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FEATURES OF RISK ASSESSMENT IN THE CREATION OF UAV FOR VARIOUS PURPOSES

Introduction

Intensive development of unmanned aerial vehicles (UAVs) in the world and their introduction into service has recently led to a significant expansion of the field of application of unmanned aerial vehicles (UAVs).

At present, UAVs are used in a wide range of applications, starting with the military and ending with domestic use.

In recent years, the development of the unmanned industry in Ukraine has taken place, in general, due to the initiative of domestic developments of UAV class I (according to the accepted classification), carried out by private and public companies. This approach allowed to quickly meet the customer's need for relatively inexpensive means of monitoring the ground situation, with generally acceptable characteristics and gain experience in the application of UAV, including in specific conditions in eastern Ukraine. At the same time, the desired development of UAVs of larger classes — II and III — did not take place, and as the world experience shows, the application of such complexes allows to solve problems on the scale of the customer's interests.

Given the above, at present there is an urgent need to expand the functionality of unmanned aerial vehicles, giving it new properties and qualities through its technical improvement, including to solve special problems.

At the same time, as demonstrated by the accumulated experience of building piloted aircraft [1; 2], the pursuit of rapid improvement of technology causes an increase in its novelty and complexity, which leads to an increase in the risks in its construction.

Therefore, at the present time, the implementation of modern risk management systems in the process of building UAVs as complex technical systems is considered extremely urgent.

The relevance and importance of practical research in this area due to the possibility of improving the decision support system, both in the formation and maintenance of programs and plans for the development of armaments and military equipment and at the stage of their implementation, in particular in research and development to develop specific samples.

Relevance of research

Studies have shown that the change of generations of aircraft is characterized primarily by its complexity, which should ensure the implementation of high tactical and technical characteristics to meet modern requirements of the customer [3].

As the analysis of foreign experience (PROJECTS X-47B, HUNTER) shows the implementation of the latest technical solutions, layouts, schemes, algorithms, programs, leads to a high degree of innovation of projects, increasing their complexity, the emergence of many

uncertainties that can not be taken into account. creates a basis for the emergence of risks of the project in a timely manner, leads to a revision of the budget, as well as the requirements of the terms of reference.

Analysis of works and publications on the topic

At present, the problems of risk management and assessment have been extensively researched in the scientific works of both domestic and foreign authors such as Adam Smit, Thomas L. Barton, M. McCartney, Johann Nikolaus Tetersen, L. N. Tepman, I.T. Balabanov, D.A. Frolov. Barton, M. Mc Cartney, Johann Nikolaus Tietens, L. N. Tepman, I. T. Balabanov, D. A. Frolov, Y. Khrustalov, A. G. Spitsin, V. V. Khrustalov, A. G. Spitsyn, V. D. Shapiro and others. Nowadays in Ukraine there are works in the field of risk assessment by such authors as V. V. Vytlinskii, M. I. Lukhanin, M. M. Mitrakhovich, E.A. Druzhinin, O.E. Mavrenkov, I. V. Odnoralov, V. P. Babak, M. S. Kulik, V. P. Kharchenko, M. G. Lutsky, and others.

So in [3; 4] examples of construction of decision support systems at realization of various projects and the organization of difficult systems are resulted.

However, due to various reasons, the issues of risk assessment of specific projects for the creation of samples of aircraft, including UAV have not been sufficiently developed for their implementation in practice. In particular, the existing existing approaches do not use a full range of technical risk indicators.

An analysis of known methods of risk theory, and scientific-methodological apparatus of risk assessment of scientific and technical support of samples of armament and military equipment showed their limitation in quantitative assessment of predicted parameters of risks of implementation of projects of new armament and military equipment by classical methods of the theory of probability and mathematical statistics.

Statement of the research task

The above findings indicate that there is a scientific and practical challenge in the area of decision support systems to support the implementation of state-of-the-art UAVs, namely, the need for a risk assessment of the design phases of new UAVs and the lack of a current assessment of the risks involved: between the need to assess the risks at the stages of design of new UAV and the current lack of a complete adequate scientific and methodological apparatus.

The goal of this article is to present the structure and basic content of the proposed methodological

approaches to the assessment of technical risks at different stages of the implementation of UAV projects.

Presentation of the main material

As a rule, the development and creation of any kind of technology is carried out within the framework of the appropriate program of development, industry or fleet of technical systems.

At the conceptual level, therefore, it is advisable to assess the risks of the implementation of the programme in general, the task of assessing the risks of implementing programmes and plans for the development of aviation technology can be reduced to the task of assessing the risks of implementing individual designs, as outlined in the algorithm (Fig. 1).
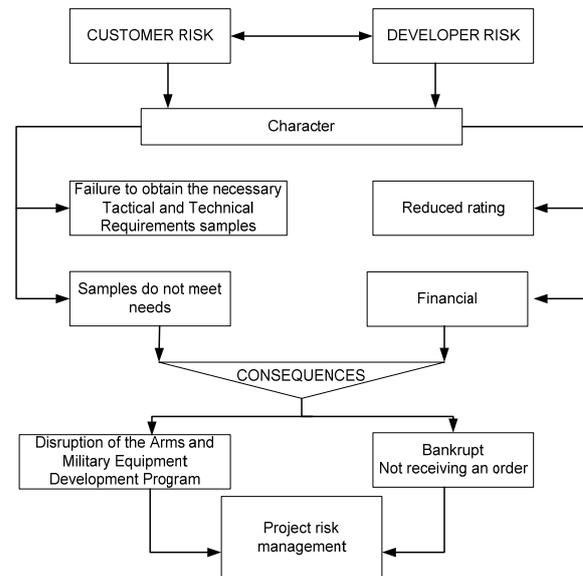

Fig. 1. Algorithm of the risk assessment task for the implementation of aviation technology development programmes and plans

In the course of the research a methodology was proposed, the purpose of which is to identify the main (most important) risk-taking factors that led (may lead) to the occurrence of negative developments during the research and development work on the creation of models of aeronautical equipment.

Input parameters of the methodology is meant to turn the results of research (statistics) of the implementation of research and development work, which was carried out in the framework of the program activities for the previous period. As output data we expect to obtain risk indicators for UAV designs and their grouping by characteristic features. The algorithm of this methodology is shown in Fig. 2.

As can be seen from Fig. 2, the output data for the further risk assessment process are statistical data on the implementation of the relevant programme activities for the previous period.
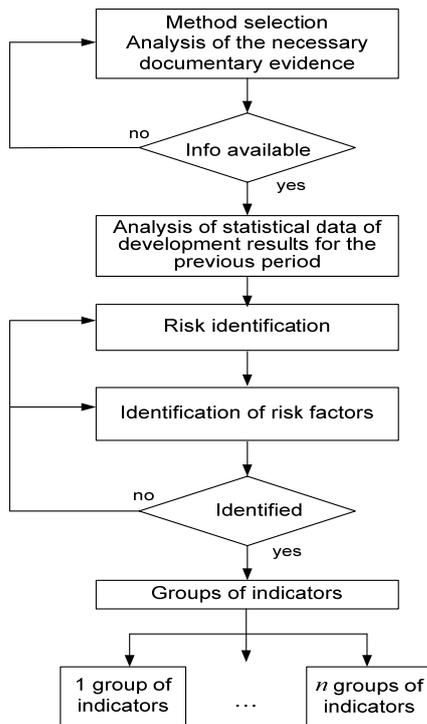
Fig. 2. Algorithm of scientific and methodical apparatus for determining risk factors

This analysis on the application of the activities of programmes for the development of armour and military equipment in previous years showed a high level of incomplete research and development work.

And the identified reasons for their termination allowed to identify the main most significant risk factors and the negative scenarios caused by them to substantiate risk indicators at the stages of development of promising samples of UAV (Table 1).

From the above risk factors, it can be seen that they can occur at almost all stages of sample development, while for UAV special attention is paid to factors that may occur in the initial stages of conceptual and external design. This can be explained by some features of the production of UAV prototypes, including a wide selection of ready-made design solutions and element base offered on world markets, instead of creating cooperation and the formation of specifications for the manufacture of components of the complex. However, to conceptualize the right concept and requirements for the entire complex and to algorithmize the control system operation for acquisition, transfer and consolidation of the data to achieve the target function requires complex operations and the right technical solutions. In general, this corresponds to the relationships shown in Fig. 3

Table 1

**Analysis of risk factors in the performance of research
and development work on the creation of samples of weapons and military equipment**

Consequences (recorded)	Risk factors
Sample not created	Tactical and technical requirements turned out to be impossible to implement; incorrect adoption of final technical decisions; insufficient (suspended) funding; the main executor (co-executors) has ceased activity; insufficient level of production and technological base of the developer (manufacturer); rupture of cooperative ties
Tactical and technical Characteristics of the created sample do not satisfy requirements of the customer	Tactical and technical requirements turned out to be impossible to implement; incorrect adoption of final technical decisions; test scores are not reliable; insufficient quality of components; technological shortcomings of the production of the main executor
The sample was created with a significant waste of time	Unstable (suspended) funding; change of the main executor (co-executors); incorrect adoption of final technical decisions; untimely execution of components, delays in the supply of components; insufficient manufacturability of the product (sample)
The actual cost of creating the sample significantly exceeded the estimated cost	Incorrect technical decisions; insufficient substantiation of tactical and technical requirements; change of the main executor (co-executors); insufficient manufacturability of the product (sample); incorrect feasibility studies; errors in the preparation of calculation materials

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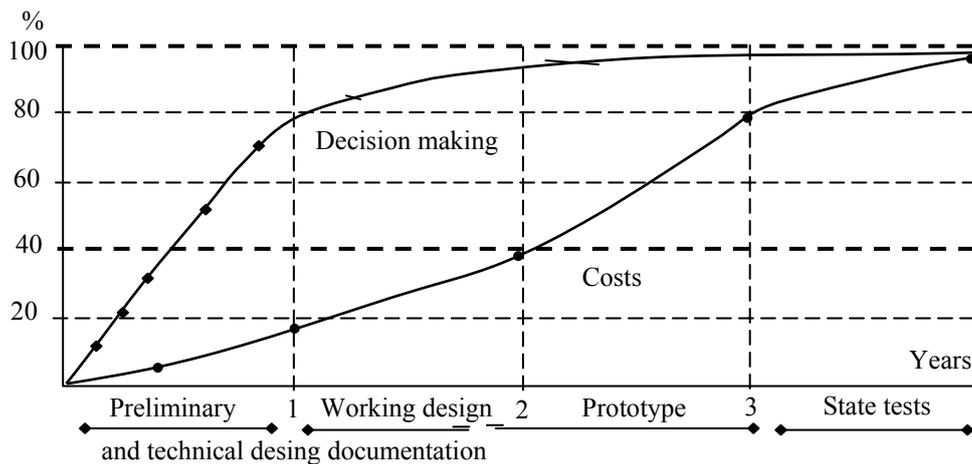

Fig. 3. Relative values of costs and volumes of the accepted
decisions during performance of research and development works

Already at the stage of development of working design documentation for the production of a prototype, the costs will be significant and, on average, reach almost 40 % of the planned financial resources. And at the stage of making a literal sample and conducting preliminary tests — 80 % of the planned financial resources for research and development work. That is, the later the risk assessment is carried out and in case of their great significance the project is terminated, the more significant will be the losses and consequences of the development of a negative scenario. At the same time, it should be noted that decision-making in the early stages, including the feasibility of continuation (according to the feasibility of the project) is more uncertain than in the later stages. Therefore, in this case, there are contradictions, the essence of which is shown in Fig. 3.

Indicative is the fact that the main scope and importance of the decisions made, including the final technical solutions is provided before the stage of development of working design documentation (Fig. 3).

Based on the above, the process of assessing possible risks (the development of negative scenarios) in the implementation of UAV building projects can be represented in the form of the following algorithm (Fig. 4).

Based on the results of the analysis of risk-generating factors, a further transition to substantiation of risk indicators of sampling projects is possible. Further evaluation of these indicators according to the selected criteria will allow a direct risk assessment of the project in general. At the same time, the definition of the main risk-forming factors was carried out through the use of analogy methods and factor analysis of statistical data.

Several methods were used in the selection and substantiation of risk indicators for the implementation of aircraft development projects, in particular: fuzzy logic and convolution.

It should be noted here that separate project risk assessments can be performed for certain groups of Indicators. Of course, the more indicators will be evaluated, the more reliable the result of the overall evaluation should be expected.

The choice of the criterion for evaluating the indicator (in this case the Indicator) is a rather complex scientific task, the correct choice of the rule for evaluating the relevant indicator will largely determine the reliability of the overall, namely quantitative risk assessment. At the same time, the conditions in which the evaluation of certain indicators is expected to be carried out indicate uncertainty in this case, which is primarily due to a number of evaluations of cases and events that did

not occur, which in turn complicates the application of statistical evaluation methods.

Further substantiation of the criteria was carried out for the relevant groups of indicators. On the first stage of the research it was suggested to define the criteria for quality evaluation of the indicators obtained by expert method. Given the nature of obtaining and determining these indicators, as well as their further application — before the opening of research and development work, it is their assessment is largely due to conditions of uncertainty. That is why a number of experts have proposed a method of fuzzy logic for evaluation, namely the following estimates (Table 3).

It should be noted that such qualitative assessments have a certain level of unambiguity for their further quantitative evaluation a proper scientific and methodological apparatus was used.
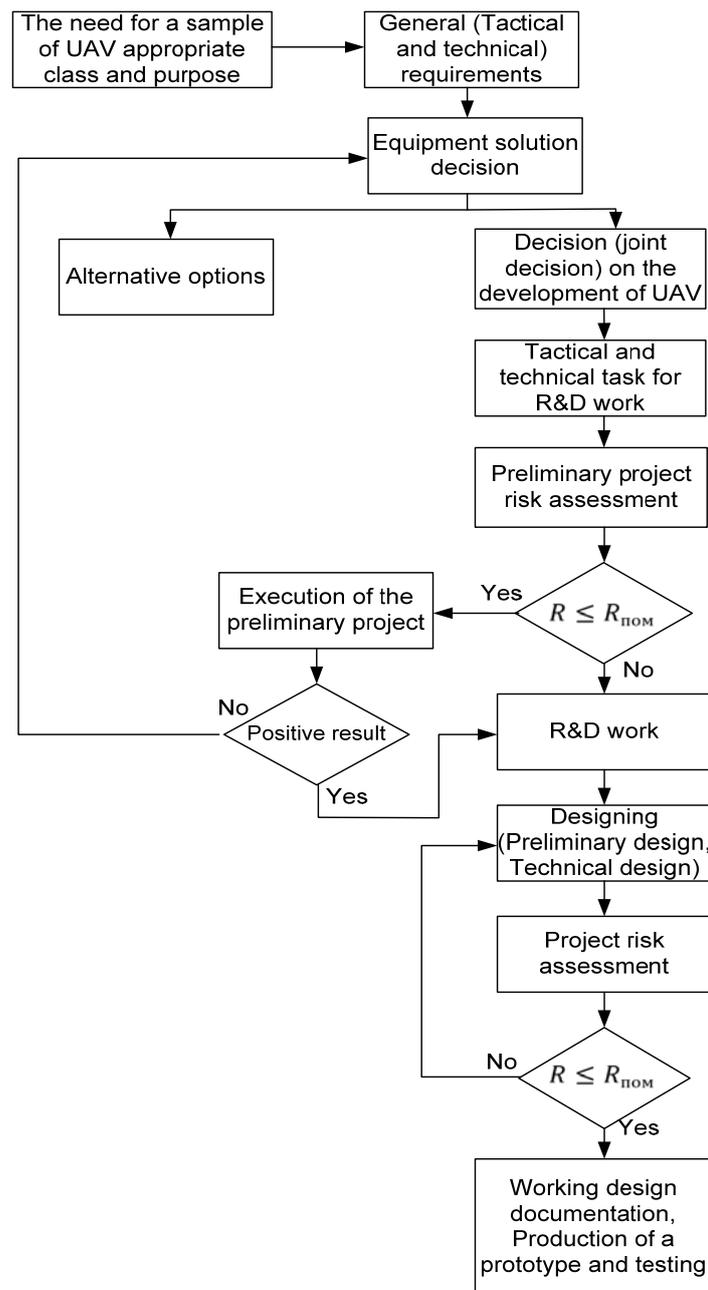

Fig. 4. Algorithm of the process of assessment of possible risks
(development of negative scenarios) in the implementation
of projects to create samples of weapons and military equipment

Table 3

Quality assessments of the 2nd (expert) group of indicators

Indicator	Quality assessment rule
Scientific and technical department (enterprises-main executor, branch)	1) unsatisfactory 2) satisfactory 3) sufficient
Qualification level of the main executor. His personnel potential	1) low-skilled 2) qualified 3) highly qualified
The degree of novelty of the project, its innovativeness (including the estimated complexity of the project as a whole)	1) a fundamentally new development 2) new design 3) modernization
The expected duration of the life cycle (operation) of the sample	1) small 2) lasted 3 long-lasting
The level of production-technological and experimental-testing base of the main executor (created cooperation as a whole)	1) retarded 2) modern 3) advanced

The next stage of the research was to determine the criteria for quality assessment of the indicators obtained as a result of the survey of regulatory documents, namely (Table 4).

Table 4

Quality assessments of the 1st (normative) indicator group

Indicator	Quality assessment rule
Degree of conformity or deviations of final technical decisions from the Tactical and technical task (Tactical and technical requirements)	1) does not answer 2) corresponds in part 3) fully compliant
Assessment of the level of the sample (coefficient of technical excellence). Comparison of the expected Tactical and technical characteristics of the sample with analogues;	1) below analogues 2) corresponds to analogues 3) above analogues
The degree of manufacturability of the product (the need to create new technological lines in the manufacture and manufacture of the product (assembly units))	1) low-tech 2) technological 3) high-tech
Degree of layout. Depth of inspection and testing of models;	1) unsatisfactory level 2) satisfactory level 3) sufficient level
The level of product unification	1) low 2) average 3) high

Next, the criteria for qualitative assessment of indicators obtained by the results of the analysis identified in the work of risk factors, namely (Table 5).

Table 5

Qualitative assessments of the 3rd (factor) group of indicators

I – subgroup

Indicator	Quality assessment rule
The degree of validity of tactical and technical requirements (the possibility of their implementation)	1) insufficient 2) a sufficient degree 3) high degree
The level of production and technological base of cooperative enterprises	1) insufficient 2) sufficient level 3) high level
The level of expected financial burdens	1) high 2) significant 3) moderate
Stability of the created cooperation for project implementation	1) highly stable 2) stable 3) unstable
Degree of experience of the main executor in realization of projects on creation of UAV	1) low 2) sufficient 3) high

Table 6

Qualitative assessments of the 3rd (factor) group of indicators
II – subgroup

Indicator	Quality assessment rule
Availability of the necessary basic technologies, parts and products of intersectoral use	1) absent 2) partially available 3) available
The degree of feasibility of Tactical and technical requirements based on the results of design calculations and justifications	1) low 2) satisfactory 3) high
Number of co-contractors, including foreign suppliers of components)	1) a large number 2) moderate 3) insignificant
The level of implementation of the latest technologies for sample production, the use of modern computer-aided design systems (CAD and CALS-technologies, etc.) in the process of sample development	1) low 2) satisfactory level 3) sufficient level
The level of dependence on purchased products, including scarce and foreign production	1) high 2) moderate 3) low

The assessment of these indicators was subsequently recommended by assigning valuation coefficients.

The key element of the proposed methodology of project risk evaluation is to determine the degree of expectation of negative scenarios development (occurrence of risk-taking factors) and to determine the resulting level of risk in the implementation of the studied project of building a sample of aviation technology.

This methodology is based on the provisions of the method of imprecise logical derivation, which ensures the use of qualitative estimates of the natural language (expert estimates) to obtain quantitative characteristics of the output variables.

In this approach, it is considered appropriate to consider the characteristics of projects in terms of fuzzy set theory as linguistic variables.

The use of methods for obtaining risk assessments based on fuzzy logic allows the use of both quantitative characteristics, which are objectively characterized by uncertainty, and qualitative, subjective assessments of experts, expressed in vague concepts, as well as formalize fuzzy descriptions using fuzzy numbers, sets, linguistic variables and vague evidence. The structural and logical scheme of the proposed method for assessing the level of expectation of the risk of the project of creating aircraft ba sed on the application of the fuzzy logic method is shown in Fig. 15.
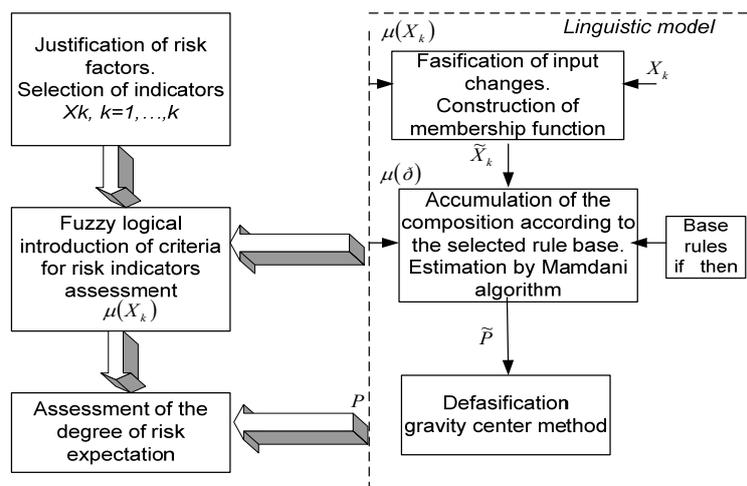

Fig. 15. Algorithm of the methodology for assessing
the level of expectation of the risk of project implementation

In accordance with the above algorithm, the basis of this technique is:

1) presentation of risk indicators defined in the work in the form of fuzzy numbers. Construction of membership functions of values of input variables on the chosen universe (fassification of input variables);

2) construction of a linguistic model, activation and composition of subconclusions in accordance with the base rules of logic IF — THEN;

3) accumulation of conclusions of fuzzy product rules;

4) bringing the initial parameter (the degree of expectation of risk) to clarity (defasification of the original variable).

The complete set of rules within the implementation of the selected Mamdani algorithm forms the basis of logic type IF — THEN, which is formed by specialists (experts) of the subject area in the form of a set of fuzzy production rules of the *P* type.

Given the reasonable groups of indicators in the second chapter, namely four groups of five indicators each, the general rule will be:

P 1.1: if *a* is *A1* and *b* is *B1* and *c* is *C1* and *d* is *D1*
and *e* is *E1,* then *f* is *F1*;
P 1.2: if *a* is *A2* and *b* is *B2* and *c* is *C2* i *d* is *D2*
and *e* is *E2,* then *f* is *F2*;
…
P1.n: if *a* is *An* and *b* is *Bn* and *c* is *Cn* and *d* is *Dn*
and *e* is *En,* then *f* is *Fn,*

where *a, b, c, d, e* — input variables (names for known data values); *f* — output variable (name for data values to be calculated); A, B, C, D, E are membership functions defined for *a, b, c, d, e,* respectively.

In the statement of the dissertation research problem, the input variables are the risk indicators of the aircraft development projects, the output variable is the level of the expected risk of the project implementation.

Examples of production rules for risk assessment of the project of creating a sample of aircraft based on the indicators substantiated in the second chapter, namely, on the example of the 2nd group of indicators in accordance with the table 5.

IF *Scientific and technical level — sufficient and qualification level of the main executor м high and degree of novelty of the project (innovation) — modernization and scientific and technical level of the sample — exceeds analogues and level of production-technological and experimental-testing base м advanced, then the degree of expectation of risk — the risk is minimal”*;

IF *Scientific and technical backlog — unsatisfactory I Qualification level of the main*

executor — low-skilled I Degree of novelty of the project (innovation) — fundamentally new development I Scientific and technical level of the sample — does not correspond to modern tendencies I Level of production-technological and experimental-testing base the degree of expectation of risk — the risk is extreme.

As can be seen, the example shows two extreme (the most optimistic and the most pessimistic) values of the evaluation of parameters that allow to draw unambiguous conclusions. When considering real projects, such unambiguous estimates of indicators are unlikely, which further encourages the use of additional iterations and algorithms for processing multivariate parameters.

The proposed method is based on the developed and researched in the framework of the linguistic model of quantitative assessment of risk indicators of the project to create a sample of JSC to determine the level of expectation of risk based on the results of the assessment of a group of indicators.

Input variables will be vague, namely previously defined risk indicators of the second group:

“Scientific and technical reserve”;

“Qualification level of the main executor”;

“Degree of novelty of the project”;

“Scientific and technical level of the sample”;

“Level of production-technological and experimental-testing base”.

Formalization of input model variables is done using the Harrington scale [5]

Further construction of membership functions ($\mu_a(X_j)$, $\mu_b(X_j)$, $\mu_c(X_j)$, $\mu_d(X_j)$, $\mu_c(X_j)$) each of the input linguistic variables is carried out by an indirect method where the expert information is only the source information for further processing by pre-formulated conditions.

In order to carry out further calculations, piecewise linear approximation functions of belonging of linguistic values of the linguistic variable “scientific and technical backlog” are constructed. In this case, the membership function of linguistic meaning — “unsatisfactory” given its extreme position and uncertainty of the type “low level” [6] is taken *Z*-linear in nature and is based on the following analytical expression:

The functions of belonging to the linguistic meaning — “satisfactory” given its average position in a particular universe and uncertainty of the type “small value” [6; 7] takes the forum trapezoid and are built on the following analytical expression:

The functions of belonging to the linguistic meaning — “satisfactory” given its average position in a particular universe and uncertainty of the type “small value” [6; 7] takes the forum trapezoid and are built on the following analytical expression:

$$\mu(x; a, b) = \begin{cases} 1, & x \le a; \\ \dfrac{b-x}{b-a}, & a < x < b; \\ 0, & b \le x \end{cases} \qquad \begin{array}{l} a_1 = 0,1, \\ b_1 = 0,4 \end{array} \qquad (7)$$

$$\mu_A^{Rk}(X_{Rk}, a, b, c, d) = \begin{cases} 0, & x \le a; \\ \dfrac{x-a}{b-a}, & a \le x \le b; \\ 1, & b \le x \le c; \\ \dfrac{d-x}{d-c}, & c \le x \le d; \\ 0, & d \le x \end{cases} \qquad \begin{array}{l} a_2 = 0,1, \\ b_2 = 0,4, \\ c_2 = 0,6, \\ d_2 = 0,9 \end{array} \qquad (8)$$

The membership function of linguistic meaning — "sufficient" given its extreme position and uncertainty of the type "great value" [8; 9] is taken S — linear form and is based on the following analytical expression:

$$\mu(x; a, b) = \begin{cases} 0, & x \le a; \\ \dfrac{x-a}{b-a}, & a < x < b; \\ 1, & b \le x \end{cases} \qquad \begin{array}{l} a_3 = 0,6, \\ b_3 = 0,9 \end{array} \qquad (9)$$

Further, in accordance with the algorithm for assessing the risks of projects for the creation of samples of aircraft, as shown in Fig. 16, membership functions are constructed for each of the other linguistic variables of the group of indicators. That according to the applied algorithm "Mamdani" allows to carry out fassification of the selected input variables. The further modeling process is performed using a specialized package Fuzzy logic Toolbox environment MATLAB [10].
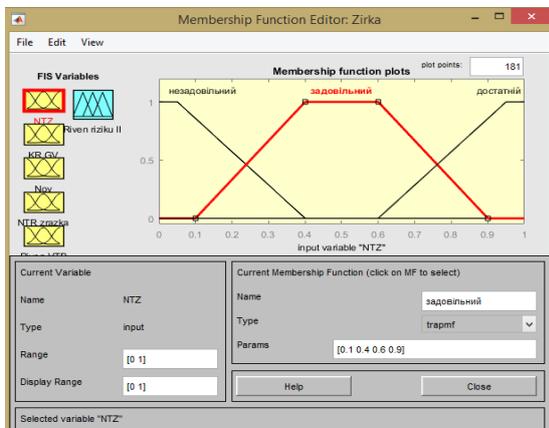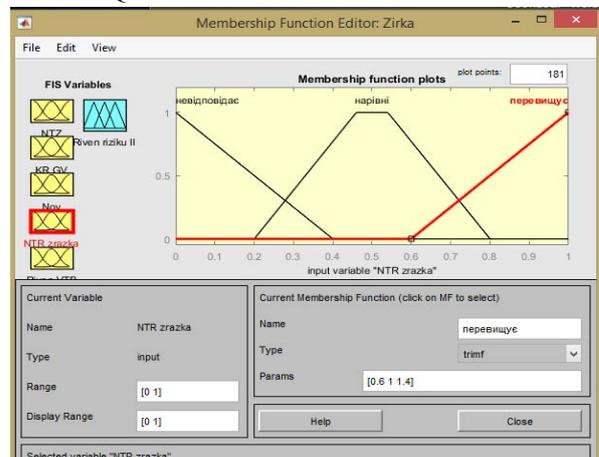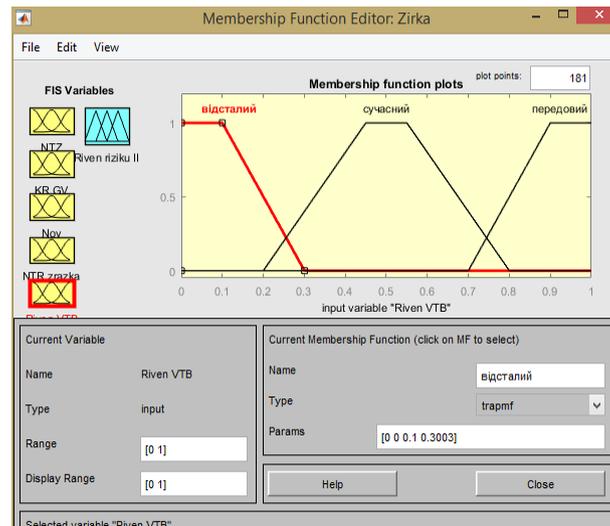

a — Scientific and technological advancement
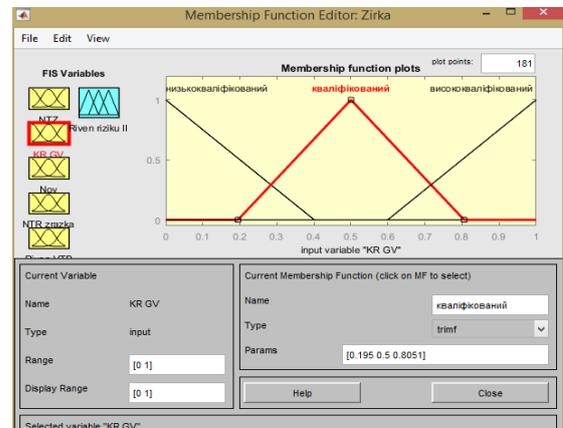
b — Qualification level of the main executor
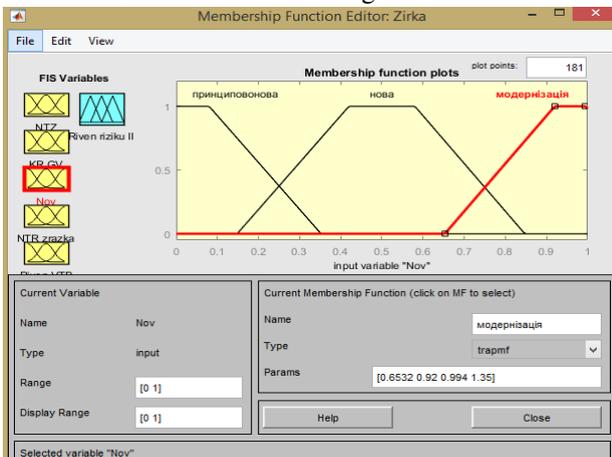
c — Degree of project novelty

d — Scientific and technical level of the sample

e — The level of production and technological and experimental test base

Fig. 16. Graphical view of the dependency function of the input variables
of the II-nd group of risk indicators in MATLAB

The level of risk expectation based on the results of the study and joint assessment of group II indicators will be a fuzzy initial variable.

The linguistic variable ⟨p, T, X, M⟩ is introduced, where *p* is the level of risk expectation; T – {"minimal", "moderate", "significant", "high", "extreme"}; X – [0,1]; M – task procedure on X = [0,1] fuzzy sets R_1 = "Minimal risk", R_2 = "Moderate risk", R_3 = "Significant risk", R_4 = "High risk", R_5 = "Extreme risk". Fig. 17 shows the membership function of fuzzy term sets of a linguistic variable "Riven riziku II".
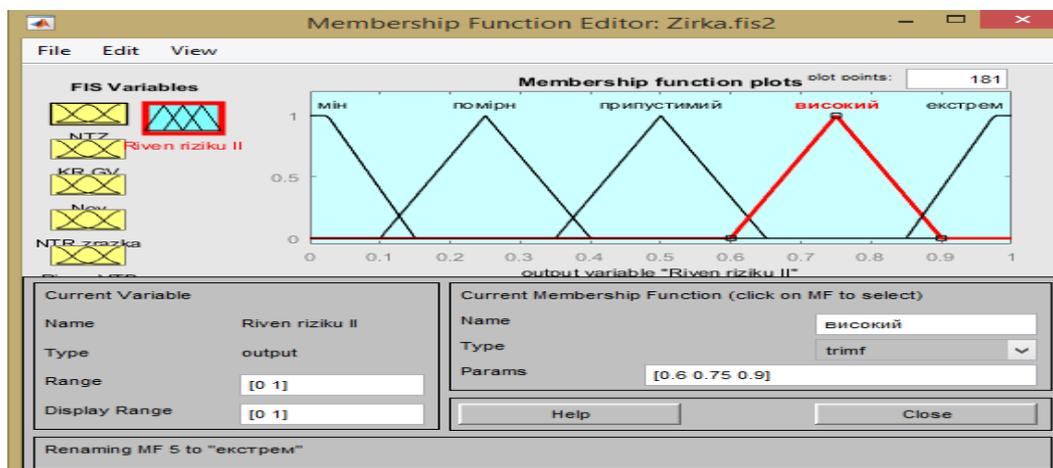

Fig. 17. Graphical view of the membership function of possible values
of the output variable of the II group of risk indicators in the MATLAB

Conclusions

Thus, the paper presents the principle of improving the existing scientific and methodological apparatus of project risk assessment taking into account the peculiarities of UAV development projects, the possibility of applying fuzzy set theory for its implementation to predict the level of expected risk of relevant projects. It is established that this approach allows to obtain quantitative estimates of risk indicators in the absence of the required volume and low reliability of statistics and the practical impossibility of formalizing the process under study.

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Зірка А., Зірка М., Кадет Н.
ОСОБЛИВОСТІ ОЦІНКИ РИЗИКІВ ПРИ СТВОРЕННІ ЗРАЗКІВ БЕЗПІЛОТНОЇ АВІАЦІЙНОЇ ТЕХНІКИ РІЗНОГО ПРИЗНАЧЕННЯ

Один із перспективних напрямів розвитку сучасної авіації пов'язаний із проектуванням та виробництвом безпілотних літальних апаратів (БПЛА) різних функціональних можливостей для застосування у військовій та цивільній сферах. Процес проєктування та виробництва сучасної безпілотної авіаційної техніки пов'язаний з багатьма факторами невизначеності, що призводить до появи відповідних ризикоутворюючих факторів. При цьому, за результатами проведеного аналізу спостерігається недосконалість застосованих при цьому систем підтримки прийняття рішень на стадіях створення зразків. Так на теперішній час не набув достатнього розвитку для практичної реалізації програмно-апаратний комплекс управління ризиками проєктів створення складних технічних систем, зокрема і БпАК. У застосованих на теперішній час підходах констатовано не повний набір індикаторів ризику, зокрема технічного характеру. А застосований, у більшості випадків, апарат теорії імовірностей здебільшого обмежено нерозвинутою базою даних достовірних статистичних показників для користувачів широкого загалу.

У роботі, за результатами аналізу попереднього досвіду виконання дослідно-конструкторських робіт з розробки зразків авіаційної техніки, зокрема і безпілотної, визначено основні ризикоутворюючі фактори та можливі негативні сценарії виконання проектів створення зразків безпілотної авіаційної техніки.

На підставі визначених ризикоутворюючих факторів запропоновано методичний апарат обґрунтування індикаторів ризиків реалізації проектів створення (модернізації) зразків безпілотної авіаційної техніки.

Запропоновано методичний підхід до критеріальної оцінки індикаторів ризиків на різних стадіях виконання дослідно-конструкторських робіт з розробки (модернізації) безпілотної авіаційної техніки.

Ключові слова: система підтримки прийняття рішення, безпілотний літальний апарат, система управління, моделювання руху, режим польоту, лінгвістична модель.

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FEATURES OF RISK ASSESSMENT IN THE CREATION OF UAV FOR VARIOUS PURPOSES

One of the perspective directions of the development to modern aviation is connected with designing and producing unmanned aerial vehicles (UAV) of various functionalities for applying in military and civilian spheres. The process of designing and producing state-of-the-art airplane-less technology involves many factors of ambiguity, leading to the emergence of corresponding risk-impacting factors. However, the results of the analysis show that the decision support systems used in this process are insufficient at the stages of the creation of the designs. Thus, at present, the hardware-software system for risk management of complex technical systems, including unmanned aerial vehicles has not been sufficiently developed for practical implementation. The approaches currently used do not state a complete set of risk indicators, including technical ones. And the applied, in most cases, apparatus of probability theory is mostly limited by an underdeveloped database of reliable statistical indicators for the general public.

The work, based on the results of the analysis of the previous experience of research and development work on the design of airplane technology, in particular of the pilotless technology, identifies the main risk-taking factors and possible negative scenarios for the development of pilotless designsю.

The main risk-taking factors and possible negative scenarios for the implementation of the design of unmanned aircraft models were identified.

In the article on the basis of the analysis of the reasons of involvement in performance of research and development works the basic risks of the indirect factors and possible negative scenarios of performance of projects of creation of samples of aviation equipment are defined.

Based on the results of the analysis of risk-forming factors, the risk indicators of the projects of creation (modernization) of aircraft models are substantiated.

A methodical approach to the criterion assessment of risk indicators at the stages of research and development work on the development (modernization) of aircraft is proposed.