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A METHODOICAL APPROACH TO THE SELECTION OF COMPOSITION
AND PLACEMENT OF ON-BOARD EQUIPMENT IN THE
MODERNIZATION OF MILITARY AIRCRAFT

Abstract. The main provisions of solving the problem of multi-criteria selection of the composition
and placement of the option of on-board equipment during the modernization of military aircraft
are considered.

Keywords: combat aircraft, on-board equipment, modernization, multi-criteria choice.

Expanding the combat capabilities of military aircraft by updating the composition of their on-board equipment and equipping them with new developments is a modern world trend. However, not all military aircraft modernization projects are equally successful. The possibility of ensuring a significant improvement in the level of technical excellence, the main characteristics that determine combat effectiveness, at relatively low costs, as in the program of modernization of B-52N aircraft to the level of Pacer Plank [1], F-16 to the level of Block 50/52 [2, 3], cannot be compared with the effectiveness of the MiG-21 modernization programs based on the MiG-21-93, MiG-21-2000 variant, when it was possible to ensure a slight increase in combat capabilities at a cost of $4 million per aircraft [4].

It should be recognized that this problematic situation has many reasons, but the decisive one among them is the inefficient subjective choice of composition and placement of on-board equipment during modernization. The complexity of the choice is determined by the number of possible options, which increases factorial with the growth of the number of developed new models of on-board equipment.
Thus, when replacing five types of equipment samples \( (n = 5) \) with new ones from 6 possible samples of each type \( (m = 6) \), there are possible composition and placement options \( N = n^m \cdot n! = 1875000 \). For \( n = 10 \) and \( m = 8 \) this number will already make \( 3.63 \cdot 10^{14} \) options. Therefore, with an increase in the number of options, the probability of an unsuccessful subjective choice increases proportionally.

In the future, the situation will worsen. The transition to a new microprocessor base will increase the number of manufacturers and, accordingly, different in terms of technical solutions, but competitive models of onboard equipment, and the natural decrease in the resource indicators of aging military aircraft, which limits the budget of modernization programs, will significantly complicate the search for options for the composition and placement of onboard equipment.

For Ukraine, this may negatively affect the implementation of the military aircraft modernization program, which is recognized as basic for ensuring the combat potential of the Ukrainian Army's aviation in the near and medium term.

The qualitative improvement of the options for choosing the composition of onboard equipment during the modernization of military aircraft is connected with the ideology of multi-criteria selection. Methodological foundations for this already exist - a general scheme of formalization of multi-criteria selection problems has been developed, specific methods of their solution have been studied [5...9], but the area of research that takes into account the peculiarities and properties of a specific subject area, requirements and limitations in the implementation of general methods remains insufficiently developed multi-criteria selection. It should be noted that taking into account the specifics of the modernization of military aircraft during the implementation of a multi-criteria selection of options for replacing on-board equipment has clearly not been developed sufficiently. Thus, the purpose of the report is to present the results of personal research on the possibility of multi-criteria selection of composition and placement of on-board equipment during the modernization of military aircraft without the use of subjective additional information.
In general, the task of choosing the composition and placement of on-board equipment during the modernization of military aircraft can be represented by a combination of two main elements

\[ \{ \Omega_X, I \} \]

where \( \Omega_X \) is a set of \( n \)-dimensional vectors of possible options for the composition and placement of the on-board equipment of the park \( X_i \) \((i = 1..N)\) and their corresponding \( M \)-dimensional vectors of parameters \( \overline{A}_i \) (the value of the components \( \overline{A}_i \) is determined by the characteristic vectors \( \overline{a}_j \) of specific equipment samples \( X_j \) from which the selection is made \((j = 1..n))\); \( I \) is a system of preferences of the decision-making management structure, i.e. a set of relationships of preference of one option over another \((X_i \succ X_j)\) according to their indicators \( \overline{A}_i, \overline{A}_i \).

Then the choice task consists in determining the set of such options \( \Omega_X^* \) that are the best in the set \( \Omega_X \) with respect to the system of preferences of the decision-making management structure \( I \).

Features of the problem under consideration are:

– the absence among equipment samples of those that have an advantage over others in terms of all characteristics \( \overline{a}_j \), that is, the choice is made only among competitive equipment samples;

– the absence of any form of external additional information to find a compromise solution, i.e. a choice is considered without the influence of a subjective factor.

So, the problem of multi-objective choice is considered in the conditions of a finite set of options, complete initial deterministic information about the options and the absence of external additional information. An essential requirement for its solution is an effort to obtain procedures suitable for practical application, rather than an abstract mathematical solution method. That is why it is important to obtain
a small set $\Omega_X^*$ of effective choices.

The first stage of solving problem (1) is the formation of a vector criterion $\vec{J}(\vec{X})$ that adequately reflects the system of advantages $I$ of the decision-making management structure. At the same time, the chosen approach to the search of the set $\Omega_X^*$ does not involve the use of any convolutions, the introduction of subjective weighting factors, priorities when the vector of selection criteria is determined. Therefore, propose to form a vector selection criterion $\vec{J}(\vec{X})$ from the components of the parameter vectors $\vec{A}_i$ describing the properties of each of the options $\vec{X}_i$, according to the structure

$$\vec{J}(\vec{X}_i) = \begin{bmatrix} \vec{J}_t(\vec{A}_i(\vec{X}_i)) \\ \vec{J}_r(\vec{A}_i(\vec{X}_i)) \\ \vec{J}_f(\vec{A}_i(\vec{X}_i)) \end{bmatrix}$$

(2)

where, $\vec{J}_t(\vec{A}_i(\vec{X}_i))$ - a vector of "target" components $\vec{J}(\vec{X}_i)$ that characterize the properties of aircraft as a means of performing combat tasks (for example, the range of target recognition, the number of targets for simultaneous observation and targeting, the range of conditions for the use of air weapons, etc.); $\vec{J}_r(\vec{A}_i(\vec{X}_i))$ - a vector of "resource" components $\vec{J}(\vec{X}_i)$, which determine the resource costs for the implementation of this variant of replacing the on-board equipment (primarily, the cost of equipment, the cost of works, average operating costs, etc.); $\vec{J}_f(\vec{A}_i(\vec{X}_i))$ - the vector of "flight" components $\vec{J}(\vec{X}_i)$ that characterize the aerobatic and flight technical properties of the aircraft, the level of flight safety under the condition of choosing a given option of on-board equipment (for example, the deviation of the flight mass of aircraft from the nominal, the deviation of the centering of aircraft from the normal, the deviation of the electric power of consumers from nominal, etc.). The proposed structure corresponds $\vec{J}(\vec{X}_i)$ to the conflicting objectives of the decision-making management structure when choosing an option for on-board
equipment for modernization:

– firstly, the chosen option should provide the best tactical and technical properties of aircraft as a means of performing combat tasks;

– secondly, the chosen option should have the lowest resource costs during implementation;

– thirdly, the chosen option should have as little impact as possible on the flight-technical properties of aircraft and the level of flight safety.

For the conditions of the problem under consideration, it is determined that the components of the "target" and "resource" parts \( J(\bar{X}_i) \) are linearly dependent on the values of the components of the vectors \( \bar{A}_i \), and for the "flight" part, this dependence should be considered in the form of penalty functions.

The general methodology of multi-criteria selection consists in the formation of a Pareto set of choice options and its refinement or reduction based on additional information and specific features of the subject area under consideration. The well-known procedure for forming the Pareto set \( \Omega^P_X \) involves sequential consideration and comparison of options for problem (1) and requires \( \frac{1}{2} \cdot M \cdot N \cdot (N-1) \) comparison operations.

It is proposed to implement a scheme of sequential selection before determining the set of Pareto options. It is suggested at the first stage to find a set of options that are not worse relative to the "flight" component \( J_f(\bar{A}_i(\bar{X}_i)) \), i.e.

\[
\bar{X}_i \in \tilde{\Omega}_X : \quad J_f(\bar{A}_i(\bar{X}_i)) \leq J_f(\bar{A}_j(\bar{X}_j)) \quad i = 1..N, \quad i \neq j.
\]  

At the second stage, it is necessary to implement the well-known iterative procedure for finding elements of the Pareto set of options among \( \tilde{\Omega}_X \).

The principle basis for the application of the sequential selection scheme is the possibility of dividing the set of options \( \Omega^P_X \) into two sets of options that differ in strength: sets whose elements have an advantage in terms of the "flight" component
The function \( J_f(\bar{A}_i(\bar{X}_i)) \) and those that do not have such an advantage. Since the power of the set \( \tilde{Q}_X \) is much smaller than the power of the set \( Q_X \), the implementation of the proposed scheme of sequential selection will allow to reduce the number of necessary operations for the determination by \( \frac{M}{M_f} \) times (where \( M_f \) is the number of components \( J_f(\bar{A}_i(\bar{X}_i)) \) and practically implement the procedure of multi-criteria selection of on-board equipment for the modernization of military aircraft.

According to the multi-criteria selection methodology [9], finding the Pareto set according to the given vector criterion is already a mathematically justified sufficient solution to the given problem. For its further specification, according to the Edgeworth-Pareto principle [10], it is necessary to use additional information.

In order to obtain a practically important solution to the problem of multi-criteria choice without the involvement of subjective additional information, it is proposed to consider the integral characteristics for each option belonging to the Pareto set \( \bar{X}_i \in \Omega_X \)

\[
\mu(\bar{X}_i) = \sum_{j=1}^{N} \sum_{k=1}^{M} \left( J_k(A_k(\bar{X}_i)) - J_k(A_k(\bar{X}_j)) \right)^2
\]

where \( N \) is the number of elements in the Pareto set.

Characteristic (4) is the total Euclidean distance in \( M \)-dimensional space between the point corresponding to the variant \( \bar{X}_i \) and the points corresponding to other variants and reflects its fundamental features [10].

Thus, options \( \bar{X}_i \) from the set \( \Omega_X \), the characteristics \( \mu(\bar{X}_i) \) of which do not have great values, are compromises, where due to the deterioration of some tactical and technical indicators, improvement is achieved due to the influence of others. The difference between the variants of this group is in the format of mutual compensation of parameter changes.
On the contrary, the options $\overline{X}_i \in \Omega^P$ in which the values of the characteristics $\mu(\overline{X}_i)$ are significantly greater than the average have a special weight for the decision-making management structure. These options are able to provide extreme capabilities of aircraft as a model of weapons, for example, the largest target detection range, the largest range of weapons for use, the largest range of conditions for the use of weapons, etc.

The choice of such options is a condition for significantly increasing the combat capabilities of aircraft after modernization. The given research methodology confirms the existence of a theoretical possibility of reducing the negative impact of a subjective factor on the results of choosing options for on-board equipment for the modernization of military aircraft. The methodical basis for increasing the level of objectivity of decision-making in the process of modernization of military aircraft is the proposed structure of the vector selection criterion, the procedure for sequential selection of the modernization option, taking into account the specific features of the subject area under consideration.

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