instructions (use of airspace) in the part concerning the procedure of listening to ATIS information and informing the ATS Units by aircraft crews for further publication in the Aeronautical Information Publication of Ukraine.

2. Increase the quality of runway inspection and data transmission for the formation of consultations and information that is transmitted to the crews.

3. Bring pre-flight training of crews, briefings in accordance with the procedures.

4. Eliminate inconsistencies in the determination of the runway condition and improve the methods for calculating the required landing distances in the Air Companies' Operation Manuals.

5. Carry out training of crews on the use of reverse thrust on dry and wet runways.

6. Require the flight crew to comply with the instructions transmitted to ATIS and to confirm the relevant information to the ATS units.

7. Carry out training of crews on the decision to perform a "Go around" procedure in case of unstabilized position of the aircraft.

8. Take measures to ensure that ATS personnel comply with the requirements of the operating instructions when transmitting weather information at the aerodrome and double-check receiving correct readacks from crews concerning having actual ATIS information on board.

CONCLUSION TO CHAPTER 4

1. PIC and co-pilot had valid commercial pilot licenses and a class I medical certificate in accordance with the established requirements.
2. The aircraft was registered in the state register of the aircraft of Ukraine and had a certificate of airworthiness in accordance with the existing requirements of the Civil Aviation Authority of Ukraine.

3. The duration of the pre-flight rest of the crew met the requirements of regulatory documents.
4. At the time of arrival to UKKK airport, thunderstorm activity was forecast, which the crew did not know at the time of departure. It confirms the lack of preparation before the flight.
5. The ATC did not provide the crew with information about weather conditions at UKKK
6. Information about weather conditions at UKKK was provided by the ATIS in full.
7. During the approach, the crew informed ATC about their readiness to perform the approach during thunderstorms.
8. The weather forecast for landing "TREND" in METAR for 15:30, 16:00, 16:30, 17:00 UTC did not predict worsening weather conditions and the occurrence of dangerous weather phenomena, but the forecast was not correct
9. Despite the fact that at the decision height, the aircraft was unstabilized, the PIC decided to continue approach and landing.
10. Just before landing, the aircraft was exposed to wind varying in strength and direction.
11. After landing, the spoilers were not released. When braking on a wet runway, maximum reverse thrust was used (it was wrong).
12. The aircraft did not respond to the control actions of the rudder and moved by inertia under the influence of external forces.
13. As a result of overrun, the plane received significant damage.

GENERAL CONCLUSIONS

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