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APPLICATION OF EXPERT METHODS TO RISK ASSESSMENT OF AIR TRANSPORT SYSTEMS

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This paper describes the elements of statistical decision-making process based on expert assessment. Failure rate functions for aircraft components have been accepted as a measure of risk when flying aircraft. Whereas, the conditional probability of occurrence of dangerous events that may result in specific unairworthiness, has been proposed as a measure of hazard when flying aircraft. The triangular probability distribution has been found to be very useful for calculating subjective probability of dangerous events to occur during operational life. Positional parameters of the distribution are referred to as: pessimistic, optimistic and the most likely service life. The presented method allows to consider uncertainty conditions in terms of risk conditions. Expert judgements after appropriate processing and describing can be used for improvement of products, prevention of failures and post-accident analysis.

1. Introduction

This paper presents a method of dependability assessment under uncertainty conditions. [1], [2] They occur when we deal with unknown design concept of an object or we cannot use historical technical data. The reason can be that due to different circumstances associated with different hazardous events it is impossible to use historical data for evaluation of behaviour of objects tested. Another reason can be that historical data are simply not available.

In such situations we rely on experts' judgement. Based on their expertise and knowledge we can estimate values of variables or number of events being under consideration. Doing so, we assume a specific time scale - a projection period or a retrospection period.

2. Bringing decision-making problem to risk conditions

From the theoretical point of view a decision making process involves definition of subjective or psychological probability as opposed to „real" probability, which is calculated on the basis of a number of historical events. Subjective probability means the extent of somebody's faith or conviction that some event is likely to occur.

In the decision making theory specific methods of reasoning associated with making decisions under uncertainty conditions have been developed. The proceeding, which allows to formalise many rational presumptions and evaluations, is referred to as a statistical decision-making process. It allows a decision-making problem under uncertainty conditions to be considered in terms of a decision-making problem under risk conditions. To be more specific, we can assume that we are interested in experts' judgements allowing to estimate parameters of failure probability distributions f(t) and failure rates $\lambda(t)$ under specific conditions of aircraft service life.

It should be noted that when evaluating dependability of aircraft the assumption is made that only long-term service tests can provide information at required confidence level about a system's behaviour during its service life. However, there is a technical paradox, viz. the higher quality of products the longer service tests. Additionally, if such tests are destructive ones, there is an additional problem with the limitation of sample size. There are some methods and techniques that allow to shorten the time of service test including so called accelerated testing methods.

However, very long-lasting service tests may be needed to obtain reliable data. Sometimes, the period of service tests can be so long that the tests are completed when economic product life is achieved. Hence, during designing, manufacturing and operating technological systems characterised by uncertainty conditions some expert systems must be used.

3. Building expert system for evaluation dependability of air transport systems

An expert system for evaluating dependability of technical systems is referred to as a collection of experts judgements and methods needed to infer future and past behaviour of objects. Such a system (Fig. 1) comprises, among other things, the objective and the task, determines time scale for the assessment, defines initial conditions and determines characteristics of the event occurring during operation, defines the class of models and mathematical methods that allow to select the type of assessment of past and future behaviour of the system, historical data and data of technical origin, selection and formal presentation of the model, indicates the model parameters to be assessed by experts, carries out expert experiments and processes data to allow decision making under risky conditions.

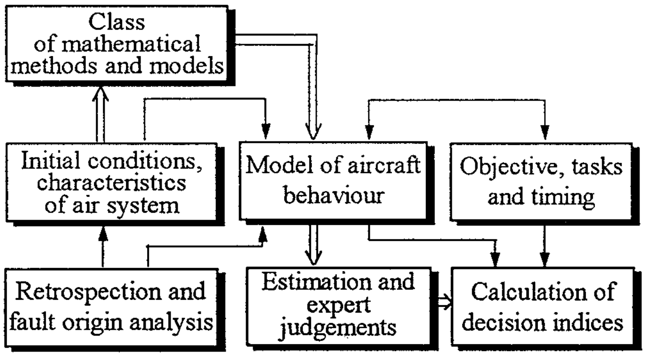

FIGURE 1.The block diagram of the expert system for evaluation of dependability of aircraft hazard

It is vital that the expert system have the expert experiment prepared appropriately to ensure objectivity of the assessment.

4. Expert assessment objectivity

The key issue for all types of testing is to ensure confidence of collected information. In the case of expert assessment the issue should be taken into special consideration. An expert opinion depends on both his or her knowledge and experience and his or her mood. From the engineering psychology point of view the expert during assessment can be governed by, among other things: limitations resulting from his or her occupational experience, aspiration for confirmation his or her way of thinking, known facts, aversion to give a pessimistic opinion, willingness to attach greater importance to negative phenomena, aversion to take responsibility for false judgement and fashionable ways of thinking. Therefore, it is advisable that the experts be provided with appropriate psychological training ensuring both objectivity of opinion and motivation to make an objective diagnosis.

Initial selection of the experts to assess dependability of systems can be guided by the following criteria: knowledge of design and operation of systems falling into a specific category, knowledge of and experience in the course and consequences of destructive processes related to the systems, knowledge of and experience in malfunction of the systems and accompanying consequences, the ability to make independent opinions and suitable features to pursue a goal during expert experiment.

5. Algorithm of statistical decision-making process

We will limit dependability assessment within predetermined projection period to evaluation of unreliability function parameters $F_i(t,H_j)$ and to evaluation of conditional probabilities $P(E_i|H_j)$ of unairworthiness of a specific aircraft component, if distinguishable dangerous conditions occur during operational life of an aircraft. [6], [7]

In the first case the expert k (k =1,2....K) at first gives his or her opinion on the occurrence of critical components i (i =1,2....I) of an aircraft followed by pessimistic estimation $a_{i,k}$, optimistic estimation $b_{i,k}$ and the most likely estimation of time to failure of the component i.

In the second case the expert k at first gives his or her opinion on the possibility of airworthiness loss of components i of an aircraft under dangerous flight conditions. Then, particular experts evaluate in which number of failure cases of the components i dangerous conditions occur.

The algorithm of statistical decision-making process based on expert judgements is shown in the block diagram in Fig. 2.

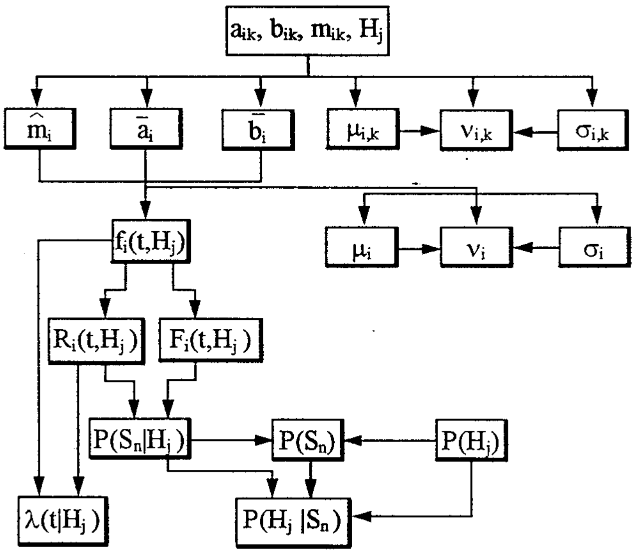

FIGURE 2. The block diagram of algorithm of statistical decision-making process based on expert judgements

Explanations to the diagram in Fig. 2:

$a_{i,k}$, $b_{i,k}$, $m_{i,k}$ - pessimistic, optimistic and the most likely estimation, respectively, of time to failure of the component i (i =1,2,...,I) made by the expert k (k =1,2,...,K),

$\mu_{i,k}$ - average estimation of time to failure of the component i resulting from the judgements made by the expert k:

$$\mu_{i,k} = \frac{1}{3}\left(a_{i,k} + m_{i,k} + b_{i,k}\right)$$

$\bar{a}_i, \bar{b}_i$ - average value of pessimistic and optimistic judgements, respectively, of expert team in respect of the component i:

$$\bar{a} = \frac{1}{K}\sum_{k=1}^{K} a_{i,k},\ \bar{b}_i = \frac{1}{K}\sum_{i=1}^{K} b_{i,k}$$

$\hat{m}$ - weighted average value of the most frequent judgements and of those approaching them from both sides

$$\hat{m}_i = \frac{1}{K}\left(\gamma \cdot m_{i,n} + \zeta \cdot m_{i,s} + \omega \cdot m_{i,w}\right), \quad \gamma + \zeta + \omega = K$$

where:

ζ - number of the most frequent estimations of safe life

γ, ω - numbers of preceding and following the most frequent judgements

$\sigma_{i,k}$ - average standard deviation of time to failure judgements made by the expert k:

$$\sigma_{ik} = \sqrt{\frac{1}{18}\left[\left(b_{i,k} - a_{i,k}\right)^2 - \left(m_{i,k} - a_{i,k}\right)\left(b_{i,k} - m_{i,k}\right)\right]}$$

$v_{i,k}$ - variability coefficient of judgements made by the expert k:

$$v_{i,k} = \frac{\sigma_k}{\mu_{i,k}}$$

μ_i - average judgement of the expert team in respect of time to failure of the component i:

$$\mu_i = \frac{\bar{a}_i + \bar{b}_i + \hat{m}_i}{3}$$

σ_i - average standard deviation of time to failure judgements made by the expert team:

$$\sigma_i = \sqrt{\frac{1}{18}\left[\left(\bar{b}_i - \bar{a}_i\right)^2 - \left(\hat{m}_i - \bar{a}_i\right)\left(\bar{b}_i - \hat{m}_i\right)\right]}$$

v_i - variability coefficient expressing coincidence of judgements made by the expert team,

H_j - dangerous flight conditions j of an aircraft, j =1,2,...J

$$v_i = \frac{\sigma_i}{\mu_i}$$

$f_i(t,H_j)$ - probability density function of the operating time to failure of the component i under flight conditions j of an aircraft:

$$f_i\left(t,H_j\right) = f_i(t) = \begin{cases} 0 & t \le \bar{a}_i \quad \text{and} \quad t \ge \bar{b}_i, \\ \dfrac{2}{\left(\hat{m}_i - \bar{a}_i\right)\left(\bar{b}_i - \bar{a}_i\right)}\left(t - \bar{a}_i\right) & \bar{a}_i < t \le \hat{m}_i, \\ \dfrac{2}{\left(\bar{b}_i - \hat{m}_i\right)\left(\bar{b}_i - \bar{a}_i\right)}\left(\bar{b}_i - t\right) & \hat{m}_i < t < \hat{b}_i; \end{cases}$$

as parameters of triangular time to failure distribution we assume average judgements of satisfactory operation of the component: pessimistic, optimistic and the most likely ones.

6. Impact of condition on changes in aircraft flight risk

On the basis of failure rate function courses we can subjectively estimate risk of the failure occurrence unless it occurred in the previous period. [1], [9]

For example, in Fig. 3 failure rate function courses are shown, which are described by the following formulae.

$$\lambda(t) = \begin{cases} 0 & t \le \bar{a}_i, \\ \dfrac{2\left(t - \bar{a}_i\right)}{\left(\hat{m}_i - \bar{a}_i\right)\left(\bar{b}_i - \bar{a}_i\right) - \left(t - \bar{a}_i\right)^2} & \bar{a}_i < t \le \hat{m}_i, \\ \dfrac{2}{\left(\bar{b}_i - t\right)} & \hat{m}_i < t < \hat{b}_i. \end{cases}$$

It should be noted that there is a method according to which expert judgements can be used additionally to verify their attitudes divided into the following categories: careful, objective and brave. Such a test can be used for the selection of experts in terms of coincidence of their independent judgements. The following proceeding can be recommended to this end. The variability v_i (i =1,2,...,I) and the ratio of the average estimations $\mu_{i,k}$ to the average estimations μ_i. The expert judgement is considered to be consistent with the team judgement when the variability v_i is close to zero. Such an attitude is considered objective. When the variability $v_i > 0$ significantly differs from zero the expert attitude is qualified as brave or careful depending on a negative or positive value of the following difference:

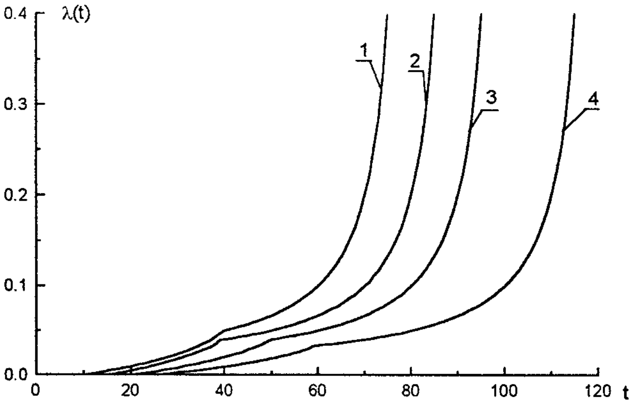

FIGURE 3. Failure rate of the airframe of the selected aircraft estimated on the basis of expert judgements: 1,2 - careful, 3 - objective, 4 - brave.

Possible results of such judgements are also shown in Fig. 3.

Variability coefficientv$_{i,k}$	$\frac{\mu_i,k}{\mu_i}-1$	Expert judgement
Quite large	Positive	Brave
Average	Close to zero	Objective
Quite large	Negative	Careful

The qualification is of significant importance because subjective judgement of aircraft reliability involves great responsibility for decisions made. Brave (optimistic) estimation can lead to the second type error, i.e. non-operational aircraft is allowed to operate. Too careful (pessimistic) estimation can lead to the first type error, i.e. operational aircraft is not allowed to operate. The failure rate function is used to partially estimate risk. Full risk is evaluated only when the extent of damages and losses has been taken into account.

The comparison of changes in failure risk and unairworthiness probability of the specific component of a given aircraft is shown in Figure 4.

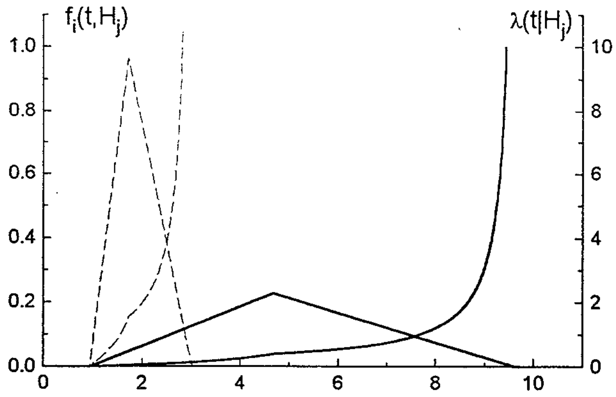

FIGURE 4. Impact of conditions on changes in aircraft flight risk $\lambda(t,H_j)$ and on object , probability density function of failure $f(t|H_j)$. Legend: - - - (H_1 -primary conditions), — (H_2 - secondary conditions).

7. Analysis of accident contributing factors and hazards during aircraft flight

Prerequisites and reasons for hazards during aircraft flight are analysed in a formal way. The following parameters are necessary to carry out appropriate statistical reasoning:

$P(H_j)$ -	probability that dangerous flight conditions j (j =1,2,...J) will occure, estimated by an analyst on the basis of expert team judgements,
$F_i(t,H_j)$ -	unreliability function of the aircraft component i (i =1,2,...I) under dangerous flight conditions j (j =1,2,...J) estimated as above. Unreliability function $F_i(t,H_j)$ is complement to unreliability function $R_i(t,H_j)$ under specific flight conditions,
$P(S_n|H_j)$ -	conditional probability that configuration n (n =1,2,...N) for airworthy and unairworthy components of aircraft under flight conditions (j=1,2...J) will occur,

$$P(S_n|H_j)=\prod_i^N F_i(t,H_j)\prod_k^N R_k(t,H_j),$$

$$(i=1,2,...,n),(k=1,2,...,n), i\neq k, j=1,2,..J, N=2^n$$

$P(S_n)$ - occurrence probability that configuration n for unairworthy and unairworthy components regardless of other different circumstances.

$$P(S_n)=\sum_{j=1}^{J}P(H_j)P(S_n|H_j), \qquad j=1,2,\ldots J, \quad n=1,2,\ldots N$$

Likelihood of occurrence of potentially dangerous flight conditions in the configuration n of aircraft components can be expressed as follows:

$$P(H_j|S_n)=\frac{P(H_j)P(S_n|H_j)}{P(S_n)}, \qquad j=1,2,\ldots J, \quad n=1,2,\ldots N$$

Each of those configurations can be regarded as a potential reason for occurrence of specific dangerous flight conditions and vice versa.

The latter expression is the Bayes formula. The Lorentz graph of accident causes for dangerous flight conditions is presented in Fig. 5. Such a measure of hazard can be useful when designing, manufacturing and operating an aircraft. [10]

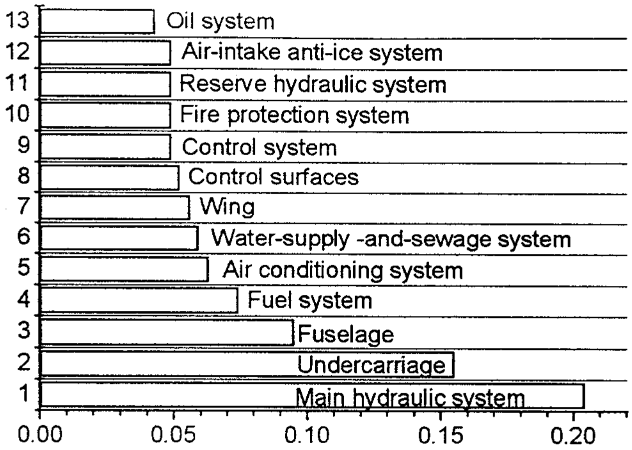

FIGURE 5. Lorentz graph of basic causes for dangerous flight conditions, where i - code index for different configurations of aircraft components states.

The above discussed statistical decision-making process can also be applied when identifying the causes for aircraft accidents. It will be the case when expert judgements are referred to the accidents occurrence provided that specific components have been damaged. Using the Bayes analysis the most likely reason for dangerous events can be identified. It requires that fault tree analysis be made previously with a top event identified as a dangerous event. Using the inversion analysis supported by expert guidelines cumulative distribution function of a failure rate can be determined for aircraft as a conventional whole. To this end we use pre-estimated parameters of triangular distributions for specific components.

However, to reconstruct development of dangerous situations, constituting specific sequences of events in reverse order to the flight phases, the event tree analysis should be used. It allows to identify the most likely consequences of air accidents and determine minimum paths of unairworthiness.

Conclusion

This paper describes the components of statistical decision-making process based on expert judgement. Failure rate functions for aircraft components have been accepted as a measure of risk when flying aircraft. Whereas, the conditional probability that dangerous events may occur to result in specific flight conditions, has been proposed as a measure of hazard when flying aircraft. The triangular probability distribution has been found to be very useful for calculating subjective probability of dangerous events to occur during operational life. After their appropriate processing and describing the expert judgements can be used for improvement of products, prevent failures and carry out the post-accident analysis.

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