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Leonīds Vinogradovs

PROBABILITY APPROACH A SURVIVE OF PASSENGERS ESTIMATION IN AN AVIATION INCIDENT SITUATION IN AN AIRPORT RESPONSIBILITY DISTRICT

Summary of the Doctoral Thesis

RTU Press
Riga 2020

RIGA TECHNICAL UNIVERSITY
Faculty of Mechanical Engineering, Transport and Aeronautics
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Professor Dr. habil. sc. ing.
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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on December 18, 2020 at the Institute of Aeronautics of the Faculty of Transport and Mechanical Engineering of Riga Technical University, 6b Kipsalas Street, Room 204.

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DECLARATION OF ACADEMIC INTEGRITY

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

Leonīds Vinogradovs ……………………………. (signature)

Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction; 5 Chapters; Conclusion; 37 figures; 24 tables; 3 appendices; the total number of pages is 124, including appendices. The Bibliography contains 85 titles.

TABLE OF CONTENTS

GENERAL OVERVIEW OF THE THESIS

The Urgency of the Problem

Actuality of theme is to assessing a probability of survival of passengers' survival under aircraft accident [AA] near airport area. The analysis of statistical data shows that the number of AA is increasing. For objective estimation of negative factors on survivability of passengers in AA, and factors, effecting the efficiency of rescue operation, it is necessary to consider and analyse data of real accidents. At first, it is necessary to analyse the fire characteristics in passengers' cabin and airport area in the case of AA. The forecasting of fire spread and dynamics of dangerous factors of fire evolution give the possibility to decline the risks of fire. At any emergency aircraft landing, expected or sudden, the choice of passengers' exits depends on the degree of the aircraft damages at landing, the position of airplane on earth or on water after landing, and also from the location of fire body, in case of its origin, fire intensity and propagation. The analysis of experimental data such as the assessment of passengers' evacuation time from a conflagrant airplane shows that it is a random variable that depends on very many factors. Therefore, in international practice of rescue, possibilities' calculations are produced for the different scenarios of fire on airplane. The standard methodology for such calculations is unavailable at present. The analysis of the data obtained as a result of experiments and practice, allows to produce the comparative estimation of different exits design. It allows to evaluate the rate with what passengers can abandon an airplane using the exits. There are different methods of design of evacuation of people at fires. Thus, all models are based on the concept of stationary passengers' stream. The discharge rate and time of evacuation depend on a variety of an evacuation motion factors. When modeling it is necessary to take into account every educed kinematics and psycho physiologic characteristics. Depending on plenitude of its account a few models of motion of stationary passengers' flow are possible. As models are based on different basic data for the calculation of the required time of evacuation, the comparison of functional ability of models to describe the motion of stationary passengers' streams can be made only qualitatively. The factors that influence the survival of passengers and their rescue are interdependent and depend on the severity of collisions of AA. All post-accident fires of aircraft have a fast-moving character. Such a problem gets up to fore reach possible wrecking variants and rescue operations for any kind of aircraft during ordinary exploitation of airports. It may be solved only with system and planning approach to this problem. Fires enlarge upon aircraft in a very short time and cause a considerable social and material damage that is difficult to estimate financially.

The Object of the Research

Problems of survival and rescue of passengers at aviation accidents with a fire on earth.

The Goal of the Research

The goal of the research is to assess an evaluation of survival probability for passengers during aviation fire accident near the area of the airport. In order to do that it is necessary to formulate models of fire situations in aviation accidents related to the probability assessment to escape. The main tasks of the research are as follows:

1. Based on the analysis of features of aviation fire accidents in airport area, to generalize and classify extended information about the fire hazard and dynamics of fire and history of dangerous factors on board of airplane.
2. To mathematically ground the physical model of fire in the salon of airplane in order to give a methodical estimation to rescue efficiency.
3. To investigate the problem of probability of passengers' survival, taking into account the fire factors in an aviation accident.
4. To estimate the required time of passengers' evacuation from the conflagrant cabin of airplane.
5. To investigate the process of rescuing passengers out of an airplane in an aviation fire accident on the ground.

Research Methods

The basic methods of the research are general conformities with the management theory, statistical methods for practical and theoretical analysis. Prognostication of fire history, dynamics of dangerous fire factors, calculation of the disposed time for a rescue, development of statistical (probability) model of passengers' survival and rescue in an aviation accident with a fire on earth, research of rescue process from an airplane cabin.

Novelty of the Research

1. The features of aviation accidents and fres and fire loading in aviation accidents at an airport are specified.
2. Recommendations on improving the rescue management are given.
3. The estimation of time needed for evacuation of passengers from the conflagrant cabin of airplane is offered.
4. The statistical (probability) model of passenger's survival is given for an aviation accident with a fire.
5. A study of evacuation process of passengers out of an airplane in the case of aviation accident.

Practical Relevance of the Research

The research allows to refine the assessment of the likelihood for survival and rescue of passengers in the case of aviation accident with on the ground. That gives an opportunity to improve and modernize the processes of rescue and evacuation of passengers and to develop the best practice for airport's rescue services.

Structure of the Doctoral Thesis

The Doctoral Thesis consists of an Introduction; 5 Chapters; Conclusion; 37 figures; 24 tables; 3 appendices; the total number of pages is 124, including appendices. The Bibliography contains 85 titles.

Thesis submitted for the Discussion

- The assessment of features of aviation accidents in airport area.
- The evaluation of fire risks in aviation accidents in an airport area with a fire on the ground.
- The formulation of statistical (probability) design for passengers' survival in an aviation fire accident.
- The research of passengers' evacuation process in an aviation accident.

The Approval of the Research Results

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Terms and definition

Aviation accident is an aviation event related to the use of an aircraft, which, in the case of a manned aircraft, occurs from the moment when a person boards the aircraft with the intention to fly until the moment when all persons on board have left the aircraft, or, in the case of an unmanned aircraft, occurs from the moment when the aircraft is ready to take off with the aim of flying until it stops at the end of the flight and turns off the main power plant, and during which:

a) a person suffers fatal or serious bodily harm as a result of: being on the aircraft;
  - or direct contact with any part of the aircraft, including parts detached from the aircraft;
  - or direct exposure to a jet of gases from a jet engine, except for those cases when bodily injury is caused by natural causes, self-inflicted or inflicted by other persons;

b) the aircraft is damaged or its structure is destroyed, as a result of which the strength of the structure is impaired, the technical or flight characteristics of the aircraft deteriorate and usually a major repair or replacement of the damaged element is required, except in cases of engine failure or damage when only one engine is damaged (including its hoods or auxiliary units),

c) the aircraft goes missing or finds itself in a place where access to it is absolutely impossible.

Note: An aircraft is considered missing when the official search has ceased and the location of the wreckage has not been established.

Investigation is a process carried out with the aim of preventing accidents and incidents, which includes the collection and analysis of information, the preparation of conclusions, including the establishment of causes and the development of recommendations for ensuring flight safety.
Aviation incident - precondition for a flight accident
Aircraft Damage Incident – in which it is possible and economically feasible to repair an damaged aircraft.
Aircraft maintenance - work performed at the stage of aircraft operation (AO) and aimed at maintaining their airworthiness and readiness for flight**.**

AA – aviation accident;
ART – airport rescue team;
AS – alarm system;
AV – aircraft (airvehicle).
CA – civil aviation;
FC – flight control;
FES – fire extinguishing system;
FS – flight safety;
FT – fire team;
HFF – hazardous factors of fire;
ICAO – International Civil Aviation Organization;
JAR – Joint Aviation Requirements;
RO– rescue operations;
RT – rescue team;
RW – runway;
SS – security service.

1. THE REVIEW OF THE STATED OF PROBLEM

An important role in ensuring aviation security is played by the interaction of international organizations whose activities are devoted to aviation safety. The most important organizations in this activity are the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA). These aviation organizations were the first to join the fight against acts of unlawful interference in the activities of civil aviation. Today, ICAO and IATA continue to be the primary organizations in the development of draft aviation security regulations at the international level. Let us consider in more detail the activities of international organizations in ensuring aviation security.

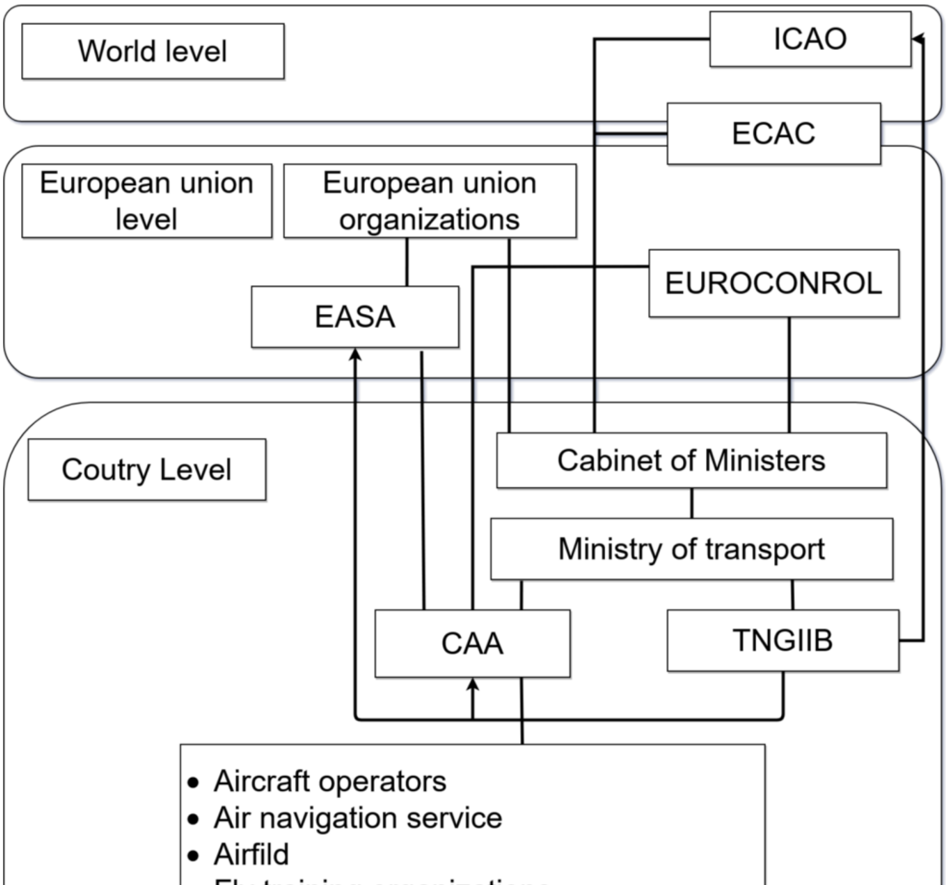


Fig. 1.1. Structure of international aviation safety organizations.

International Organizations

ICAO – (International Civil Aviation Organization) is a specialized agency that sets international standards for civil aviation and coordinates its development in order to improve safety and efficiency.

IATA (International Air Transport Association) is an international non-governmental organization. The headquarters is located in Montreal (Canada). IATA has 101 offices around the world with 200 airlines, mostly major carriers.

ACI (Airport Council International) is the only global trade office of airports in the world**.**

EASA (European Aviation Safety Agency) is the European Union (EU) agency for the regulation and execution of tasks in the field of civil aviation safety. EASA was established on July 15, 2002. The main task of EASA is to ensure the highest level of safety in civil aviation through certification of aviation products, approval of aviation organizations, development and implementation of standardized European rules.

JAA (Joint Aviation Authorities) is an international organization that regulates aviation legislation for pilots and airlines in most countries located in Europe.

ECAC (European Civil Aviation Conference) – an intergovernmental organization established by the International Civil Aviation Organization (ICAO) and the Council of Europe.

Euro Control – with the main goal of developing a pan-European air traffic management system within the framework of the European Common Sky project.

Studies of airplane accident history testify that basic factors resulting in victims are blows and fires. Exemplary relative distribution statistics data on the number of died passengers in accidents versus the stages of flight are shown in Fig. 1.1.

Fig. 1.2 Accidents (%). Passengers died (%). The flight segment duration time (%).

Approximately 90% of all flying accidents are described as “survived” or “technically survived”. On the average, from 1500 (100%) passengers in a year, in Figure is shown the annually had perishing in aviation accidents whole world. About 900 (60%) passengers have not survived in accidents. Other 600 (40%) have not survived in the “technically survived” incidents. The fire loading and basic fire-dangerous zones of airplane are certain.

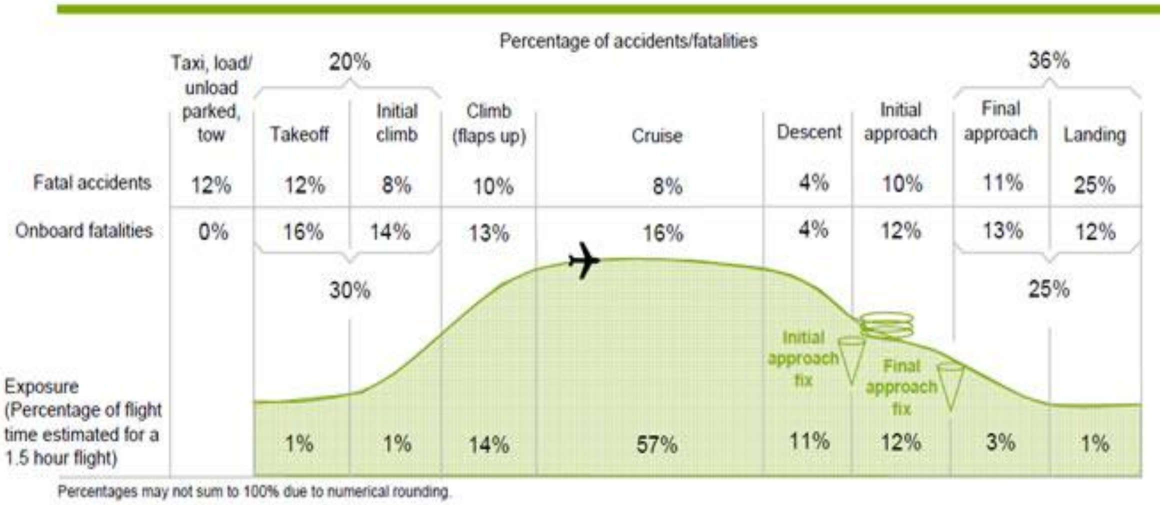


Fig. 1.2. The structure of accident in flight.

Approximately 90% of all flying accidents are determined as “survived” or “technically survived”. On the average, from 1500 (100 %) passengers in a year, On Figure is shown the annually had perishing in aviation accidents whole world. About 900 (60 %) passengers have perished in the not “survived” accidents. Other 600 (40 %) – have perished in the “technically survived” incidents.

Fig. 1.3. Accident statistics. The number of fatalities in aviation accidents from 1963 to 2018.

A study of accident materials has shown that most of them occur on/or near the runway. The diagram shown in (Fig. 1.4) shows that:

- 31 % of the incident occurred in an area within 1000 m of the threshold and 30 m on either side of the runway center line;
- 16 % of accidents occurred in an area outside the end of the runway within 500 m of it and 30 m on either side of the runway center line.

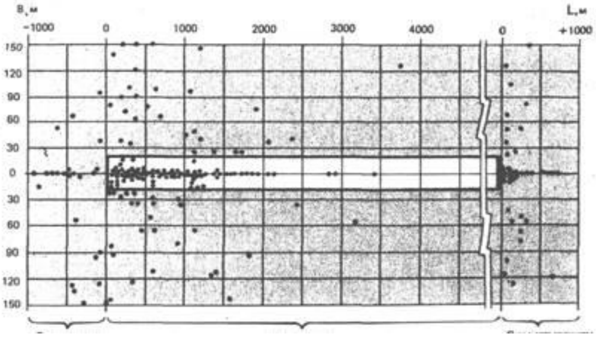


Fig. 1.4. Runway accident location diagram.

Main cases of aviation accidents that take place in the territory of airport or near the airport area are considered, analysed and presented. These areas are areas of operation of airport rescue team and services. In Table 1.1, these cases are located in order of complicated conditions for extinguishing fire and saving (evacuation) of passengers who have suffered in the accident.

List of events in emergency situations of fire on airplane on the ground.

Table 1.1

Factors Characterizing Aviation Accident

No. AI	Factors		
	State and condition of fuselage.	Character of fire on airplane	Condition of passengers
1	The undercarriage is full-out, is free of damages	Fire in engine	All or most of the passengers are able to move independently and evacuate
2		Landing carriage on fire	
3		Small intensity fire outside the fuselage	
4		Fire of avionics spilled under the fuselage	
5	A fuselage (passenger cabin) is partly damaged	Medium intensity fire around the fuselage caused by the spill of avionics	Some passengers are not able to move independently and evacuate
6		Medium intensity fire under the fuselage caused by the spill of avionics	
7		Fire inside the fuselage	
8	The fuselage is considerably damaged	Fire of air-fuel spilled out under the fuselage, fire in the fuselage	Most of the passengers are not able to move independently and evacuate.
9	The fuselage is on the ground, a passenger cabin has considerable damages		
10	The fuselage is inverted, has considerable damages		

Over the past decades, aircraft fires have become the fourth most common cause of death in commercial worldwide aviation

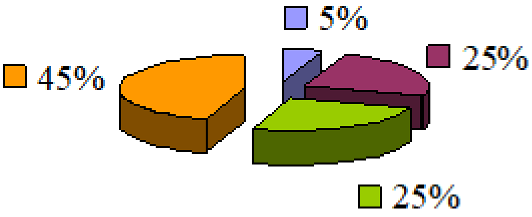
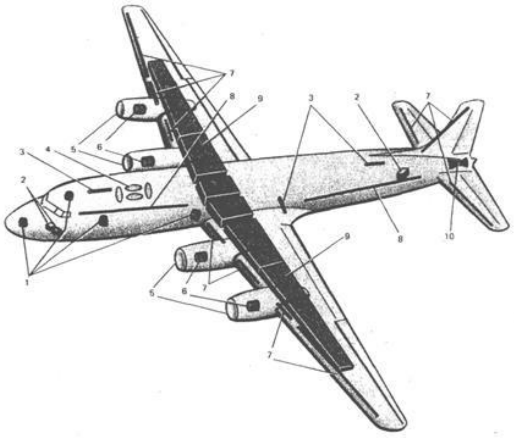


Fig. 1.5. Statistics inside cabin fires on airplanes for 10 years.

The pie chart shows statistics on aircraft cabin fires due to:

- 5 % hazardous substances present in the baggage of passengers;
- 25 % passenger hand luggage and other accessories;
- 25 % aircraft cabin equipment that is the cause.

The fire loading and basic fire-dangerous zones of airplane are certain:



Basic fire dangerous zones of airplane:
1 – tanks with a hydraulic liquid;
2 – storage batteries;
3 – petrol heaters (on air courts with reciprocates);
4 – oxygen bulbs;
5 – power-plants;
6 – oily tanks of power-plants;
7 – deicer system;
8 – system of conditioning; heating of ventilation;
9 – fuel tanks.

Fig. 1.6. Basic fire dangerous zones of airplane.

The increase of volumes of air traffic and growing intensity of flights require assuming measures on providing passengers’ survivability. Rescue supplies are of great importance, the primary purpose of which is to evacuate passengers out of airplane that is engulfed in flame. All of it poses a very actual problem to passengers’ rescue in aviation accidents in an airport area. An airplane, as possible object of fire, has a set of features that have influence on the process of burning:

- there is a significant quantity of avia-fuel and other combustible liquids aboard;
- the application as decoratively-finishing construction materials in passenger cabin, such as different sort of plastics, possessing high mass speed of combustion, high ability of smoke and emission of toxic components under incomplete combustion at burning in an enclosed volume of cabin;
- the small ability of fuselage cover to resist fire which leads to rapid flash-through and burning out of the fuselage skin in the fire, the air-fuel pouring out around an airplane and allowing fire to penetrate into the passengers cabin.

Fires in passenger cabin behave like the fires in enclosed volumes. Their characteristics are high-slay of smoke-screen, small size of zone of burning, high temperature gradient on the height of apartment and small (as compared to outward fires) temperature of fire, and also presence of the products of combustion of considerable concentrations of high-toxic substances. The dangerous factors of fire complicating rescue and safe evacuation of passengers in aviation accidents are: high-toxic substances penetrating into the enclosed volume of passengers cabin; rapid decrease in oxygen concentrations in the air of passenger cabin; relatively high medium-volume temperature in the cabin. The determination of unfolding situation then dangerous fire factors take their maximum legitimate value when influence does not present a threat to the health of man will be attained. The parameter characterizing the dynamics of fire will be the complex quantitative index – fire loading. Fire loading is usually understood as the total amount of warmth that is disengaged in the surrounding volume after combustion of all flammable materials and objects. The ratio of fire loading to the area of surface where it takes place is called a specific fire loading. For some applications it is also assumed to determine the fire loading as the total mass of all fuel materials that are in the space of attributed to the unit-area of this space. The fire loading is divided into permanent and temporal. A permanent fire load is elements of finishing of passenger cabin consisting of combustible materials. The temporal fire loading is combustible and flammable objects that are in a cabin. Providing the passengers' survivability conditions and decreasing of airplane fire accident severity of consequences may be attained by to meeting the following requirements:

- the fire fighting on airplane must begin before the dangerous factors of fire exceed their allowable critical maximum;
- the time of fire localization and extinguishing of basic area of burning must not exceed the set value;
- the time of inhibition of the localized fire must be sufficient for evacuation of passengers from an emergency airplane.

In addition, it is necessary to follow the principle of increase of the forces and facilities, brought over to fire-fighting on an airplane.

When investigating passengers' survivability in aviation accidents in an airport area, it is necessary to take into account two basic factors:

- Length of time that passengers can stay in a conflagrant airplane; we will consider that this time is sufficient for evacuation of all passengers; The limit is a moment when the first passenger dies. Let us designate it as – $t_{r.}$
- Number of times needed to evacuate all passengers from an airplane using modern facilities and technologies, side and surface emergency equipment, qualification of crews and personnel of rescue services. Let us consider it as a required time and designate as – t_p

Mathematical design allows to estimate the sizes of t_r and t_p for different scenarios flows of events and gives an opportunity to estimate and, that is important, to compare the dynamics of critical factors development in the cabin of conflagrant airplane, the level of danger and probability of passengers' death in multifarious situation, to define the most fire-dangerous from the point of view of fire-safety types of airplanes and airlines.

2. THE WAYS TO DEVELOP THE MODEL THAT SPECIFIES THE AVAILABLE SAFE EGRESS TIME (ASET) FOR BRINGING OFF PASSENGERS FROM THE CONFLAGRANT CABIN OF AIRPLANE

The analysis of statistics of accidents of the ICAO countries testifies that one of the main causes of heavy injuries of people at fires in the passenger cabin is poisoning from the products of complete and incomplete combustion and from toxic substances. To solve such a task let us introduce a concept of critical level K_{K} that specifies the "dose" of dangerous factors for passengers' life in the event of fire in a conflagrant cabin of airplane. There are many risk factors for passengers in the passenger cabin of airplane. As to calculate each of them is a highly intricate problem, let us introduce the following complex criteria chosen from the variety of dangerous fire risk factors: toxic – K_{KV} and thermal – K_{T}. Coefficient K_{KV} is the "dose" of the toxicity of the poisonos substances disengaged in the conflagrant cabin of airplane. Coefficient K_{T} is the thermal dose. So the complex coefficient specifying the critical level of hazard in the conflagrant cabin of airplane in time is

$$K_{\mathrm{K}} = K_{\mathrm{KV}} + K_{\mathrm{T}}. \tag{2.1}$$

The substances rendering the negative affect to a human organism and environment are called toxic. As the index of burning products toxicity let us define the ratio of such quantity of product to the unit of volume of closed space in which burning disengaged gaseous products cause death of 50 % of experimental animals. The level of toxicity of substances is characterized by the level of toxic dose – the quantity of substance that has impact on animal or human organism and causes a certain toxic effect.

The Toxicity of combustion products is defined by three factors:

- the value of specific coefficients of the selected toxic gases;
- the values of partial density of gases;
- the time that affects human organism.

Let us estimate the index of toxicity by calculating the total index of toxicity K_{m}:

$$K_{\mathrm{m}} = \frac{C_{\mathrm{CO}}}{CL_{50\mathrm{CO}}} + \frac{C_{\mathrm{CO2}}}{CL_{50\mathrm{CO2}}} + \ldots + \frac{C_i}{CL_{50i}}, \tag{2.2}$$

where C_{CO}, C_{CO2}, and C_{50i} are the average concentrations of gases obtained during testing, mg/m^3; $CL_{50\mathrm{CO}}$, $CL_{50\mathrm{CO2}}$, and CL_{50i} are average mortal concentrations of gases under the 30-minute isolated exposure to experimental animals. By the value of this index all materials may be attributed to the following rank of danger: extraordinary dangerous, highly dangerous, mildly dangerous, and low-hazard. Many researchers engaging in studies of fire's conditions of all the variety of toxic gases in fire four most dangerous: oxide of carbon (CO), dioxide of carbon (CO_2), hydrogen chloride (HCL), and hydrocyanic acid (HCN). The time dependency of oxide of carbon CO and dioxide of carbon CO_2 concentration is presented in Figs. 2.3 and 2.4.

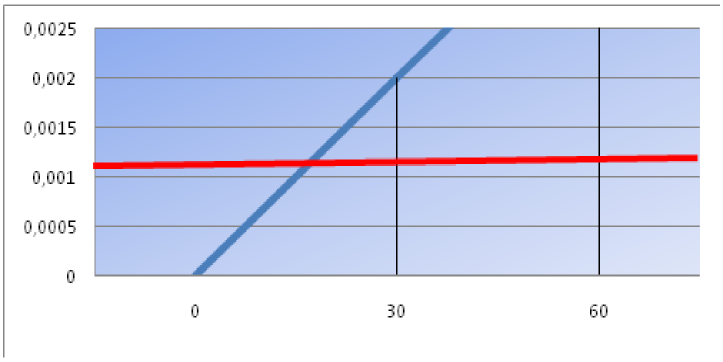


Fig. 2.1. Dynamics of change of concentration of CO, kg/m^3.

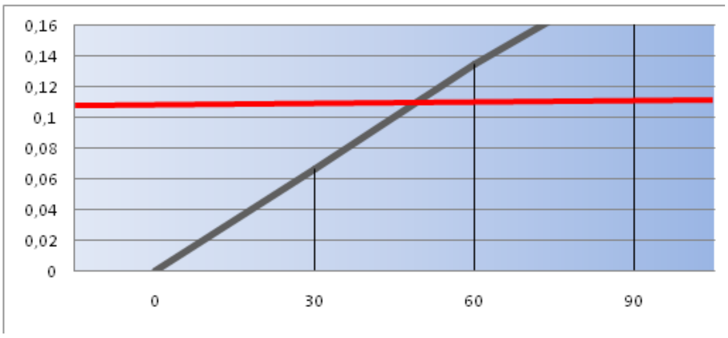


Fig. 2.2. Dynamics of change of concentration of CO_2, kg/m^3.

Oxide of carbon. As a result of interaction with hemoglobin of blood oxide of carbon forms a nonactive carboxyhemoglobin that induces abnormality of oxygen delivery to fabrics of organism. The time of action is from 3 to 60 minutes under concentration of 0.2–1.0 % of dioxide of carbon. It causes apneusis (breathing acceleration), increasing respiratory ventilation rate, increasing of adrenalin rate. Under a concentration of 19–20 % it causes loss of consciousness and death within a few minutes.

Oxide of carbon, dioxide of carbon, hydrogen chloride, and hydrocyanic acid determin the total complex coefficient of K_{KV} that includes the coefficients of the oxide of carbon, carbon dioxide, hydrogen chloride, and hydrocyanic acid:

$$K_{KV} = K_{CO} + K_{CO2} + K_{HCL} + K_{HCN}. \qquad (2.3)$$

It is very difficult to determine these coefficients. When researching such problems as burning, it is usual practice to compare the results that are obtained by means of empirical analytical dependencies worked out on the basis of statistical data and nature experiments.

At any fire thermal energy is evolved. The quantity of the evolved heat depends on the condition of air-ventilation in the hearth of fire, thermo-physical properties of surrounding materials and design, which affect the fire loading. The fire temperature rise in a closed apartment has a monotonous character and practically arrives at a maximum value in one and a half minutes.

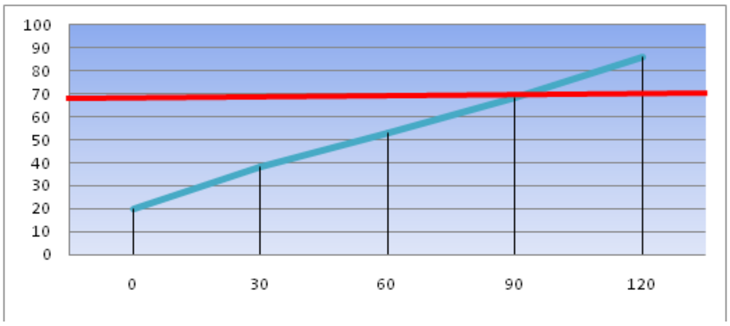


Fig. 2.3. Dynamics of change of temperature, °C.

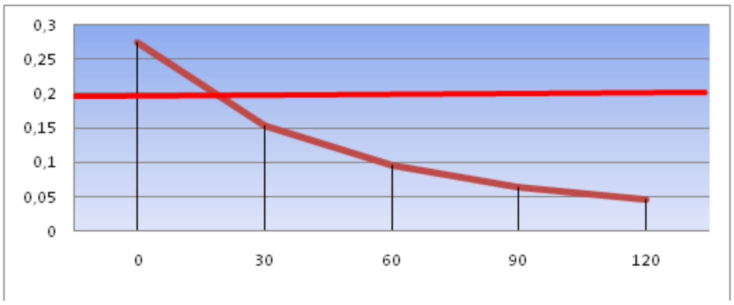


Fig. 2.4. Dynamics of change of visibility, m.

During fire escalation, oxygen, which is in the air, is taken in burning of substances and materials, thus creating the fire loading. The lowered content of oxygen is typical for any zone of fire where there is smoke: zones of burning, zone of thermal impact, and zone of smoke-screen.

The simple geometry of cabin of airplane and clear pattern of combustible elements allows applying the simplified method for the estimation of temperature heating in a cabin. The initial expressions for the estimation are as follows.

1. Equation of energy balance in the fixed volume at a fire:

$$\frac{\mathrm{d}}{\mathrm{d}\tau}\left(\frac{PV}{\alpha-1}\right)=\psi\eta Q_{\mathrm{H}}^{\mathrm{P}}+C_P^{\mathrm{TER}}T_P^{\mathrm{TER}}G_{\mathrm{B}}-C_PTG_{\mathrm{r}}-Q_{\mathrm{W}},\qquad(2.4)$$

where P – pressure, Pa ; V – the volume of apartment, m^3;

$$\alpha=\frac{C_P}{C_V}\approx 1,4,\qquad(2.5)$$

r – time, s; ψ – rate of burning-out, kg/c; η – combustion efficiency; $Q_{\mathrm{N}}^{\mathrm{P}}$ – heat effect of conflagrant materials, J/kg; C_P – gas heat capacity at constant pressure, J/(kg K); T – medium-volume temperature of air in a cabin, K; G_{B} un G_{r} – mass air flow rate depending on fire entering and leaving an apartment, kg/C; Q_{W} – total heat losses in the lounge of cabin, J/C; “TER” – overhead index showing the parameters of environment conditions outside the cabin.

2. Equation of mass balance:

$$\frac{\mathrm{d}}{\mathrm{d}\tau}\left(pV\right)=G_{\mathrm{B}}+\psi\eta-G_{\mathrm{T}}, \tag{2.6}$$

where p is medium-volume gas density in the apartment of fire, kg/m^3.

To estimate the total heat losses in the design of cabin Q_{W} in equation (2.4), it is necessary to know the temperature of airplane cladding, which be found in the heat balance equation for passing through the thin metallic cladding.

3. Equation of heat balance:

$$\frac{\mathrm{d}T_{\mathrm{M}}}{\mathrm{d}\tau}=\frac{\alpha_{\mathrm{GW}}\left(T-T_{\mathrm{M}}\right)-\alpha_{\mathrm{WG}}\left(T_{\mathrm{M}}-T^{\mathrm{TER}}\right)}{\delta_{\mathrm{M}}\rho_{\mathrm{M}}C_{\mathrm{M}}}, \tag{2.7}$$

where T_{M} – average temperature of cladding on a surface of airplane, K; α_{WG} un α_{GW} – coefficients of thermal emissivity from the gas environment to the surface and from the surface to gas accordingly, J/(m^2 K C); δ_{M} – thickness of cladding, m; P_{M} – density of cladding material, kg/m^3; C_{M} – heat capacity of cladding, J/(kg K).

Because of plenty of fire risk factors, for a quantitative estimation of level of criticality in the conflagrant cabin of airplane it is convenient to estimate a complex criterion, including two factors: toxic – K_{KV} and thermal – K_{T}. Coefficient K_{KV} is a “dose of toxicity of the poison substances” disengaged in the conflagrant cabin of airplane. Coefficient K_{T} is the thermal dose. If it is assumed that at a fire in the cabin of airplane a passenger gets the “dose of poisonous substances” from four products of burning – oxide of carbon, dioxide of carbon, hydrogen chloride, and hydrocyanic acid, we can define the total complex coefficient K_{KV}, which specifies the summary of the four poisonous substances in the conflagrant cabin taking into account the impact of each of them. The analysis of aviation accident investigations shows that the accuracy degree of quantitative estimation of criticality coefficient of condition in the cabin of conflagrant airplane can be determined by experimental calculation methods.

The above equations (2.4), (2.6), (2.7) can be limited, i.e. dispense with the equations of the balance of oxygen and other gases, if we assume that the oxygen in the room is sufficient for intensive combustion during the time when critical conditions for passengers in the burning cabin are reached. For the same reason, we believe that during the fire time of interest to us, the pressure in the room practically does not change:

$$P=\text{const}. \tag{2.8}$$

Using the assumption (2.4), with V = const, we obtain:

$$\frac{\mathrm{d}}{\mathrm{d}\tau}\left(\frac{PV}{\alpha-1}\right)=0, \tag{2.9}$$

then

$$G=\frac{\psi\eta Q_{\mathrm{H}}^{\mathrm{P}}+C_{\mathrm{P}}^{\mathrm{TER}}T^{\mathrm{TER}}G_{\mathrm{B}}-Q_{\mathrm{W}}}{C_{p}T}. \tag{2.10}$$

Substitution of expression (2.10) into equation (2.6) gives

$$G_r = \frac{1}{V}\left(G_{\mathrm{B}}\psi\eta Q_{\mathrm{H}}^{\mathrm{P}} + \frac{\psi\eta Q_{\mathrm{H}}^{\mathrm{P}} + C_{\mathrm{P}}^{\mathrm{TER}} T^{\mathrm{TER}} G_{\mathrm{B}} - Q_{\mathrm{W}}}{C_P T} \right). \tag{2.11}$$

The accepted assumption (2.9) allows us to use the Gay-Lussac law:

$$pT = p_{\mathrm{beg}} T_{\mathrm{beg}} = \mathrm{const}, \tag{2.12}$$

where the subscript "beg" means the initial conditions. If we differentiate relation (2.12), then we can find a connection between the derivatives

$$\frac{\mathrm{d}T}{\mathrm{d}\tau} = \frac{T^2}{\rho_{\mathrm{beg}} T_{\mathrm{beg}}} \cdot \frac{\mathrm{d}T}{\mathrm{d}\tau}, \tag{2.13}$$

which will allow us to write equation (2.11) with variables T and τ

$$\tau\frac{\mathrm{d}T}{\mathrm{d}\tau} = \frac{T^2}{V\rho_{\mathrm{beg}} T_{\mathrm{beg}}} \left(\frac{\psi\eta Q_{\mathrm{H}}^{\mathrm{P}} + C_P^{\mathrm{TER}} T^{\mathrm{TER}} G_{\mathrm{B}} - Q_{\mathrm{W}}}{C_P T} - G_{\mathrm{B}}\,\psi_2 \right). \tag{2.14}$$

The use of the system of equations (2.7) and (2.14) makes it possible to solve the problem of finding the desired temperature T and reducing the temperature due to heat losses in the skin of the aircraft T_{M} with the correct determination of the values of the terms of the equations. Some parameters of them, such as, α_{GW}, α_{GW}, δ_{M}, P_{M}, C_{M}, $Q_{\mathrm{H}}^{\mathrm{P}}$, are from reference books, others, for example: T_{beg}, T_{Mbeg}, P_{beg} T^{beg}, V, C_P and $C_{\mathrm{p}}^{\mathrm{TER}}$, ψ, G_{B} are set taking into account the geometry and damage to the cabin, the conditions of the fire, etc.

Heat losses into the skin are defined as

$$Q_{\mathrm{W}} = \alpha_{\mathrm{GW}}^{\mathrm{M}} \left(T - T_{\mathrm{M}}\right) F_{\mathrm{M}} + \alpha_{\mathrm{GW}}^{\mathrm{PAR}} (T - T_{\mathrm{PAR}}) F_{\mathrm{PAR}}, \tag{2.15}$$

where the index "M" denotes the parameters that determine the heat loss into the skin; index "PAR" have parameters that determine heat loss into non-combustible interior items of the cabin; F_{PAR} – area, respectively, of the trim and non-combustible interior items of the cabin, m^2; T_{PAR} – temperature of non-combustible interior items, K_0.

The parameter T_{PAR} can be approximately determined by the formula

$$T_{\mathrm{izol}} = T_{\mathrm{sāk}} + 0{,}2\left(T - T_{\mathrm{sāk}}\right) + 0.00065(T - T_{\mathrm{sāk}})^2. \tag{2.16}$$

This relationship describes quite satisfactorily the change T_{PAR} in the initial section of the development of a fire in the cabin, when T increases monotonically.

The system of equations (2.7), (2.14), (2.15), (2.16) gives a completely closed description of the problem posed and allows you to get the result using a program based on numerical methods of software.

However, experience with accident investigation shows that, with the degree of accuracy acceptable for this study, to determine the "temperature dose" is possible using a formula obtained by approximating experimental data.

Based on the foregoing, for the coefficient of “temperature dose” K_{T} – we take the ratio of the time a person spends in the cabin of a burning aircraft to the time of death. When

$$K_{\text{T}} = \frac{\tau_{\text{T}}}{\tau_{\text{CT}}}, \tag{2.17}$$

where τ_{T} – residence time in an environment with temperature T, s; τ_{CT} – time of death at temperature T, s.

As the fire progresses, the temperature of the gaseous environment in the volume of the passenger cabin changes. The dependence of the time of death onset on temperature is determined by the formula:

$$\tau_{\text{CT}} = 1.23 \cdot 10^{5} \cdot \text{e}^{-0.432(T-273)} - 15. \tag{2.18}$$

Then the coefficient, that characterizing quantitatively the “temperature dose” in the burning cabin of the K_{T} is determined by the expression:

$$K_{\text{T}} = \int_{0}^{\tau} [1.23 \cdot 10^{5} \cdot \text{e}^{-0.432(T-273)} - 15]^{-1} \text{d}\tau. \tag{2.19}$$

The final formula for estimating the complex criticality factor in a burning cabin of an aircraft is obtained as the sum:

$$K_{K} = -K_{\text{KV}} + K_{\text{T}}. \tag{2.20}$$

The risk factor K_{K} was calculated using the method described for burning “block chairs” using data from Fig 2.5.

As you can see from the graph, the time to reach the coefficient $K_0 = 1$ is 90 seconds.

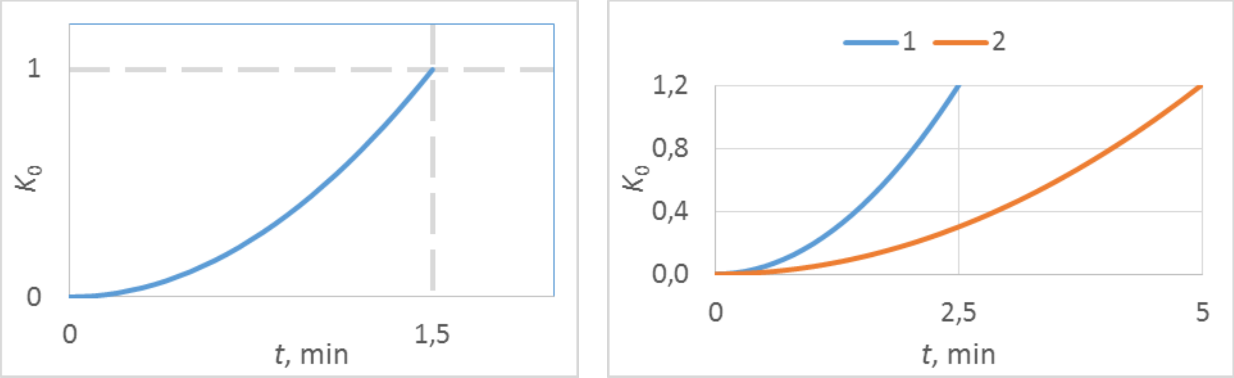


Fig. 2.5. Results of experimental data during firing of finishing materials.

Fig. 2.5 shows the results of experimental data when, during the firing of decorative and finishing materials on a large-scale test site, there were options for finishing materials for the passenger cabins of IL-18 and IL-62 aircraft. As can be seen from the graphs, the hazard ratio per unit reaches 2.5 and 5 minutes. The arson in this study was carried out with 300 mL of alcohol spilled on the passenger seat. Animals (white rats) were dead between 90 and 120 seconds after the start of the fire. However, the nature of the flow and time curves confirms the legitimacy of the application of the hazard factor K_{K}.

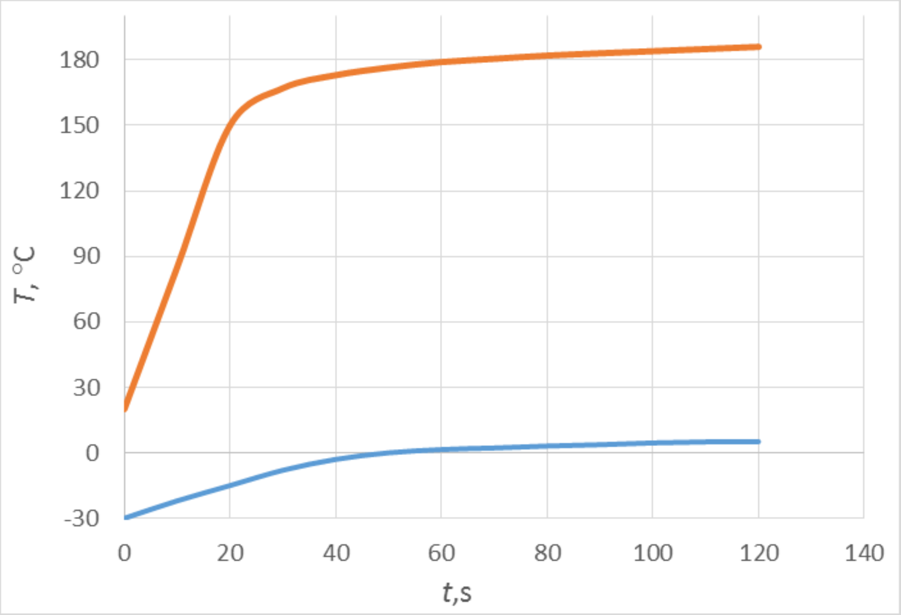


Fig. 2.6. Change in the average volumetric temperature in the cabin of a burning aircraft.

Calculation has been made for alloy D16T. Average room temperature curve goes to the stationary area at the 60th second and approximately equal to 185 °C

3. THE PROBABILISTIC MODEL OF PASSENGERS' SURVIVAL IN AVIATION ACCIDENTS WITH A FIRE ON THE GROUND

A mathematical model gives an opportunity to estimate and, that it is important, to compare a danger and frequency of fire occurrence and probability of death of passengers in one or another situation, to define the most dangerous from the point of view of fire safety types of air ships and airlines. Probability of survival of passengers at fire on airplane on the ground depends on the following factors:

- number of passengers and rescue operation (depending on the type of airplane and qualification of flying and rescue personnel);
- closeness of the site of aviation occurrence to the airport;
- degree of airplane fuselage destruction, especially in the passenger cabin;
- ability of passengers to self-evacuate;
- history and intensity of fire (fuel pouring out, fire in power-plant, fire in passenger cabin, etc.).

These are the parameters that specify the passengers' survivability in the event of fire on airplane. It is necessary to estimate them when analyzing the statistical data and managing their collection. Obviously the offered model will consist of the matrix of emergency situation events and probability of passengers' survival.

Table 3.1

Matrix of Events of Emergency Situations

State of emergency situation (i)	1	2	…	…	i	$i + 1$	…	…	$n - 1$	n
P_i – probability of survival of passengers in situation i	P_1	P_2	…	…	P_i	P_{i+1}	..	…	P_{n-1}	P_n
N_i – probability of origin of situation i	N_1	N_2	…	…	N_i	N_{i+1}	..	..	N_{n-1}	N_n

The number of accident situations is n. Let us define that $n = 10$ as in Table 1.1,

The matrix of emergency events (Table 3.1) is developed starting from 1) the most favorable situation ($i = 1$) – an aviation accident takes place practically on the takeoff strip of the airport, the passenger cabin actually is not wrecked, almost all passengers are able to self-evacuate, the amount of fuel pouring out is negligible; to 2) catastrofic accidents ($i = n$) – an aviation accident happened in a remote from an airport area, there are considerable damages of passenger cabin, most passengers need to be evacuated, large amount of fuel is pouring out.

Obviously, the value of passengers' survival probability P_i is maximal in favorable situations, and minimal in catastrophic situations (i):

$$P_1 > P_2 > \ldots P_{i-} > P_i \ldots > P_n, \tag{3.1}$$

$$\sum_{i=1}^{n} P_1 = 1.0.$$

Where the probability of occurrence of a specified situation is N_i. It is logically possible to suppose that most often there are situations that are “favourable” (i.e. in the airport) or “catastrophic” – fire accident with large damage and large amount of fuel pouring out with the airplane far away from the airport rescue command. Intermediate situations, probably, occur considerably rarer.

$$N_{(1,2,3\ldots)} > N_i \ldots < ..N_{(n-1,n)}, \tag{3.2}$$

$$\sum_{i=1}^{n} N_I = 1.0. \tag{3.3}$$

So the complete matrix of emergency situation events has at least 16 situations – 2^4; 4 situations that have two extreme values:

- near an airport – far from an airport;
- fuselage is not destroyed (negligible damage) – fuselage is severely damaged;
- fuel has practically not spilled – great amount of fuel has spilled out and inflamed;
- passengers can self-evacuate – passengers to be evacuated by a rescue command.

There are not such statistics in open literature sources, although in principle to manage such statistics collection would benefit and give opportunity to apply the methods of multi-variable statistical analysis.

We will continue further simplification of model, whereas it is necessary to process the available statistical data.

The logical mathematical systems theory describes the process of emergency situation as a chain of interactive events. The interrelation of them has qualitive and quantitative components that are always in dialectical interdependence. The mathematical tools of the system examine binary variables and functions, and traces to minimal number of the simplest.

Therefore, supposing that ability of passengers to self- evacuation and the level of fuel spread correlate with the level of fuselage destruction, let us simplify the matrix of events to nine states.

- level closeness of aviation accident to the airport: “in an airport” ; “near-by an airport”; “far away from an airport”;
- level of fuselage destruction in aviation accident: “little”; “medium”; “considerable”.

Table 3.2

Matrix of situations of emergency events

Level of destruction of airplane	Remoteness from an airport		
	In an airport, $i = 1$	Near-by an airport $i = 2$	Far away from an airport $i = 3$
Little, $j = 1$	$\boldsymbol{P_{11}}$	$\boldsymbol{P_{12}}$	$\boldsymbol{P_{13}}$
Medium, $j = 2$	$\boldsymbol{P_{21}}$	$\boldsymbol{P_{22}}$	$\boldsymbol{P_{23}}$
Considerable, $j = 3$	$\boldsymbol{P_{31}}$	$\boldsymbol{P_{32}}$	$\boldsymbol{P_{33}}$

P_{ji} – probability of passengers’ survival in situation ji.

Let us arrange all hypothetical situations of **aviation accidents** with fires on the plane into three groups.

Group I. Favorable accidents, states *i* = 1…4:

- the airplane is landing on an undercarriage, it has minor damages.
- passengers are able to self-evacuate out of airplane;
- low-level fire outside the passenger cabin;
- aviation accident has occurred on the territory or nearby airport.

Fig. 3.1. Situation of favorable accidents (Group I).

Group II. Unfavorable accidents, states *i* = 5…7:

- fuselage is partly damaged (landing not on an undercarriage);
- part of passengers is not able to self-evacuate out of the airplane;
- fire, fuel leakage near the passenger cabin;
- disposition of accident not far away from the airport.

Fig. 3.2. Situation of favorable accidents (Group II).

Group III. Catastrophic accidents, states *i* = 8…10:

- fuselage and passenger cabin are considerably damaged;
- greater part of passengers are not able to self-evacuate out of the airplane;
- fire in the passenger cabin;

– disposition of accident is far away from the airport.

Fig. 3.3. Situation of catastrophic accidents (Group III).

Let us subdivide the emergency states:

I – “favourable” – with a high degree of probability to survive;

II – “unfavourable” – with a moderate degree of probability to survive;

III – “catastrophic” – with small probability to survive.

These groups of situations are accordingly marked green, yellow, and red.

The probability of occurrence of dangerous situation I, II, and III are designated as N_{I}, N_{II}, and N_{III}.

Then the initial matrix table of the emergency states will be as shown in Table 3.3.

Table 3.3

Matrix of the grouped emergency situations

State of emergency situations (•)	I	II	III
Probability $N(\bullet)$ of emergency situation(•) occurrence	N_{I}	N_{II}	N_{III}
Probability of passengers’ survival $P(\bullet)$ in an emergency situation (•)	P_{I}	P_{II}	P_{III}

Thus, total probability of passengers’ survival in the airplane accident with a fire on the ground can be calculated with formula

$$P_{\text{survive}} = \sum_{\mathrm{I}=\mathrm{I}}^{\mathrm{I}=3} P_{\mathrm{I}} N_{\mathrm{I}}. \tag{3.4}$$

Or this formula of average probability’s estimation of survive for passenger to fall into an aviation accident with a fire. Certainly, it is very difficult to set forth the probabilistic terms of occurrence of emergency situation $N(\bullet)$, and actually it is not so important. But the probability of survival $P(\bullet)$ can be calculated with methodological calculations of survival used at fires in civil and industrial building and are adapted to the flying accidents. The offered model gives an opportunity to estimate the risk of mortality in a fire accident. Thus, it is possible to compare the fire rescue opportunities for the types of airplanes and airlines and also to make a provision of insurance fund for differentiated payout to families of the lost and injured. When evaluating the danger level of aviation accident, there is a task to evaluate the factors of exposure hazards for passengers of the emergency situation. Expert and insurance organizations, as well as the owners of companies can run into such problem. To evaluate the hazard level, it is necessary to know the number of victims and economic disbenefit. Actually, the estimation of influence of striking factors on people and airplane at accident is taken to outline two functions: a dependence of number of dangerous fire factors on distance from rescue command to the accident disposition and a dependence of damage level against number of factors.

The probability of passengers’ survival in an aviation post-accident fire is significantly lower than in a fire accident in civil building. The application of the model in question allows to evaluate the fire hazard in an aviation accident on the basis of probabilistic method by the direct processing of statistical data.

The result obtained from the research are actual statistical data that increase objectivity and evidence of the conducted expert studies.

4. THE MODEL FOR DETERMINATION OF THE REQUIRED TIME FOR PASSENGERS' EVACUATION OUT OFF THE CONFLAGRANT AIRPLANE CABIN AT AVIATION ACCIDENTS IN AN AIRPORT AREA IS OFFERED

The time required for evacuation out of airplane t_p is specified as the time of stationary passenger's motion as far as evacuation exits from the most remote disposition of passengers. All paths of stationary passenger's motion are subdivided into lane's stages (passage-way, evacuation exit, platform, ladder) with length l_i and width δ_i. The initial stages are aisles, cabin-center gangways, between auxiliary attachments, etc. When estimating the ASET (available safe egress time) the length and width of every evacuation lane on airplane is accepted de-facto. Path length to a ladder and also through evacuation hatches on inflatable ladders are specified in accordance with the length of ladder. A path length through hatches is defined equal to zero. The hatches' width is defined no more than 0,7 m. Also, a platform is specified as independent horizontal lane, having length l_i. The estimated time of passengers' evacuation (ASET) t_p is specified as a sum of stationary passengers' motion time along the separate lanes of way t_i:

$$t_\text{p} = t_1 + t_2 + t_3 + ... + t_i, \tag{4.1}$$

where t_1 – the time of stationary passengers' motion in initial stage, s; t_2, t_3, ... , t_i – the time of stationary passengers' motion along each following lane after the first stage, s.

The time of stationary passengers' motion in the first stage of way is t_i.

$$t_1 = \frac{L_1}{V_1}, \tag{4.2}$$

where l_1 is the length of the first stage of lane, meter; and V_1 is the velocity of stationary passengers' motion on a horizontal lane in the first stage, m/s (determined in Table 1.1 depending on density D).

The density of stationary passengers' motion in the first stage of lane D_1 is found by using the following formula:

$$D_1 = \frac{N_1 f}{l_1 \delta_1}, \tag{4.3}$$

where N_1 – the number of passengers in the first stage; δ_1 – width of lane in the first stage of lst lane, m; f – average area of iconography of man, m^2/persons:

- adult man without an outerwear – 0.1;
- adult man in outerwear – 0.125;
- teenager – 0.07.

The velocity of stationary passengers' motion in the stages of way (V_1) after the first stage (Table 4.1) depends on the intensity of stationary passengers' motion in each of these stages of way and is calculated for all stages of way, including hatches:

$$q_i = \frac{N_{i-1}\delta_{i-1}}{\delta_i}, \tag{4.4}$$

where δ_i, δ_{i-1} are width of stage i and previous stage $i - 1$, m; and q_i, q_{i-1} are intensity of stationary passengers' motion in stage i and in previous stage $i - 1$, m/min; [the intensity of stationary passengers' motion in the first stage $q = q_{i-1}$ is determined in a Table 4.1 by value D_1, see (4.3)].

If the value of q_i determined by Formula (4.4), is less or equal to $q_{\max}$, then the time of motion in stage t_i (min) is equal to

$$t_i = \frac{l_i}{v_i}, \tag{4.5}$$

whereby values of $q_{\max}$ (m/s) are specified equal:

16.5 – for evacuation lanes;

19.6 – for openings;

11.0 – for inflatable ladders.

If value of q_i determined by Formula (4.4) is bigger than $q_{\max}$, then it is necessary to increase the value of the width of this lane δ_i, until the terms are met:

$$q_i \le q_{\max}. \tag{4.6}$$

The intensity and velocity of stationary passengers' motion in stage i are determined in Table 4.1 at value D = 0.9 and more.

Table 4.1

The intensity and velocity of stationary passengers' motion during evacuation depending on flow density

Flow density D, m^2/m^2	Escape Route		Opening, intensity of q, m/min
	Velocity v, m/min.	Intensity of q, m/min.	
0.01	100	1.0	1.0
0.05	100	5.0	5.0
0.10	80	8.0	8.7
0.20	60	12.0	13.4
0.30	47	14.1	16.5
0.40	40	16.0	18.4
0.50	33	16.5	19.6
0.60	28	16.3	19.05
0.70	23	16.1	18.5
0.80	19	15.2	17.3
0.90 and more	15	13.5	8.5

Note: The intensity of motion through an opening at fluency 0.9 and more, is equal to 8.5 m/min, and is specified for an opening width of 1.6 m and more. If the opening width is less, the intensity of motion is determined with Formula $q = 2.5 + 3.75\delta$.

At the beginning of stage i the intensity of stationary passengers' motion q_i (m/ min) is found by formula

$$q_i = \frac{\sum q_{i-1}\delta_{i-1}}{\delta_i}, \tag{4.7}$$

where q_{i-1} – intensity of stationary passengers' motion on, meeting at the beginning of stage i, m/min; δ_{i-1} – width of lanes in stages of confluence, m; δ_i – width of lane in the examined stage, m.

Similarly the time of passengers' run-up is evaluated to escape to the nearest exit:

$$T_{\text{tm.r-p.ev.}} = \frac{L_{\text{av.d.ar.ex}}}{V_{\text{cr.ex}}}. \tag{4.8}$$

The required passengers' run-up time for evacuation can be added to the total evacuation time only in the case when the carrying capacity of all exits is larger than the velocity of passengers' movement in the cabin. In accordance with the requirements of ICAO, the equation has to be used that specifies the required time for passengers to escape off the airplane:

$$T_{\text{tm.ev.}} \cdot 2K = 90 \text{ s}, \tag{4.9}$$

where K is the coefficient that specifies the passengers' motion to the exits on one side of the airplane.

The chart of evacuation lane route indicates how each passenger can reach the certain exit. This evacuation chart must be easy to vision. Every exit has to ensure a equal work-load. That increases the probability of passengers' survival at impact loads resulting from the accident.

5. ESTIMATION OF PRODUCED SURVIVE OF PASSENGERS GK METHODOLOGY APPROBATION

The organization of emergency and rescue work in aviation is a strictly regulated modern aviation sub-sector. An emergency plan must be drawn up at each airport, setting out the means and means of dealing with the consequences of accidents. This plan must include instructions on the measures to be taken in the event of an emergency and which include periodic inspections. The plan must provide for the procedures for the elimination of any possible consequences of the accident, as well as define the persons whose job responsibilities will be to be familiar with these procedures and to perform their duties promptly in the relevant situation. The following Latvian air traffic and airport officials may declare an emergency situation at the airport:

- Latvian air traffic tower dispatcher;
- ART operational manager;
- FT shift chief;
- Head of Fire and Crisis Management / FT Chief;
- Chairman of the Airport Board.Katras ārkārtas situācijas sadaļā ir norādītas tās amatpersonas – iniciatori, kas ir tiesīgi izziņot konkrēto ārkārtas situāciju.

One of the main objectives in training the flight crew to operate in an emergency is to teach flight attendants to quickly recognize the occurrence of an emergency, to control the occurrence of such conditions and to identify other hazardous situations that may arise as a result of their chosen operation and to take the necessary due to an emergency. The pilot-in-command of an aircraft is responsible for carrying out the prescribed operating procedures in an emergency. In aircraft rescue operations, more emphasis is placed on rescue than on firefighting**.** The most important rule is to fight only those fires that interfere with rescue. Structural firefighting, protective clothing provides protection against the very high temperatures caused by the combustion of aviation fuel. In the Republic of Latvia, all AV operators perform training evacuation from their AV during the certification process. Irrespective of the principal place of business, an emergency plan shall be drawn up to provide assistance to victims and their relatives in the event of an accident to any of the aircraft of the aircraft operator.

Assess and determine whether airport firefighting with a nozzle can control the further spread of flame and temperature.

Four delete positions are used in the delete tests.

1. Erase in a straight line from the lowest position. The liquid is delivered about a meter above the ground by moving the nozzle to the right or left.
2. Extinguish in a straight line with an extended handle so that rescuers are at a safe distance. The liquid is delivered directly to the fire site by moving the nozzle to the right or left.

3. Erasing from the maximum height with the shaft fully extended. The nozzle is raised as high as possible above the fire site, supplying the liquid directly to the fire, moving it to the right or left. This method is called the rain method.
4. Fuselage piercing position. The liquid is supplied through the nozzle directly inside the fuselage. The effectiveness of each method is evaluated by the extinguishing time until 90% of the fire is extinguished, which means that the combustion in the main area is eliminated, but there are still a few insignificant flames.

It took an average of 27 seconds to eliminate 90 % of the fire in an area of 730 square meters using a pull-out tower at the maximum low position, using a roof-mounted barrel – 51 seconds. When using only foam with a pull-out nozzle, the average time required was 38 seconds, but with a roof-mounted barrel – 51 seconds. So the tower extinguished the fire 25 % faster in the case when the task was to eliminate 90 %. Using only foam to 100 % fire eliminate the tower took an average of 65 seconds and 541 gallons. At the same time, the roof-mounted system required more than 1000 gallons in two attempts, and one fire failed. Using both foam and powder, both systems extinguished all fires. After clearing 90 %, the average time of the tower is 23 seconds, for the roof system – 25 seconds. When 100 % cleared, it took 30 seconds for the tower and 34 seconds for the roof system.

The faster extinguishing time was facilitated by the fact that the tower had access to places where the roof system was unable to do so, thus using liquids and chemicals more efficiently.

AV B737-300, B767-300 critical area calculation (airBaltic)

“Critical area” is a term used to rescue AV passengers and crew. It differs from other concepts in that, instead of limiting and extinguishing the whole fire, it requires limiting only the area of the fire adjacent to the fuselage. The aim is to preserve the intact fuselage and provide durable conditions for AV passengers and crew. The size of the restricted area required to achieve the defined objective for a particular aircraft has been determined experimentally.

The theoretical critical area is a rectangle, one dimension being the total length of the aircraft and the other the length varying according to the length and width of the fuselage. Experiments have shown that AV with a fuselage length of 20 m or more at a wind speed of 16-19 km / h and blowing at right angles to the fuselage has a theoretical critical area of 24 m from the fuselage to the wind and 6 m from the wind. to the wind. For smaller AVs, the corresponding length is 6 m on both sides. However, a transition is used to provide for a gradual increase of the theoretical critical area for fuselage lengths of 12 m to 18 m. Table 5.1

Table 5.1

Theoretical critical area AV

Total lengh	Theoretical critical area A_T
$L < 12$ m	$L \times (12\text{ m} + W)$
12 m $< L <$ 18 m	$L \times (14\text{ m} + W)$
18 m $< L <$ 24 m	$L \times (17\text{ m} + W)$
$L > 24$ m	$L \times (30\text{ m} + W)$,

where L – total length of the aircraft; W – aircraft fuselage width.

In the dissertation, the calculation of the time required for evacuation has been performed for the development of a particularly dangerous fire. In the case under consideration, fire is characterized by an increase in the rate of the hazard factor.

Based on the above, a scheme of the considered method has been developed. In the case of emergency, in order to effectively use the means for passenger evacuation, evacuation options are important, depending on the number of emergency exits, the time required to prepare them for work, etc. Therefore, it is necessary to find out the number of main and additional emergency exits and their location in the specific type of AV and to show them schematically - to find out the technical characteristics, possibilities of use, the type of main and additional emergency exits. It is assumed that passengers will be evenly distributed across the emergency exits.

The calculation of the required evacuation time has been performed for the most dangerous fire development variant, which is characterized by rapidly increasing fire hazard factors. First, the critical duration of a fire is calculated by reaching the permissible limit for each hazardous fire factor in the area where people are present:

- after increasing temperature;
- after loss of vision;
- after a decrease in oxygen content;
- after combustion of each gaseous product.

The airtight fuselage cabin has two entrance doors for passengers and crew, two service doors, two hatches for luggage-cargo bays, as well as hatches for technical compartments. The compartments for the main support chassis and the front chassis support close with shutters. The front passenger and crew entrance doors, cargo bay hatches and technical hatch covers may be closed from the outside with individual aircraft keys.

The arrangement of passenger cabin of some referenced type of emergency airplane is shown on Fig. 5.1

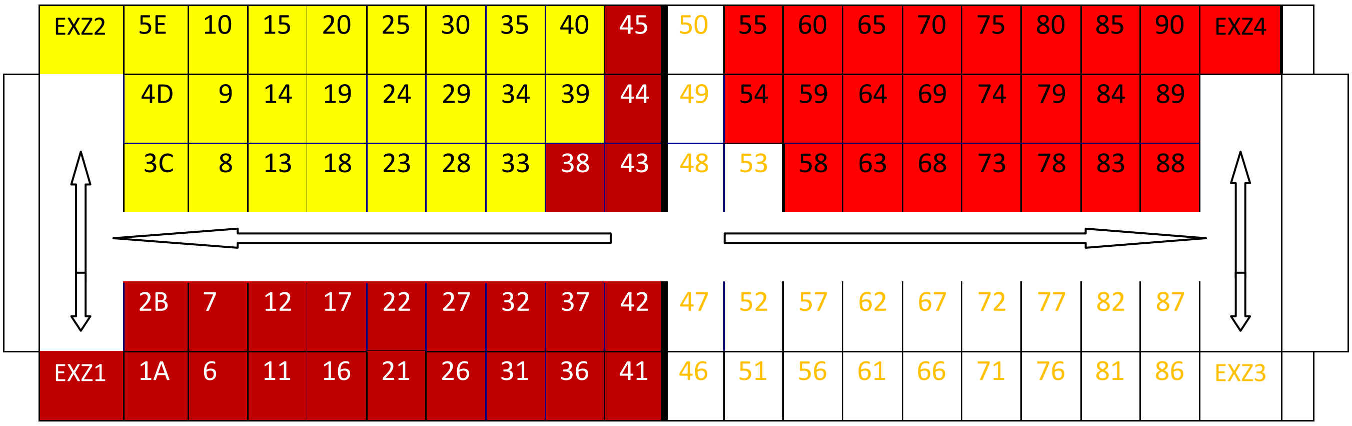


Fig. 5.1. Chart of a passenger cabin of the referenced type of airplane.

🟥 – EX1 and arm-chairs assigned to it; 🟧 – EX3 and arm-chairs assigned to it;
🟨 – EX2 and arm-chairs assigned to it; 🟥 – EX4 and arm-chairs assigned to it.

The calculation of required evacuation time is done for the most dangerous case of fire spreading, which is specified by the fastest rate of spreading of dangerous fire factors. Let us determine geometrical distances:

- width of an arm-chair;
- spacing of arm-chairs;
- half of the width of an aisle in passenger cabin.

So, the escape distance is equal to the width of an arm-chair + half of the width of an aisle + spacing of an arm-chair (length of aisle) + EX.

Conditions:

- An airplane is in normal position, landing gear down, wheels out.
- Typical composition of passengers with normal health:
  - 60 % men;
  - 30 % women;
  - 5 % people older than 60 with the proportional number of women;
  - 5 % children under 12.

It is possible, to calculate the escape time of passengers. The results of calculation are shown in Table 5.1.

Table 5.1

Escape time to EXIT

Seat No.	Time, s	Seat No.	Time, s
E-45	13.6	E-50	13.6

So we take into account the maximal time of escaping – 13.6 s.

To accurately determine the time of evacuation of passengers, it is necessary to have the values of the speeds of independent and non-independent leaving the aircraft by two evacuation routes, as well as the dimensions of the passenger cabin, indicating the main and emergency exits. Then, using the above formulas, the evacuation time is determined for the simulated emergency conditions on the aircraft and for the rescue operation. The total evacuation time will depend on the selected evacuation method: through a door with inflatable ladders, through a door with fabric gutters, through hatches with ropes, etc.

In all cases, it is necessary to determine the capacity of emergency exits (the average rate of evacuation from the aircraft by one person through each of the emergency exits separately). The time of preparation of hatches, chutes, inflatable ladders for evacuation of passengers will also be of great importance.

The calculation results show that the type of a short-haul aircraft with a margin met the estimated time, and confirm that in the event of an emergency landing, all passengers of the liner and crew members will have time to leave the aircraft within 67.5 seconds before a possible fire breaks out $5 \cdot 13.6 = 68$ s.

Thus, the average value of the travel time of the passenger in the cabin was obtained. However, in this calculation there is no variance (spread) of the random value of the travel time, which can lead to a significant change in the required evacuation time. In fact, with a large spread of travel time, the required time value may be less, with a small or even moderate spread of time. For example, the evacuation of passengers of the same physical type - only men of the same size and age, groups of schoolchildren of the same age, tourists of retirement age, etc. will be more uniform in evacuation time than with a mixed grouping.

CONCLUSIONS

1. On the basis of an analysis of the situation in the airport area, the survival of passengers (how long passengers can always be in a burning aircraft) in T_R and emergency sleepers should be assessed. When modeling a fire in an aircraft cabin, methodically and mathematically evaluate the effectiveness of emergency and rescue activity.
2. Mathematical modeling, which allows to identify the values of T_R and T_P in different development scenarios, makes it possible to identify and compare the dynamics of the development of critical conditions in the cabin of a burning aircraft. In order to quantify the critical level in the cabin of a burning aircraft, there are many fire risk factors, so it is necessary to evaluate a complex criterion that contains two factors: toxic – K_{KV} and temperature – K_T. The factor K_{KV} shows the toxic dose of toxic substances released into the combustible cabin of an aircraft. Coefficient K_T – temperature dose. The dissertation evaluates the time required for passenger evacuation from a burning cabin.
3. Assuming that a person receives a toxic dose of toxic substances in a AV cabin fire from four combustion products – carbon monoxide (CO), carbon dioxide (CO_2), hydrogen chloride (HCL) and hydrogen cyanide (HCN) – the total complex factor K_{KV} is obtained, which characterizes the dose of toxic substances in the passanger cabin during fire, which consists of four factors, characterizing the effects of each of carbon dioxide, carbon dioxide, chlorine and hydrogen cyanide separately, respectively.
4. The analysis of the accident investigation practice shows that within the limits of this study, the numerical value of the critical condition coefficient in the cabin of a burning aircraft can be determined by means of an experimental calculation method.
5. The proposed model makes it possible to assess the risk of death of passengers in fire situations. Such a task may be faced by experts and insurance organizations, as well as airline owners, in order to assess the level of danger (data on the consequences of accidents, the number of victims, economic losses) and to set up an insurance fund to cover the families of victims.
6. Analysis of existing models, estimating the time of passenger evacuation from a burning aircraft, demonstrate that the passenger AV can use a simplified analytical model that summarizes the peculiarities of possible accident scenarios by evaluating the existing data in a theoretical experimental way.
7. The approbation of the specific model showed that the time required to leave the crashed aircraft (medium-range type as SSJ-100) in the scenarios presented by the airport management services complies with the ICAO standard (90 s) or is close to it. This confirms that in the event of an emergency landing, all liner passengers and crew members will be able to leave the aircraft until critical conditions occur in the cabin of the aircraft.