Aircraft’s risks modelling on visual piloting stage

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Abstract. In accordance with ICAO strategy, which aims to improve the safety of air transportation around the world, the key task of aircraft flight safety management during the visual flight stage is to identify and assess the risks that can be realized for various random reasons. Visual piloting stage is one of the most important part of aircraft’s flight, because the risks of realizations of “human factor” reach maximum values, especially in bad weather conditions or because of realizations of another hazards. Risks during aircraft’s flight must be manged by every company-participant of aviation-transport system, including aerodromes. The developed logical-probabilistic models make it possible to determine the most probable risks at the final stage of the approach, during landing, run on the runway and take-off under low visibility conditions, to make their subsequent assessment and assess the level of risk for each aerodrome, as well as, if necessary, to develop a set of measures to reduce them.

1. Introduction

The main task in aviation area facing countries around the world in accordance with ICAO Standards and Recommended Practices [1-4] is to develop and implement the Safety Management Systems for all levels of the aviation transport system. The development and effective operation of the Aerodrome Safety Management System will minimize risks to an acceptable level and keep them at this level for a long time. The problem of aviation risks estimation and assessment is one of the topical problems, which requires new modern scientific approaches. Mostly scientists concentrate their efforts on creation of risks identification and prognostication models [5-9].

Proactive and predictive approaches to flight safety management imply the identification of threats with the subsequent assessment of the probability of incidents and accidents due to them.

Researches show that most of the accident occurs at the stage of visual piloting of the aircraft, although this stage takes the minimum amount of time for the entire flight (Fig.1), [10].

It is clear from Fig. 1 that percantage of fatal accidents during taxiing and takeoff is not less then 12% and during final approach and landing is about 36%. Meangwhile the time spent for these stages is about 5% of the whole 1,5 hour flight.

These evidences indicate that the visual piloting phase is the most dangerous phase of the aircraft flight, at which the maximum number of threats can potentially be realized [11]. These threats come from various sources, both from the imperfections of the systems themselves and from the external environment. For effective safety management at this stage, it is necessary to take into account the most probable threats and the conditions in which they can be realized. This will allow to identify and assess the risk in the implementation of one or more threats and, possibly, prevent them.

Risks should be assessed by all parties involved in the technological process - on the part of the airline (the risks of failures associated with aircraft and improper actions of the crew), the organization of air traffic control (risks connected with failures of corresponding equipment, “human factor” etc) and the aerodrome (activity of ll aerodrome services – failures if equipment, “human factor” etc - which provide the aircrafts’ operations). In addition, there are threats from the environment, which must be taken into account, since this is an objective reality in which technological operations are carried out.

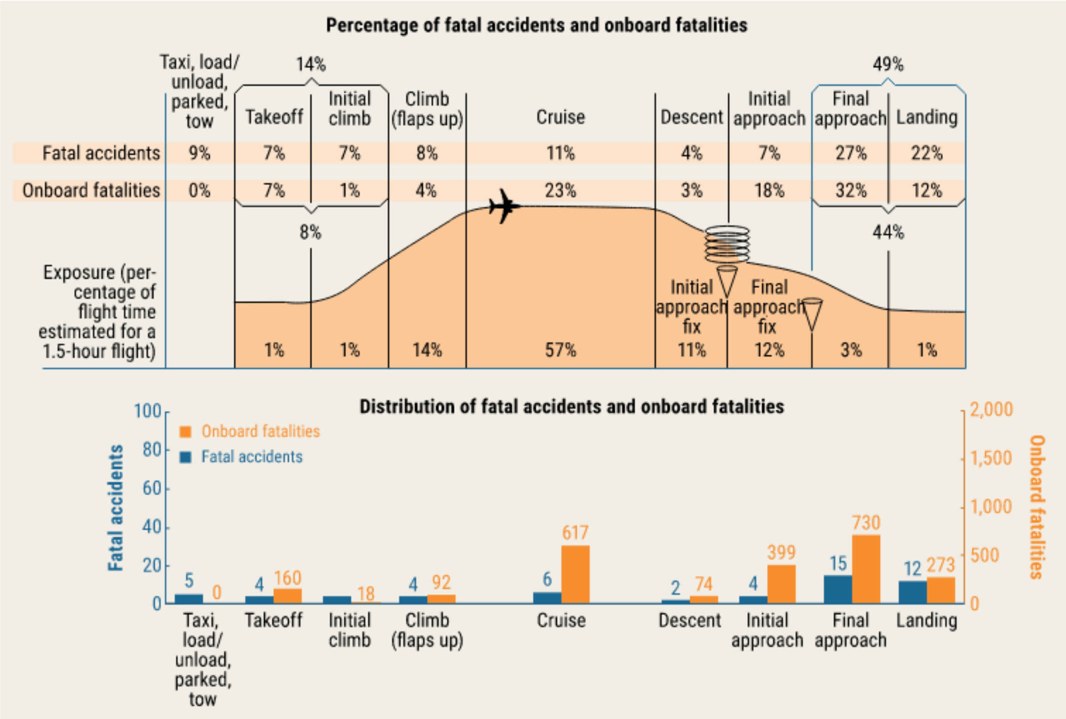

Figure 1. Percentage of accidents/fatalities during the flight *Source: Boeing Commercial Airplanes.*

Hazards identification and risk assessment activities should be provided both individually by every participant and jointly.

The mathematical approach to risks of the aircraft during the visual piloting stage evaluation and assessment is proposed in this report.

2. Materials and Methods

2.1. Rational and method explanation.

For aircraft’s risks modelling on the visual piloting stage the logic-probabilistic method (FTA – fault trees analysis) was applied. This method is widely used for risks assessments in different areas, including aviation, [12]. The main idea of this method is that potential hazards are considered as faults in the system, there certain combination may finally lead to the dangerous result (incident or accident). Hazards are random events; thus, the accuracy of the results is highly dependent on the accuracy of the initial data.

The research approach was as follows:

- The visual piloting stage was divided by local stages, such final approach stage and landing and takeoff in low visibility conditions.
- Every stage was analyzed from the point of view of what are the participants of the process and what are the most possible hazards, which may create risks for the aircraft.

- For each stage the logical scenario of risks realizations was created.
- All possible hazards were presented as initial data, classified and coded in special way.
- For each logical scenario the FTA method was applied thus the local FTA-models where obtained.
- Using these models, it is possible to calculate risks for each scenario of each stage of aircraft's flight during the visual piloting [13].

These scenarios are logical models of the visual piloting phase, which take into account most possible hazards that can be realized from the aerodrome side, environmental factors [14], taking into account certain hazards that can be realized by the pilot and various aircraft's systems.

The initial data are classified based on their sources of origin (Fig. 2).

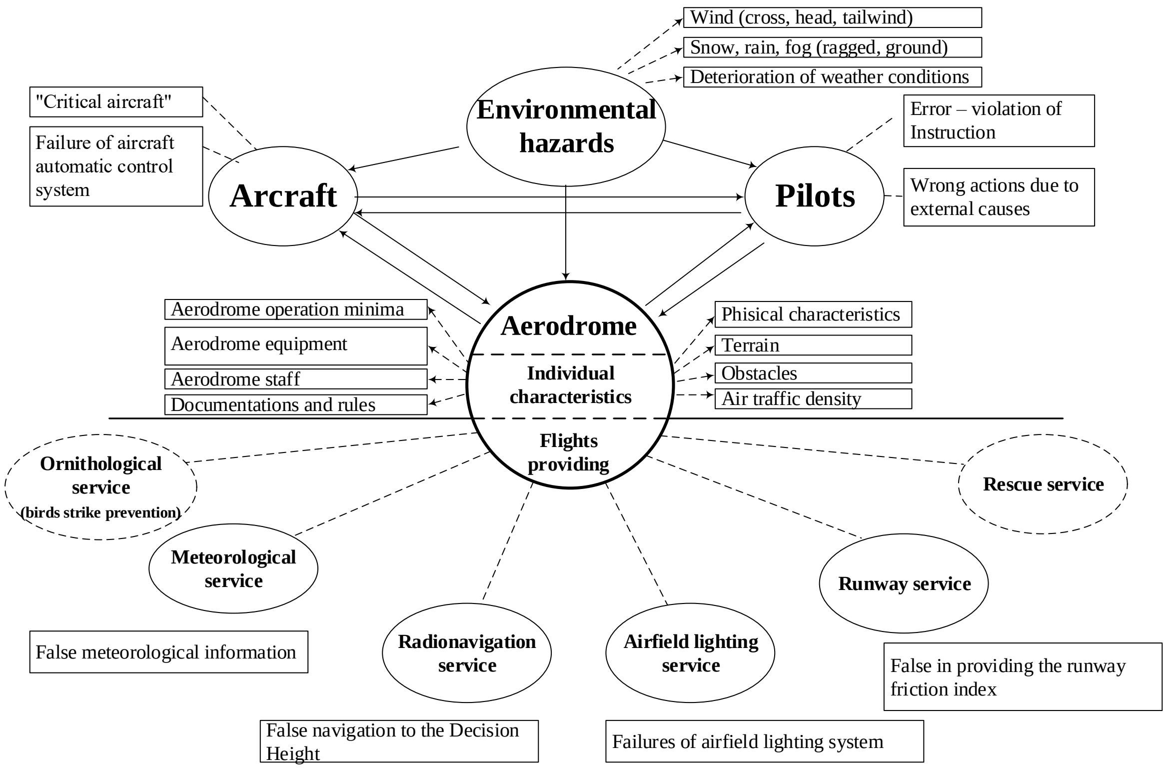

Figure 2. Most probable hazards in the aerodrome, taking place in the modeling.

2.2. The classification of most probable hazards is as follows:

2.2.1. Environmental hazards - Z_1:

- frequency of strong crosswinds - z_{11};
- frequency of heavy rain, snow - z_{12};
- frequency of ground fog - z_{13};
- frequency of meteorological conditions corresponding to the I category - z_{14};
- frequency of meteorological conditions corresponding to low values of visibility for takeoff - z_{15};
- frequency of deterioration of meteorological conditions - z_{16}.

$$Z_1 = f(z_{11}, z_{12}, z_{13}, z_{14}, z_{15}, z_{16}).$$

2.2.2. Hazards associated with aircraft system failures - Z_2:

• frequency of failure of the automatic control system of the aircraft, which is to violate the accuracy of the approach to the landing of the aircraft in automatic or direct modes - z_{21};

• frequency of failure of various aircraft systems due to which the aircraft requires mandatory landing at the aerodrome ("critical aircraft") - z_{22}.

• aircraft which takeoff speed is more then V_1- z_{23}.

$$Z_2 = f\,(z_{21}, z_{22}, z_{23}).$$

2.2.3. Hazards associated with errors of the pilot (crew) of the aircraft– Z_3:

• frequency of aircraft's pilot error, type "violation of the Instruction" - z_{31};

• frequency of aircraft's pilot error, type "wrong actions/ inaction in certain circumstances" - z_{32}.

$$Z_3 = f\,(z_{31}, z_{32}).$$

2.2.4. Hazards associated with failures of aerodrome meteorological equipment - Z_4:

• frequency of providing incorrect information about the value of runway visual range (RVR) - z_{41}.

$$Z_4 = f(z_{41})$$

2.2.5. Hazards associated with failures of aeronautical radio equipment for precision approach – Z_5:

•frequency of reducing the accuracy of the aircrafts navigation during the approach to the Decision height) – z_{51}.

$$Z_5 = f(z_{51})$$

2.2.6. Hazards associated with failures of various subsystems of the aerodrome lighting system - Z_6:

• frequency of failure of the approach lights, type "there is information about the failure" or use "nil facility" of approach lights - z_{61};

• frequency of failure of the approach lights type "no information about the failure" - z_{62};

• frequency of failures of the runway lights type "no information about the failure" - z_{63};

• frequency of failure of runway edge lights or center line lights type "no information about the failure" - z_{64};

• frequency of failure of the runway lights - z_{65};

• frequency of failures of runway end lights - z_{66};

$$Z_6 = f\,(z_{61}, z_{62}, z_{63}, z_{64}, z_{65}, z_{66})$$

2.2.7. Hazards associated with the professional activities of the runway service aviation staff - Z_7:

• frequency of the event when the runway friction coefficient does not correspond to the nominal value - z_{71};

• frequency of the event when there are foreign objects on the runway surface that may threaten aircraft's safety - z_{72}.

$$Z_7 = f\,(z_{71}, z_{72})$$

2.2.8. Hazards associated with the professional activities of the rescue service aviation staff – Z_8:

• frequency of adverse events that cause the impossibility of preventing the accident that occurred with the aircraft in a fatal accident (crash), for example, lack of foam to extinguish the fire, unpreparedness of aviation staff, etc.) - z81;

$$Z_8 = f\,(z_{81}).$$

3. Scenario of incident/accident and their FTA-models

3.1. Scenario which creates risk during the approach, and is characterized by the following events -

the aircraft is in a rectangle of accuracy near the Decision Height, the following hazards were implemented:

1. Environmental factors (snow, rain) or the failure of the meteorological system, or the failure of the approach lights "there is information about the failure" or the use of lighting system in “nil facilities” of approach lights.

2. Error of the pilot of the aircraft type "violation of the Instruction" - descent below Decision Height in order to establish visual contact.

3. Establishing false visual contact below H_{MAPt} (missed approach point) due to environmental factors (surface fog) or failure of runway lights.

4. 1. Incorrect actions of the pilot during landing and run on the runway.

5. 1. Landing result – ACCIDENT, or

4.2. Correct actions of the pilot during landing and run on the runway.

5.2 Landing result – INCIDENT.

The example of the FTA-models, which describes one of the local scenarios, is presented in the Figure 3.

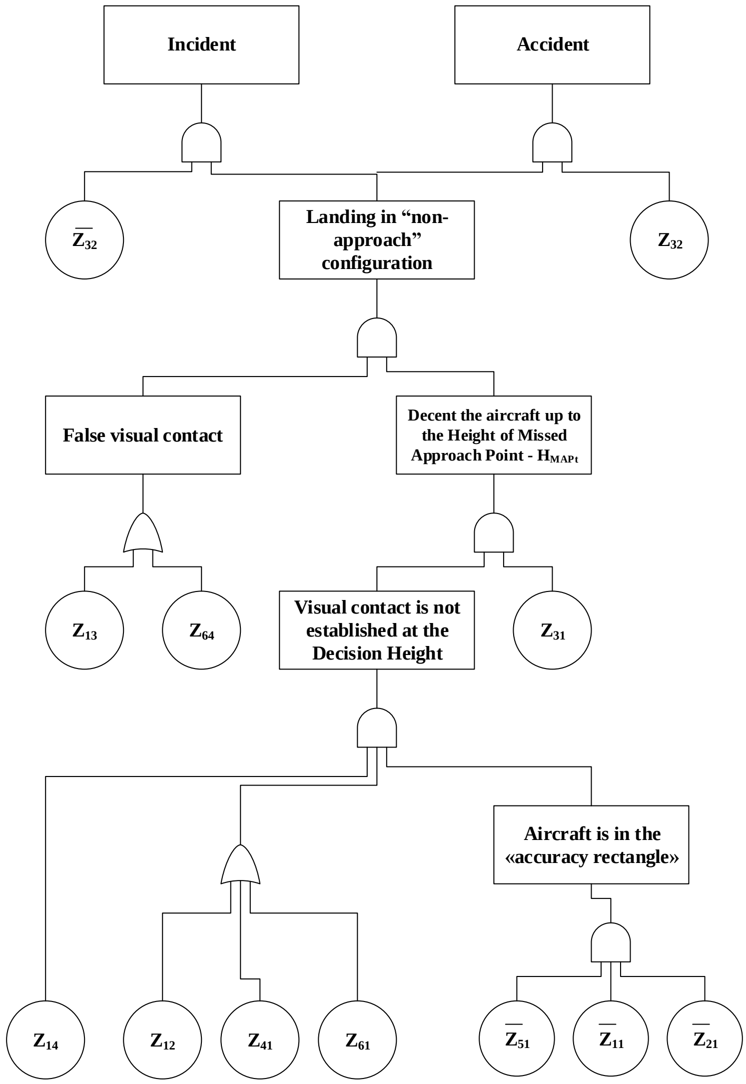

Figure 3. FTA-model of risk during aircraft’s approach in I category minima conditions.

This example describes two possible scenarios, which may take place during I category approach and landing.

Mathematical presentations, which describe this FTA-model are as follows:

$$R_{\mathrm{AC}} = \begin{vmatrix} z_{12} \\ z_{41} \\ z_{61} \end{vmatrix} z_{14} \begin{vmatrix} \bar{z}_{51} \\ \bar{z}_{11} \\ \bar{z}_{21} \end{vmatrix} z_{31} \begin{vmatrix} z_{13} \\ z_{64} \end{vmatrix} z_{32} \qquad R_{\mathrm{INC}} = \begin{vmatrix} z_{12} \\ z_{41} \\ z_{61} \end{vmatrix} z_{14} \begin{vmatrix} \bar{z}_{51} \\ \bar{z}_{11} \\ \bar{z}_{21} \end{vmatrix} z_{31} \begin{vmatrix} z_{13} \\ z_{64} \end{vmatrix} \bar{z}_{32}$$

When put the quantitative parameters of initial data (frequencies of hazards) it is possible to obtain the values of aircraft's accidents and incidents risks for described scenario.

Similar models are developed for all local scenarios that create the risk of an aviation accident or serious incident at the stage of visual piloting during approach and landing in the operation minima of I, II and IIIA categories (more than twenty FTA-models in total) and during low visibility takeoffs (four FTA-models in total).

3. Results

Using the developed models and substituting the initial data corresponding to the specific aerodrome it is possible to define the following:

- calculate and assess aviation accidents/incidents risks measures (safety performance indicators) provided by the aerodrome during some time or at specific period (for example, in winter, during reconstruction etc.);
- predict aviation accidents/incidents risks measures for future period of time;
- evaluate risks in case of partial failures of aerodrome equipment, which is used to provide the visual piloting phase of aircraft's flight;
- make the efficiency assessment of resources spent for safety.

Practical implementation of presented models will make possible to implement a predictive approach in Safety Management System at civil aviation aerodromes.

4. Discussion

In accordance with the requirements of ICAO documents [1,15], safety performance indicators may be both qualitatively or quantitatively. For qualitative presentation the matrix of risks is suggested, where risk index is presented as combination of probability and severity of consequences. Risk index is defined with method of experts' evaluation, which main disadvantage is subjectivity.

A qualitative representation of risks at the initial stages of Safety Management System implementation to determine lagging indicators is quite acceptable, however, the transition to proactive and predictive approaches requires the use of quantitative risk assessment methods for more accurate determination of leading indicators. The FTA-models may take into account most important individual characteristics of the aerodrome thus the risks evaluation will be more accurate and objective.

Conclusion

The perfect operation of Safety Management System of the civil aviation aerodrome is impossible without hazards definition and risks indicators estimation and assessment. The qualitive analysis is more preferable as far as it gives more accuracy and more potentials to realize proactive and prognostic approach to risks management.

Risks analysis on the basis of developed FTA-models may give the opportunity to asses future risks in the system, to estimate most significant measures, to evaluate the efficiency of organizational and technical actions directed on risks mitigation.

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