EVALUATION OF AIRCRAFT PASSENGER CABIN FIRE SAFETY AND MEASURES FOR IMPROVEMENT

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ABSTRACT*: This research has been carried out on aircraft passenger cabin fire safety problem. The pathways of decreasing the fire danger are considered. The algorithm of fire safety implementation was presented. Risk management would decrease the state of danger in the cabin as the subject of the research, therefore, increase the safety to the maximum level available today.*
KEYWORDS: *Aviation incident and/or accident, fireproof structural and decoration materials, fire safety, fire risk, fire dangerous stress/load, passenger cabin fire danger decrease.*

1. General

Ensuring safety of any object requires ability to employ methods and practices of protection against dangers in force. Hence why analysing fire safety problems it is necessary to evaluate two terms: Danger and Safety. Both of them are interconnected by the term of Risk. Thus a linkage between interconnected events Danger - Risk - Safety is established, where the most questionable term is the Risk. Here is the most popular definition: Risk – a probable danger of any failure caused by actions undertaken, also, the actions as they are if leading to failure of the results anticipated. From the middle of the XX century one of the risks on air transport had become the fire risk. It is often possible to make forced landing after fire is emerged on board yet the conditions for passengers in the cabin remain sustained at safe levels. However such cases have collateral victims who lose their lives after landing because of flame and smoke penetrated into cabin. The fires in cabins and under their floors generate extreme stress factors and along the delay of the crew actions may lead to a catastrophe.
Forecasted by ICAO yearly world increase of pax transportation volume by 4-7% meanwhile the safety remaining at the same level will lead to yearly 4% increase of deaths caused by fires.[1]
According to statistics around 75% of air accidents happen at take-off, landing and approach stages of flight, i.e. within airport vicinity and one of the major causes of human deaths is emergency aftermath fires.

2. Aircraft passenger cabin fire risk levels

The epicentres of fire in an aircraft might be:

- Aero engine
- Fuel system
- Electric power network
- Passenger cabin
- Crew cockpit
- Service compartments - cargo/baggage, technical/crew

Fires inside cabins are related to fires in confined spaces. They feature high density smokes, small burning spots, great gradient of temperatures along the cabin height, low temperature of fire (comparing with external fires), also, great concentration of highly toxic substances in burning products. Burning may start as a result of reckless care to fires, short cuts in electrical wiring of an aircraft, carrying flammable substances and materials by passengers and other causes.

In the table below are shares of fires on aircraft structural elements. [2]

Nr	Types of fires on aircrafts	Share of totals
1	Fires on fuel spills/leaks located on one and both sides of a/c	55%
2	Fires and burnings on power plants	25%
3	Fires and burnings inside passenger cabins	12%
4	Fires and burnings on landing gears	5-6%
5	Other fires and burnings	2-3%

The results of a series of fire tests prove that one of the major causes of heavy injuries made to human beings in passenger cabin fires of aircrafts [3] are intoxications with fully or partially burned fire products. The results of analysis made on air samples taken during fire tests indicated that after 2-3 minutes from the start of a flamed burning lethal concentration levels reached:

- Carbon oxide
- Hydrocyanic/Prussic Acid
- Acronitryl
- other toxic substances.

By the 3rd minute of burning the oxygen concentration decreased to 6%, and the carbon concentration rose up to 12% per volume. Concentration like that is lethal to human beings.
Up to 40% of passengers' deaths happen due to their intoxication by toxic products of burning decoration materials in cabins, thermal traumas and evacuation procedure problems. The heavy consequences concerned (including those with losses of humans) determine the problem actuality and therefore require effective measures to enhance fire safety of passengers on air transport.

The major fac5-tors of danger during fires inside passenger cabins are:

- great speed of fire propagation and high temperature of flame;
- quick accumulation of burning toxic products and loss of visibility;
- situational panic.

At fires inside cabins the temperature along height rises rapidly. The tests showed the temperature at floor level may remain at 50°C while can reach 250°C at 1.30..1.50 metres above the floor.
The burning occurs on the surfaces of walls, ceiling, passenger armchairs, however may also take place in the cabins' volume due to burning drops of molten plastics flowing down from passenger cabin and cockpit decorations and structures. When fire gets through the cabin walls to the core structures (stringers, bulkheads and the skin) the temperature in the cabin top rapidly increases (up to 900°C) and open flames spread. Very high temperature can melt and start burning of some types of passenger armchairs made with magnesium alloys. That would hinder and compromise killing the fire.

As soon as at fires inside passenger cabins the factors of danger increase rapidly and the conditions become ultimately fatal it is utterly vital to evacuate human beings in a fast and safe manner.
Taking into account the safety of evacuation process as the major condition the evaluation of fire risk is verified.
The factors of fire danger inside the passenger cabins are the following:

- presence of fire sources;
- massive fire load;
- limitations of evacuation feasibility;
- absence of smoke removal system;
- high concentration of human bodies across the volume.

At present various polymer materials are widely used in decoration of cockpits, passenger cabins and cargo compartments of modern aircraft designs. At start of a fire all of them burn easily and produce great amount of heat and noxious fumes. These are the main reasons of deaths there.
The amount of fire load in structural and decorative polymer materials in passenger cabins may comprise about 2 to 3.5 metric tons, which in case of a fire would become not only a source of air contamination, but also the carriers of toxic volatile compounds.[4]
Great volumes of fire prone polymer materials used for decoration and trim in modern aircraft designs are determining to the fire risks, thus creating the requirement to apply thermally stabile compounds.[5-6]
Introduction of fire safe materials to aircraft interiors should extend the time period of the so called "safe" evacuation of humans from 2…4 minutes at present till 10 minutes.

3 *Aircraft passenger cabin fire safety improvement directions.*

Evaluation of aircraft passenger cabin fire safety level greatly depends on calculation of the fire risk. This is a process of complex calculation which is based on accounting of the evacuation time, floorplan, dangers and fire risks, protective equipment available.

The risk determinating methodical approaches are the following:

- direct assessment based on data processing;
- model analysis, setting various events' probabilities' interconnection;
- technical analysis.

In order to perform the fire risk analysis the collection of aircraft specification data is required. It would encompass:

- specific design features;
- thermo-physical characteristics of the materials used for furnishes, structures, equipment mountings;
- types, quantities and disposition of fire prone substances and materials;
- number and probable locations of humans;
- fire protection, aural warning systems and evacuation control.

At the same time into account are being taken the below mentioned factors:

- possible fire progression dynamics;
- composition and characteristics of the fire protection system;
- possible effect of the fire on human beings and structures.

The frequency of actual fire situations equals the number of fires happened on the protected facility during a yearly period. The evaluation of frequency parameters of possible fire events could be performed upon statistical data.[8]

A risk of a fire is deemed as acceptable when:

$$Q_B \le Q_B^H,$$

where Q_B^H *– is a normalised value of a fire risk, which is set as one of a million per calendar year, i.e.* $Q_B^H=10^{-6}$ *year* $^{-1}$*; and where* Q_B *– calculated value of a fire risk.*

A fire risk calculated value could be found as a maximum value of the fire scenarios considered:

$$Q_B=\max\{Q_{B,1},...Q_{B,i}...\ Q_{B,N}\},$$

where $Q_{B,i}$ *– calculated value of a fire risk for the i-th scenario, N – number of fire scenarios considered.*
The fire scenario is deemed as a variant of a fire progression taking into account the place of it's start and character of it's development, when the worst conditions for human beings take place.[10]

A fire risk calculated value for the *i-th* scenario is found in accordance with the formula:

$$Q_{B,i}= Q_{n,i} *(1-K_{an,i})*P_{np,i} * (1-P_{Э,i}) *(1-K_{n,э,i}),$$

where $Q_{n,i}$ *– a fire events' frequency per year period is found using statistical data. When statistics are not available it is allowed to use as* $Q_n = 4\cdot10^{-2}$*;*
$K_{an,i}$ *– a coefficient for automatic fire extinguishing equipment. It is allowed as* $K_{an,i}=0,9$ *because in this particular case it is not necessary;*
$P_{np,i}$ *– a probability of human presence in the aircraft, found from the proportion* $P_{np,i} = t_{функц,i}/24$*, where* $t_{функц,i}$ *– a time period of human presence in the aircraft, in minutes;*
$P_{э,i}$ *– a probability of evacuation for passengers;*
$K_{п.з,i}$ *– a coefficient for automatic fire protection equipment which is used for safe evacuation of humans at fire is in accordance with legal requirements.*

The probability of evacuation is calculated as per following formula [9]:

$$P_э = \begin{cases} \dfrac{0{,}8t_{бл} - t_р}{t_{нэ}}, \text{ если } t_р < 0{,}8t_{бл} < t_р + t_{нэ} \text{ и } t_{ск} \le 6 \text{ мин;} \\ 0{,}999, \quad \text{если } t_р + t_{нэ} \le 0{,}8t_{бл} \text{ и } t_{ск} \le 6 \text{ мин;} \\ 0{,}000, \quad \text{если } t_р \ge 0{,}8t_{бл} \text{ или } t_{ск} > 6 \text{ мин;} \end{cases}$$

where $t_р$ *– calculated time for evacuation, in minutes;*
$t_{нэ}$ *- time period of evacuation since the beginning of the fire, in minutes;*
$t_{бл}$ *- time period since the beginning of the fire till the exits become blocked due to fire dangerous factors with the ultimate tolerable values come into force, in minutes;*
$t_{ск}$ *– time period when humans are blocking the evacuation paths (human flow density in the evacuation paths is above 0.5 value), in minutes;*

Blocked exits time period $t_{бл}$ is found by calculating the time till fire dangerous factors reach the ultimate tolerable values in the paths of evacuation at different moments of time.

The coefficient for automatic fire protection equipment which is used for safe evacuation of humans at fire is in accordance with legal requirements $K_{п.з.}$ can be found by the following formula:

$$K_{п.з} = 1-(1- K_{обн}* K_{СОУЭ}) *(1- K_{обн}* K_{ПДЗ}),$$

where $K_{обн}$ *- a coefficient for automatic fire protection equipment which is used for safe evacuation of humans at fire is in accordance with legal requirements;*
$K_{СОУЭ}$ *- a coefficient for fire warning and evacuation control systems are in accordance with legal requirements*;
$K_{ПДЗ}$ *- a coefficient for smoke expelling system is in accordance with legal requirements.* [9]

Conclusions

The analysis accomplished here has shown that the average value of a fire risk could be calculated if based on the fire scenario modelling. The risk of a fire is calculated for the specific aircraft design, either existing or proposed, and also for the specific conditions of the accident followed by a fire. The risk of a fire is as required and is not higher than one of a million per year period even while a human being is located as far as possible from the cabin exit point.

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