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Features of the Application of Fuzzy Logic Elements in the Decision Support System for Aircraft Operation

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Abstract:
The materials of the article develop a mathematical model and algorithm for solving the problem of preparing a decision on extending the service life, taking into account the aging of the aircraft airframe structure under operating conditions. Based on the achievements of cognitive psychology and the results of research on human mental activity, the conceptual foundations of the design and construction of decision support systems are considered, which are intended to automate the intellectual activity of persons making decisions on the extension of the operation of aircraft products. The structure of the mathematical model provides for the use of elements of fuzzy logic when analyzing images of the technical condition of the aircraft airframe. The methodology of expert assessments for the synthesis of a generalized quality criterion for complex reliability management systems is considered in detail. Methods for solving problems of choosing the optimal solution are shown.

Keywords: power elements, fuzzy logic, operation of aircraft, mathematical model, expert, decision support system, technical condition, change forecasting

1. Introduction

At the present stage, the Ukrainian military aviation operates aircraft for which their developers and manufacturers do not provide operational support and maintain airworthiness. Over the past two decades, Ukrainian scientists have conducted a number of studies, based on the results of which the heads of the aviation engineering service have made appropriate management decisions to change the volume and frequency of maintenance work, extend service life, and transfer to operation according to technical condition.

The implementation of measures to further maintain the airworthiness of the aging aircraft fleet [1] requires the systematization and implementation of modern methods and methods of reliability management in the formation of informed decisions on determining the ways of further application.

In the process of performing work on maintaining the airworthiness of aircraft, it is necessary to assess the technical condition of the airframe in order to meet flight safety conditions. This raises the problem of the reliability of the results of assessing the reliability of power elements (hereinafter referred to as the PE), since this is related to the results of statistical processing of aircraft fleet control data, the number of which is always limited in practice.

In fact, the established resource indicators, such as the permitted operating time and service life, of aircraft are related to the technical condition of the airframe structural components. The possibilities of increasing the resource indicators of aging aircraft are implemented on the basis of resource calculations using the hypothesis of linear summation of fatigue damage when processing data from on-board flight parameter control devices, which is comprehensively investigated in [2].

The continuous growth of the amount of information and the constant complication of the tasks performed by the aging fleet of aircraft indicate the need to improve existing and create new innovative systems for making and approving management decisions. These include the so-called decision support systems (hereinafter referred to as DSS-Decision Support System), which are capable of implementing in real time a continuous controlled decision-making process in complex situations that have many components and are characterized by uncertainty and unstable structuring.

The problematic issues of decision-making regarding the extension of the service life of aging aircraft have only been partially investigated in works on technical diagnostics [1]. Therefore, there is a need to develop methods that allow increasing the reliability of decisions made by an official (hereinafter referred to as the decision-maker, DM) for a specific situation of extending the service life of an aircraft based on the results of defects in the airframe design during its inspections in operating units and aviation enterprises.

In the processes of aircraft operation, where the term “management decision systems” is more often used, DSS is an interactive application system that provides end-users of aircraft, who make decisions about its further operation, with easy and convenient access to data and models of maintenance of serviceability, in which the corresponding algorithms for decision-making in semi-structured and unstructured situations with various input data have been worked out. At the same time, DSS supports and enhances (but does not replace or cancel) the reasoning and assessments of the decision-maker. The essence and importance of expert assessments does not decrease, control over decision-making remains with the person [3].

2. Task statement

The conceptual basis for the design and construction of DSS is an anthropocentric approach, which is due to the following circumstances:

1. DSS is supposed to automate the intellectual activity of a person - experts and decision-makers. Therefore, the basis of the functioning of DSS is the achievements of cognitive psychology and the results of research into human mental activity.
2. The central core of DSS is a knowledge base, which is formed from information from experts - specialists from operating units, aircraft repair enterprises, scientific institutions and management. These are experts of different levels and qualifications, therefore the completeness and reliability of the information that enters the specified knowledge base directly depends on their number, experience and level of education and training.
3. One of the main properties of modern DSS is the possibility of self-learning. This means that along with the application of mathematical methods and models of operations research based on probability theory, mathematical statistics, optimization methods and discrete mathematics, DSS involves the processing of expert information using updated mathematical apparatus - the theory of fuzzy sets and continuous logic, pattern recognition, the theory of artificial intelligence systems and informal decision-making theory.

Analysis of data obtained using non-destructive testing of the airframe structure allows dividing the studied aircraft into separate groups (ranks) depending on the operating methods and, accordingly, predicting the probability of trouble-free operation during the operation of the airframe structure.

The imperfection of known decision-making methods is that information about the technical condition of the aircraft is characterized by incompleteness and limited volumes of operational data, which significantly affects the validity of decisions when managing the aircraft operation process.

One of the directions of developing methods for aircraft classification is to develop a mathematical model of bionic processing of experimental data, which simulates the mechanisms of functioning of biological systems and allows air traffic controllers to understand the validity and feasibility of various decision options when making decisions [4]. To increase the reliability of air traffic controllers' decision-making, it is necessary to develop a mathematical model that will simulate the thinking process of experts, taking into account the results of the analysis of the reliability of the aging aircraft fleet.

3. Research Methodology

Today, most decisions on the further operation of the aircraft are made based on the results of expert assessments, based on the base of expert knowledge, skills and abilities of relevant specialists and decision-makers. At the same time, the criteria field is not structured and not systematized for decision-making, input data on the parameters of the technical condition of the AO, the relationship between them, operational limitations, etc. may not be sufficiently taken into account, which may lead to insufficient justification of the decision being made. Expert assessment methods are adequate methods for studying complex technical and ergatic systems. This is explained both by the difficulties of formalizing multi-criteria tasks and the fundamental impossibility of formally solving the goal-setting problem, which consists in determining the dimension and qualitative composition of the vector of criteria.

The objective function f(x) of a complex system in a small neighborhood δ of the operating point can be represented by a linear scalar convolution

$$f(x) = Y(x) = \alpha_1 y_1(x) + \alpha_2 y_2(x) + \cdots + \alpha_S y_S(x),$$

where $y_1(x) \dots y_S(x)$ – are partial quality criteria that make up the vector $y = \{y_k\}_{k=\overline{1}}^{s}$; $\alpha_k, k \in [1, s]$ – are weight coefficients; $x = \{x_i\}_{i=\overline{1}}^{n}$, $n \in \delta$ – is the vector of optimization arguments.

When presenting the objective function of an object in this form, two tasks arise:

1) determining the dimension s and the qualitative composition of the vector of criteria y;

2) establishing the values of the weight coefficients α_k, $k \in [1, s]$.

Both tasks can be solved by expert assessment methods. Provided that the system is created and studied according to a pre-established methodology, traditional for systems of this class, the set of partial criteria is given. But most often it is not possible to determine in advance which of the system indicators should be included in the list of quality criteria and which are insignificant for the problem being solved. This is typical for newly developed, as well as rather complex systems, such as human-machine control systems and decision-making systems. The problem arises of developing general methods that allow reasonably compiling a necessary and sufficient set of private quality criteria. In this case, s criteria are necessary and sufficient within the framework of a specific multi-criteria system if:

- the use of any additional criteria or their combinations does not change the results of solving the problem;
- the rejection of at least one of the selected s criteria changes the results of solving the problem.

Currently, heuristic methods and elements of fuzzy logic are usually used to determine the dimensionality and qualitative composition of the vector of criteria. They are based on an individual opinion (postulate) expressed by a specialist (expert) about the estimated value, based on his professional experience and level of training. The main disadvantage of this approach is subjectivity and the possibility of arbitrariness. The procedure of the expert assessment method allows to reduce this disadvantage. The method consists in the fact that to assess some quantitative characteristic, the postulates of not one, but several persons (experts) competent in this matter are used. It is assumed that the "true" value of an unknown quantitative characteristic is within the range of expert assessments and the "generalized" collective opinion is more reliable. The unknown quantitative characteristic is perceived as a random variable, the distribution law of which is the expert's postulate. To establish the final assessment, the statements of all experts are studied in total and processed as some kind of initial statistical material. The processing is carried out using the concepts of mathematical statistics [5].

Here we consider the methodology of expert assessments, developed for the task of synthesizing a generalized quality criterion for complex control systems, and practically used in the task of studying specific human-machine decision-making systems. Highly qualified specialists in the field of design and operation of decision support systems for objects of the class under consideration are involved as experts. Their number is usually determined by the complexity of the problem being solved.

The development of the methodology begins with the formation of a group of organizers of the examination (Fig. 1) and involves two stages of forming a generalized criterion. At the first stage, experts name those private quality indicators that, in their opinion, participate in the generalized criterion. At the second stage, they weigh the private indicators, assessing the relative influence of each on the generalized quality criterion.

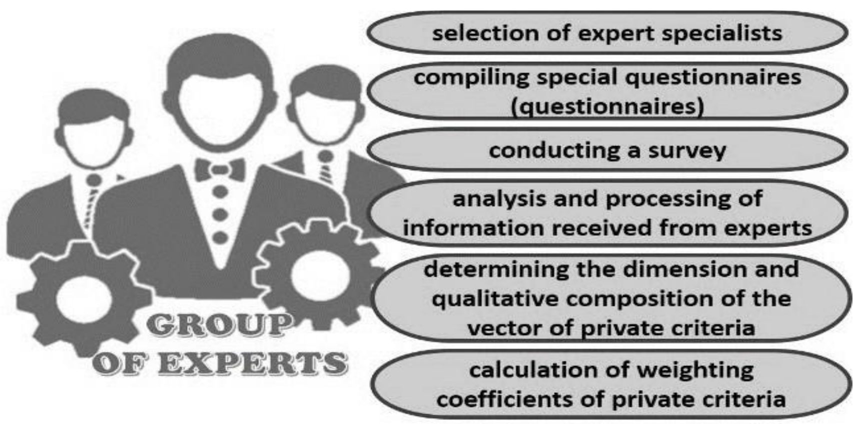

Figure 1: Responsibilities of the group of organizers of the examination

First stage. Two forms of questionnaires are used. In questionnaire No. 1, the organizers formulate the goal (goals) that the designed system should meet; give a brief description of the properties and features of the control object and the working conditions of the human operator; describe the specific modes in which the designed system should function; set the task of expert assessment and provide instructions (with an example) for its implementation. The expert is asked to formulate the basic requirements (in verbal form) that the designed complex system should satisfy in the given operating conditions. Each of the experts separately gets acquainted with the content of questionnaire No. 1, asks (if necessary) clarifying questions to the organizers of the examination and, based on their professional experience, writes down the requirements that, in their opinion, this system should meet. All completed questionnaires are sent to the organizers. They analyze the set of various requirements for the system identified by the experts and, based on this analysis, compile a list of already formalized private optimality criteria. The criteria included in the initial list can usually overlap in content, that is, they express the same requirement for the system, although they differ in form. In other words, the initial list of private criteria is deliberately excessive and expresses the desire not to miss essential requirements.

To identify truly significant private criteria, the organizers present the experts (again, each one separately) with the initial list they have compiled and questionnaire No. 2. It suggests studying the list and selecting from it the most important, in the expert's opinion, private criteria, and distributing them by rank in order of importance. To obtain a collective opinion about the most important criteria, the organizers calculate the sum of the ranks of the experts who voted for each criterion from the initial list. The criteria that received the smallest sum of ranks are selected in the final list. The number of selected criteria depends on the complexity of the task, but usually there are from three to eight. An increase in the number of criteria reduces the reliability of the experts' judgments in assessing their relative importance. In addition, it is necessary that the difference between the number of votes cast for the least important of the selected criteria and the most important of the cut-off criteria be as large as possible.

The selected indicators are the initial set of private criteria, from which a generalized quality criterion of the designed complex system is formed. This does not mean that the necessary and sufficient number of private criteria has been obtained, since it is possible that the removal of some of the criteria will not affect the result of solving the task. However, at this stage, the question of the necessity and sufficiency of the set of private criteria cannot be resolved, it is resolved at the next stages of the study.

The second stage. The weight coefficients of the generalized criterion are determined by the method of expert assessments. Here we consider a variant of the problem when experts assess the relative influence of individual indicators on the generalized criterion of a complex system in some fixed (for example, nominal) mode. The result is a database for further determination of the weight coefficients of the generalized criterion, presented in the form

$$Y(x) = \sum_{k=1}^{s} \alpha_k y_{0k}(x),$$

where $y_{0k}(x)$ – dimensionless (normalized) partial quality criteria; α_k – weighting factors, on which additional normalization conditions are imposed to prevent trivial decisions

$$\sum_{k=1}^{s} \alpha_k = 1 \, , \alpha_k \geq 0.$$

When solving the tasks of monitoring the technical condition of the airframe structure, the subject area consists of numerical and linguistic values of the database on the dimensions of cracks, the depth and area of corrosion, the dimensions of the deformation of the airframe, the coordinates of the damage site, regulatory data on tolerances, service life, etc.

The use of identification procedures when assessing the technical condition allows you to estimate parameters when their dimensions are precisely known. At the same time, calculating the difference between the reference and actual state, i.e. performing a comparison, is a necessary operation of the process of localization of the technical condition. In addition, the number of parameters that characterize the technical condition is often unknown. Therefore, the shortcomings of existing diagnostic technologies and decision-making systems include the need to form requirements for experimental information on dynamic changes in the system, the use of which will allow you to classify and compare possible technical states.

Fig. 2 shows the structure of the mathematical model, which includes bionic model modules that reflect in a formal form the transformations carried out by the DM when generalizing the results of the action of operational factors and forming multidimensional control data into images of the psychosemantic space of the subject area.

In the bionic mathematical model, it is proposed to consider three modules, the dimension of which is determined by the number of parameters of the subject area of control of the aircraft airframe PE.

In the first module, estimates of the indicators of the loss of strength of the PE are formed based on data processing of the control means of each individual airframe PE and determining the list of discrete elements of the surface of damaged PE.

The use of fuzzy cluster analysis methods allows you to determine the image of the technical condition of the airframe depending on the number and parameters of the loss of strength of damaged PE.

In the second module, based on fuzzy logic decision-making algorithms, the results of analytical calculations and stochastic modeling of the rate of strength changes are corrected depending on the assessment of structural aging.

In the third module, multidimensional scaling methods are applied to the results of strength control of individual PEs of the same type for the aircraft fleet, with subsequent determination of factors that affect the durability of the structure and allow for predicting durability [6].

Using assessments of the compliance of experimental data with mathematical models of changes in the strength of PEs allows for the formation of possible solutions for the DM to extend the intended service life of the aircraft airframe structure.

Experts, based on the results of non-destructive testing of the PE structure and analysis of the general technical condition of a particular aircraft, can adjust the assessment of the strength of the structure obtained by the calculation method.

One of the fundamental features of solving the problem of choosing the optimal DSS solution when using fuzzy logic methods is the influence of expert information, which determines the advantage of a particular indicator on the method of its solution.

All numerical methods for solving multi-criteria problems are reduced to three main groups: the method of the main indicator, the method of the resulting indicator, lexicographic methods (methods of successive concessions) [3].

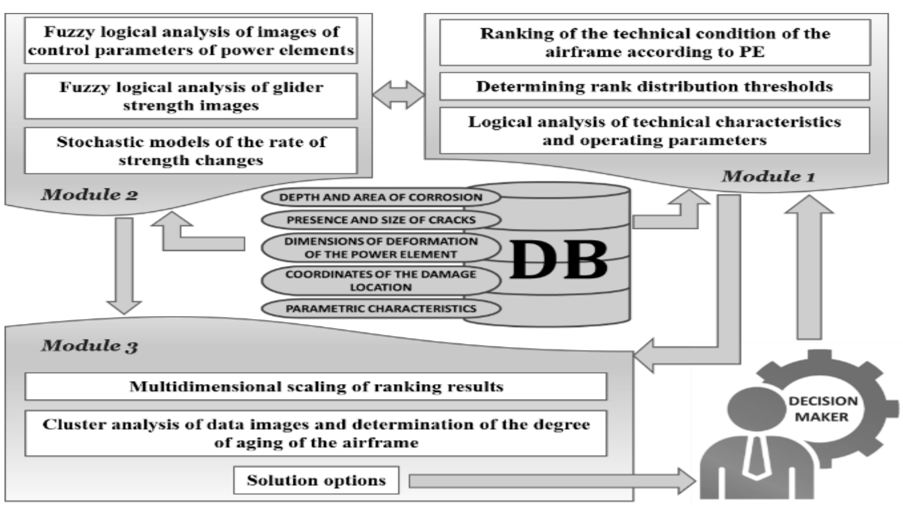

Figure 2: Structure of the mathematical model of data analysis

The method of the main indicator is based on the transfer of all quality indicators, except for any homogeneous one, which is called the main one, to the category of constraints and inequalities. The method of the resulting quality indicator is based on the formation of a general indicator using intuitive assessments of the influence of its own quality indicators on the resulting quality of the system's performance of its functions.

The essence of the lexicographic method is to first select the set of alternatives with the best score on the most important indicator. If there is only one such alternative, then it is considered the best; if there are several, then from their subset, those with the best score on the second indicator are selected.

In both the classical and fuzzy formulation, the choice of a method for solving a multi-criteria problem is determined by the type of available expert information about the advantages of indicators or their importance.

4. Conclusion

The presented mathematical model of data analysis has been repeatedly applied and tested in practice, in real conditions of aircraft operation. Its efficiency and accuracy of the results of assessing the technical condition and predicting its changes have been proven on more than 40 aircraft.

The implementation of the developed methodology into the decision-making system made it possible to reduce the time for forming a decision and implementing measures to maintain serviceability, optimize resource allocation, increase the limits of using aircraft resource indicators – the service life of experimental aircraft was extended by more than two times – from 20 to 40...45 years, which gives a significant practical and economic effect.

The use of fuzzy logic elements in DSS allows for improved processing of relevant information and knowledge regarding the actual technical condition of the aircraft, and provides the decision-maker with the opportunity to improve the efficiency and validity of decisions regarding the further operation and intended use of the aircraft.

Effective and efficient DSS should be based on complexes of methods and algorithms similar to the proposed one and aimed at increasing the reliability and validity of DM decisions for a specific situation.

Recommendations

The mathematical model of data analysis proposed in the work when preparing solutions, after further development and bringing it to the level of a working computational computer program, can be used as a reliable tool for solving aircraft reliability management problems.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

References

1. Pashchenko S.V., & Khilchenko M.F. (2012) Methodology for increasing the resources of aviation equipment. *Collection scientific works of the State research institute of aviation,* No. 8 (15), 161-167.
2. Aviation safety. Edited by V.P. Babak. (2004) *Kyiv: Technics*. - 584.
3. Herasimov B.M., Lokazyuck W.M., Ohsiyuck O.G., & Pomorova O.W. (2007) Intelligent decision support systems. *Kyiv: Publishing House of the European University*. - 335.
4. Bolohin A., Bolohina Y., & Tymchuk Yu. (2025) Ranking of the technical condition of aircraft according to the diagnostic data of the glider design *International scientific and technical journal "Systems Research and Information Technologies"* 98-106.
5. Voronin A.M., & Ziatdinov Y.K. (2018) Theory of multi-criteria decision making. *LAP LAMBERT Academic Publishing,* - 215.
6. Gorokhov G.T. (2011) Bionic model of fuzzy logic analysis of parameters of control and technical inspections of aviation systems. *Collection scientific works of the State research institute of aviation,* No. 7(14), 193-198.