UNCERTAINTY AND DEPENDABILITY OF THE RISK MODEL APPLICABLE TO OPERATION OF AIRCRAFTS

NIEPEWNOŚĆ I WIARYGODNOŚĆ MODELU RYZYKA W EKSPLOATACJI STATKÓW POWIETRZNYCH

Jerzy Lewitowicz

Air Force Institute of Technology (ITWL)
e-mail: jerzy.lewitowicz@itwl.pl

Abstract: *The problem of risk appears as decisions are frequently made or must be made on the basis of results that are obtained for very scarce number of real cases, objects and short series. Therefore fundamentals for really crucial choices must be inferred from correlations that are burdened by a high degree of indeterminacy. On the other hand, risk should also be considered for such circumstances when assessments are performed under excessive certainty. This paper deals with a model of risk that is considered for the subsystem of aircraft maintenance and the subsystem of its operation where operational (flights) efficiency and safety of flights are the matters of crucial importance.*

Keywords: *risk, model of risk, maintenance*

Streszczenie: *Problem ryzyka wynika z tego, że często decyzje podejmowane są, lub muszą być podejmowane w oparciu o wyniki uzyskane dla małej liczby przypadków, obiektów, krótkich serii i bazują na korelacjach obarczonych dużym stopniem nieoznaczoności. Z drugiej strony ryzyko rozważane powinno być w sytuacjach przyjmowania ocen z nadmierną pewnością. Opisano model ryzyka rozważanego w podsystemie eksploatacji utrzymywania zdolności statku powietrznego i w podsystemie jego użytkowania, w którym kluczowym stają się efektywność działania (lotów) i bezpieczeństwo lotów.*

Słowa kluczowe: *ryzyko, modelowanie, eksploatacja*

1. Introduction

The main objective of aircraft operation is the efficient use of their capabilities by performance of flights. Regular operation is the major criterion that makes it possible to check the applicability of aircrafts to their tasks. Operation of aircrafts is carried out in two basic subsystems, namely maintaining the equipment availability and actual operational tasks. The major objective for execution of processes within these subsystems is to make sure that the avionic tasks (cross-country flights, missions) shall be successfully completed. It is associated with the risk that aircrafts are insufficiently prepared in terms of their technical condition (technical risk) and are unable to perform the desired task (technically operable and capable to fly) as well as the risk of regular operation during flights – the risk of safe flight completion.

The risk is defined as a superposition of frequencies or probabilities that any undesired incident may occur – a hazard /danger with defined consequences of such an event [3, 4, 5, 8]

2. Model of risk in the aircraft maintenance system

Development of operation programs needs prediction of future course and importance of operational incidents, both those that may happen in a very near future as well as those with time horizon of a few dozen years. These are the circumstances that bring about the fact that any actions and submitted action plans are burdened with risk [3, 8]. It is the risk associated with uncertainty in validation of both operation and maintenance incidents. That kind of risk is considered in terms of optimizing possible loss. Major measures that are intended to cut down loss include stand-by hot reserves and early warning structures.

Risk and uncertainty included in plans for operation and maintenance of aircrafts results from the unavoidability of the following rough estimations – lack of certainty:

- future demand for availability of the operation system,
- future desired handling of the operation system, both in the area of regular tasks as well as maintaining the flying and technical capacities with backup and overhaul facilities,
- future possibilities to supply the operation system (e.g. with fuel),
- qualifications and motivation of persons conducting operation procedures

- future economic and financial circumstances,
- approval by social environment and co-existence with natural environment,
- ability to take control under emergency conditions, e.g. after an accident or an avionic catastrophe.

The term of risk is associated with uncertainty, with possible detrimental consequences or losses under various reliability states. The status of airworthiness enables the completion of an avionic task (ZL). In turn, the status of airworthiness, or technical inoperability, may lead to several hazardous circumstances – depending on the phases of the flight, i.e. whether the incident happens on the ground (during a standstill period SP, during taxing or a landing run) or in air (during any phase of the flight). Such circumstances may lead to the following consequences:

- prevention from commencement of the avionic task (ZL) execution,
- withholding execution of the avionic task (ZL),
- occurrence of an avionic accident or catastrophe that lead only to material damage, or to material damage and human injuries or even fatalities (among the crew, passengers or people on the ground).

In deliberations dedicated to reliability issues the risk refers to both a technical object (OT) and the entire operation system (SE), where the latter (SE) includes technical facilities and personnel along with mutual relationships between them. The period until the moment when any disadvantageous incident occurs, e.g. a defect, illness of a personnel member, health problems of the crew, weather conditions (lightning shot, hail, icing, voltage decay of the power mains, etc.) can be and should be considered as a random variable. It means that the above incidents can be associated to specific probabilities of occurrence with a defined function of frequency.

The basic measures that correspond to a loss of the object availability or an occurrence of hazard within the time interval $[0, t]$ are usually the cumulative distribution function $Q(t)$ (the reliability function) defined as $Q(t) = P(T \leq t)$, where P is the probabilistic measure of the random variable T that may be considered as the time of availability or durability as well as intensity of incidents λ .

For some specific incidents, application of appropriate prophylactic measures may be conducive to advantageous alterations of the probability values but it is impossible to achieve surety that incidents that correspond to

specific phenomena shall occur at desired moments of time. The operation of aircrafts and the use of the operating system (SE) is always associated with a risk that the desired objectives of aircraft operation shall not be achieved and consequently the risk to be held responsible for failure to complete the operating task along with all the entailed outcomes. Therefore, the aviation practice demonstrates a relatively high probability of the system availability under specific external circumstances, where that high probability, nearly surety that the system is in sound operating condition is achieved by additional measures, such as redundancy, stand-by hardware and equipment and safety coefficients. The method that assists to reduce the probability of an undesired incident is the analysis of the core source of the defect origination under the assumption that the incidents are associated with deterioration of the operation potential demonstrated by aircraft.

The analysis of sources for undesired incidents that lead to technical unavailability is carried out with the use of various methods, including Fault Tree Analysis (FTA) or Event Tree Analysis (ETA) and similarly FMECA, HAZOP, SPC, RCM [9]. The mentioned methods differ from each other chiefly in procedures that are applied to the analysis of the knowledge about a specific aircraft and the information resources that are necessary to complete the mentioned analysis.

Failures of technical facilities and systems are the consequences of their complex and sophisticated nature, uncertain and variable conditions for their operation (external operation loads).

The uncertainty that is associated with operation of the equipment and systems during all phases of their lifetime results from [2, 5]:

- uncertainty that is caused by missing or incomplete knowledge about objective reasons for specific circumstances during the phases of engineering design, detailed engineering and further operation of the equipment,
- uncertainty that is caused by the awareness of own limits in acquiring and processing of information.

Uncertainty is expressed by the measures of probability, possibility and necessity, trust and trustworthiness. All the measures present dualism in their nature, i.e. when a specific event is unavoidable, the opposite event is unfeasible, when the event is probable, the opposite event is unimaginable.

There are three rules that make it possible to manage the uncertainty [1, 2, 7]:

- the rule of minimum uncertainty (minimum entropy) – only those solutions are acceptable, for which loss of information (resulting from

simplifications, transformations or resolutions of conflicts) is the least, i.e. the solution with minimum uncertainty is chosen.

- the rule of maximum uncertainty (maximum entropy) – all the solutions are applicable after making sure that information that is not indicated by the collected data is not attached by accident.
- the rule of uncertainty invariance (the rule of data protection) – the number of uncertainty should be preserved after transformation from one mathematical formulation to another.

Operation systems are used under circumstances of risk and uncertainty whereas the management of the systems is based on available information that is usually uncertain by its nature. To minimize the risk level the executives must properly evaluate the degree of the information uncertainty. When large sets of historical information are accessible, the evaluation procedures take advantage of probabilistic methods (based on the theory of probability and mathematic statistics).

However, in a number of cases the executive has only scarce information available and, what is worse, that information is additionally burdened with uncertainty and incompleteness, which is a troublemaking factor for description of the problem in the categories of probability. If so, the decision-making process must involve incorporation of expert opinions.

Risk, in a common meaning of that term, is understood as a measure for estimation of hazards that results either from events that are probable but remain out of our control or from consequences that are entailed by the decisions already made. In general, risk is the indicator of circumstances or an incident that may lead to a damage or loss. It is proportional to the probability that such an incident shall occur and to the amount of loss that it may bring about. All operation procedures must take account for *risk* either as a deterministic or a probabilistic factor.

In terms of the deterministic approach, risk is measured by loss that occurs when the breakdown (the status of worthlessness) takes place under clearly defined circumstances. On the other hand, the probabilistic approach assumes risk associated with system operation in terms of the probability calculus, as it has been mentioned before.

The model of risk is described by specification of elementary incidents (e.g. hazards, reasons for incidents, failures, avionic catastrophes for examination of flight safety) that may lead to breakdown of an aircraft and elimination of it from the operation system. The model assumes that there always is one, predominant reason for any air incident and it is the reason that initiates the entire sequence of causes and effects associated with an undesired avionic incident (NZL). Parameters that are attributable to the model include the

function that represents intensity of hazards to which the system is exposed λ_{BL} as well as accumulated intensity of hazards to the system of flight safety Λ_{BL} . These functions are described by means of the following equations:

$$\lambda(t) = -\frac{1}{B(t)} \frac{\partial B(t)}{\partial t} \quad (1)$$

$$\Lambda_c(t) = \sum_{j=1}^{j=n} \int_0^t \lambda_j(\tau) d\tau \quad (2)$$

where t is the variable that represents time and n stands for the number of hazards.

The total intensity of a hazard to the system of flight safety $\lambda_c(t)$, under the assumption that the elementary hazards are mutually independent, is expressed by the following sum:

$$\lambda_c(t) = \sum_{i=1}^{i=n} \lambda_i(t) \quad (3)$$

Predictions of operation incidents that are distinguished by a high level of risk become possible and reasonable under circumstances when the collected information exhibits a cyclical repeatability or an unambiguous trend. The forecast parameter (PZE) adopts the following form:

$$PZE(Y) = \frac{\partial f(X_1, X_2, \dots, X_n)}{\partial (X_i)} \cdot \frac{X_i}{f(X_1, X_2, \dots, X_n)} \quad (4)$$

where Y is the measure of alterations and reaction to independent variables X that are described by means of the function $f(X_1, X_2, \dots, X_n)$. It is the function that can be used to describe safety of flights (BL) or reliability of a technical system (R).

The formula (4) makes it possible to check the value of the function $f(X_1, X_2, \dots, X_n)$ at any point X_i , which can be construed as examining how a specific parameter (e.g. risk) is vulnerable to a selected destructive factor that is represented by the variable X_i .

3. Risk within the aircraft operation subsystem

When to assume that probability of an adverse incident within the area of the aircraft operation, i.e. the failure to complete an avionic task is equivalent to the probability of unreliability Q_z and, in consequence, this unreliability leads to the hazard of loss and damage that are expressed by the probability of loss Q_s , the risk shall be measured as a product of probabilities.

$$PR = Qz \cdot Qs \quad (5)$$

Depending on the level of hazard to a safe continuation of a flight, where the hazard is caused by an undesired event, the risk is considered as a consequence of circumstances that are detrimental to the flight safety. Such circumstances are subdivide into sophisticated (complex), hazardous, emergency and catastrophic [4, 6].

Research on risk, e.g. seeking for a core reason for an avionic incident requires calculation of the probability that a flight shall be safely completed. Probability of a safe flight P_{BLo} depends on the course in development of possible circumstances.

For all possible factors that may disturb the flight ($i = [1, N]$) the probability of a safe flight that is associated with the risk in flights, is expressed in the following way [6]:

$$P_{BLo}(t) = \prod_{i=1}^N \left\{ p_{ACZ_i}(t) + [1 - p_{ACZ_i}(t)] p_i(BP / ACZ_i) \right\} \quad (6)$$

where:

ACZ and $\overline{ACZ}$ – status of the flight when disturbing factors may appear or not,

BP and $\overline{BP}$ – status, when the disturbing factor could be parried (eliminated) by the aircraft crew or not,

AP and $\overline{AP}$ – possible final status of a safe flight, either successful or unsuccessful,

λ – intensity of transitions between a variety of possible circumstances during a flight,

The expression (6) comprises probabilities of incidents with indication that these incidents may be (and actually they are) functions of time.

When reasons for avionic incidents are narrowed to M predictable defects and malfunctions, where the aircraft crew (pilot) is able to neutralize such disturbances – either to counteract or mitigate their effects – and the elementary probability of each such incident is p_{ui} , the overall probability of a safe flight can be calculated by means of the following formula:

$$P_{BLo}(t) = \prod_{j=1}^M \left\{ p_{u_j}(t) + [1 - p_{u_j}(t)] p_j(BP / \overline{USZ}_i) \right\} \quad (7)$$

where: $p_j(BP / \overline{USZ}_i)$ is the elementary probability of the fact that the j^{th} defect or malfunction is eliminated or alleviated after its occurrence.

References

1. Abramowicz-Gerigk T.: *Identyfikacja przyczyn i prognozowanie skutków uszkodzeń w systemie CTO na przykładzie bezpieczeństwa manewrów statku na akwenu ograniczonym*. XXXIII Zimowa Szkoła Niezawodności, Szczyrk 2005.
2. Bukowski L., Bukowski M.: *Systemowa analiza ryzyka w eksperckich metodach oceny niezawodności systemów*. XXIX Zimowa Szkoła Niezawodności, Szczyrk 2000.
3. Downarowicz O.: *System eksploatacji zarządzania zasobami techniki*. Wydawnictwo ITE, Gdańsk – Radom, 1997.
4. Lewitowicz J.: *Podstawy eksploatacji statków powietrznych – systemy eksploatacji statków powietrznych*. Tom 3. Wydawnictwo ITWL, Warszawa 2006.
5. Lewitowicz J., Kustroń K.: *Podstawy eksploatacji statków powietrznych – własności i właściwości eksploatacyjne statku powietrznego*. Tom 2. Wydawnictwo ITWL, Warszawa 2003.
6. Lewitowicz J., Kowalczyk G., Sibilski K.: *Flight safety as considered in probabilistic terms*. International Conference ICAS, No. ICAS 2008-6.3.4, Anchorage 2008.
7. Lewitowicz J., Żyłuk A.: *Podstawy eksploatacji statków powietrznych – techniczna eksploatacja statków powietrznych*. Tom 5. Wydawnictwo ITWL, Warszawa 2009.
8. Powierża L.: *Zarys systemów bioagrotechnicznych*. Wydawnictwo ITE, Radom, 1997.
9. Szpytko J.: *Kształtowanie ryzyka w eksploatacji środków transportu*. XXXVIII Zimowa Szkoła Niezawodności, Szczyrk 2010.

Prof. Jerzy Lewitowicz DSc., Eng is an employee of the Air Force Institute of Technology (ITWL). The major area of his interest includes development of the cutting edge military technologies, in particular issues related to air forces as well as construction and operation of aircrafts and helicopters, where he pays distinct attention to technical diagnostics and logistics. His scientific output covers more than 400 printed papers, he is also the author or a co-author of handbooks, such as *Problems of research studies and operation of air technology (Problemy badań i eksploatacji techniki lotniczej)*, six volumes (1993-2006), *Fundamentals for operation of aircrafts (Podstawy eksploatacji statków powietrznych)*, five volumes, (2001-2009). Being a recognized expert, he developed more than 400 opinions and scientific reviews and, last but not least, he actively attended above 120 scientific and technological conferences.