Economic feasibility of modifications to the design of transport aircraft

Sergeys IGNATYEVS*,[1], Sergey A. MAKUSHKIN[2], Sergiy SPIVAKOVSKYY[3]

*Corresponding author
[1]Faculty of Economics and Management, Baltic International Academy,
4 Lomonosova Str., LV-1003, Riga, Latvia,
stranik7@inbox.lv*
[2]Faculty of Management, Russian State Social University,
4 Wilhelm Pieck Str., 129226, Moscow, Russian Federation,
anna_lakomkina@mail.ru
[3]Department of Business, Higher Colleges of Technology,
Corniche Road, 25026, Abu Dhabi, United Arab Emirates,
sergey_spi@yahoo.com

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Abstract: *The relevance of the subject matter is conditioned by the need to fully justify the implementation of modifications to the structures of transport aircraft from an economic standpoint, in order to save money during their construction and improve the functioning of the system for planning further design developments in this line. The purpose of this study is to establish a coherent model of the economic feasibility of aircraft modifications, which allows effectively solving the issues of cost savings in their design and subsequent launch into mass production and operation. The leading approach in this study is a combination of analytical research of the issues of transport aircraft modification with empirical research of the economic feasibility of such measures, in the context of creating a coherent concept of the need for a set of measures to improve the structure of air transport. The findings indicate the presence of a clear relationship between a wide range of parameters that determine the indicators of economic feasibility of modernizing transport aircraft, as well as significant economic advantages of a high-quality modification of the aircraft design.*

Key Words: *aviation, design modifications, transport aircraft, economic feasibility*

1. INTRODUCTION

The problems of improving the design characteristics of aircraft are very acute in the context of their high operational cost and the need to bring them into compliance with international standards of air transportation. The current situation leads to the forced operation of the aircraft for a significant period of time (up to 25-30 years) without carrying out a high-quality overhaul and with very high intensity (up to 3,500-4,500 flight hours) for one year. Such a situation leads to a decrease in the safety of air transport in the conditions of almost constant resource utilization of the operated aircraft [1]. According to estimates of foreign experts in the aviation industry, the resources of air transport operated on international airlines amount to up to 50,000-60,000 flight hours, which corresponds to approximately 25,000-30,000 flights,

without major repairs of the aircraft. In the current situation, the issues of assessing the economic feasibility of modifications to the design of transport aircraft, in order to improve it and create optimal conditions for safe air transport, are of particular importance [2]. This requires a thorough study of the possibilities of making modifications to the design characteristics of aircraft currently in operation to determine the economic feasibility of such a process.

The economic feasibility of modifications to the design of transport aircraft is designed to contribute to the effective solution of the problems of the management of air transport in general. To date, air transport is still considered one of the safest, given the frequency of accidents on international and domestic lines. At the same time, the durability of effective practical operation of aircraft is usually limited to the maximum permissible condition of the air vehicle, determined by the standards established during its design and construction. For different types of aircraft built in different conditions and using different technological solutions, these standards may differ significantly. At the same time, the established requirements of the normative technical documentation (NTD) are considered mandatory, since their non-compliance can cause serious accidents during the aircraft operation [3].

Since the USSR, there have been significant differences between the existing system of control over the safety of the operation of air transport and the one adopted in the United States or European countries. The main differences were in the use by Soviet engineers of a step-by-step determination of the service life of the aircraft and its real resource, while abroad there was a weighted assessment of the actual technical condition of the aircraft according to the total indicators. In the former USSR, a conditional division was assumed into the stages of operation of the aircraft, the duration of which was determined according to the practical inter-repair resource [4]. At the time of putting the fleet of air transport vehicles into operation, such a resource was assumed at the level of 5,500-6,500 flight hours, which approximately corresponded to 3.5-4 years of service. Carrying out modifications to the design of the transport aircraft immediately before its commissioning allowed significantly increasing the mentioned indicators. Such a measure had a favorable effect both on the overall condition of the vehicle and on the safety of its subsequent practical use, as well as significantly increased the time intervals between repairs.

At the same time, the modification of transport aircraft in the future is of great importance in terms of reducing operating costs, aimed at maintaining the aircraft in working condition for as long as possible [5]. Taking into account the significant number of transport aircraft that are currently operated on domestic and international airlines, this problem is very relevant throughout the state and requires detailed consideration. A qualitative assessment of the economic efficiency of aircraft structure modifications is necessary for a comprehensive solution of the issues of managing the fleet of aircraft in the country and optimizing the state budget funds allocated annually for the development of the aviation industry in the country.

2. METHODS

This study used a combination of analytical research of the issues of transport aircraft modification with empirical research of the economic feasibility of such measures, in the context of creating a coherent concept of the need for a set of measures to improve the structure of air transport. The chosen combination of research methods allows conducting an objective and balanced study of the economic feasibility of modifications to the design characteristics of aircraft currently operated on internal and external airlines, in order to optimize the costs of their operation. In addition, the methodology of this study includes economic calculations for

the purpose of practical determination of the economic efficiency of carrying out modifications to the structure of the air transport. The basis of this research is numerous theoretical and practical developments of researchers, devoted to the issues of economic feasibility of modifications of the design features of transport aircraft, to improve their flight characteristics and reduce operating costs for the maintenance of the aircraft. In order to form the most objective, qualitative picture of the study and to facilitate the perception of the information provided, all scientific developments borrowed from the Russian authors presented in this study were translated into English. Thus, the methodological basis of this study was selected in strict accordance with the stated topic and assumes the highest quality of its disclosure, both from a theoretical and practical standpoint. This study was carried out in several stages.

1. The first stage included a theoretical study of the possibilities of carrying out structural modifications of currently operated air transport, in order to improve its operational characteristics, as well as an assessment of economic feasibility of the need for such operations, in order to generally reduce operating costs when servicing a modern fleet of transport aircraft.

2. The second stage included a calculation study of the possibilities of evaluating economic feasibility for making structural improvements to the design of transport aircraft, with the implementation of all the necessary calculations and practical feasibility evaluation. At the same time, in the course of the necessary calculations, specific results were obtained, which were subject to comparison with the results obtained by other researchers who dealt with the problems of economic feasibility of structural modifications of modern transport aircraft.

3. The final stage included formulation of conclusions that serve as a practical reflection of the results obtained, and summarise the theoretical and practical research carried out in the course of the study. The conclusions contain the main information obtained during the study of various aspects of the economic feasibility of modifications to the design of modern transport aircraft.

3. RESULTS

The design characteristics of the currently operating air transport are of significant importance in terms of ensuring the safety of air transport and optimising the operating costs of maintaining the transport aircraft [6]. Modern computer technology has reached such a level of development that numerical modelling of load distribution on the structures of air vehicles does not present significant complexity [7]. At the same time, the issues of economic feasibility of performing such operations are at the forefront today, since making modifications to existing structural solutions can entail significant resource costs and affect the financial condition of the entire industry. In this context, it is necessary to create a qualitative model for calculating the economic feasibility of the aircraft design modification, taking into account the peculiarities of operation in specific conditions [8]. For this purpose, it is necessary to designate the concept of durability of the modified design of the air transport, which has the value of:

$$D_{mod} = KD_{ini} \tag{1}$$

where D_{ini} – value of the durability of the initial structure, without modification; K – the coefficient of damage to the structure of the transport during operation.

In turn, the value of the damage coefficient is taken as the ratio:

$$K = \frac{M^t_{bend\ mod}}{M^t_{bend\ ini}} \tag{2}$$

where $M^t_{bend\ mod}$ – parameter of the equivalent bending moment in the control section of the structure for a typical flight of a modified aircraft; $M^t_{bend\ ini}$ – the parameter of the bending moment in the control section of the structure for a typical flight of the aircraft until the modification is carried out.

The parameters that determine the control value of the K coefficient are determined experimentally in each specific case, and depend on the type of aircraft, its structural and operational characteristics, and the features of conducting design tests [9].

At the same time, to calculate the temporary economic effect of carrying out modifications, it is necessary to take into account the indicators of the time of operation of the aircraft after making changes, as well as the nature of possible repair work [10]. To this end, it is necessary to focus on the experience gained in this industry in assessing the economic feasibility of aircraft modifications, which takes place in foreign companies [11]. According to the methods available today, the economic costs of modification of the aircraft are determined by the equation:

$$E_c = \left(C_c + C_{sp} + C_{ic} + C_{tp} + C_{ma} + C_{in}\right)K_{ir}K_{dr} \tag{3}$$

where C_c – the cost of components required for the aircraft modification; C_{sp} – the cost of spare parts required for the aircraft modification; C_{ic} – the cost of completion of individual components of the aircraft after the completion of the main work on its modification; C_{tp} – the cost of work on the necessary training of personnel servicing the aircraft after its modification; C_{ma} – the cost of the maintenance of the transport aircraft; C_{in} – the cost of insurance of the aircraft; K_{ir} – inflation rate; K_{dr} – depreciation rate.

At the same time, the aircraft modification can be carried out taking into account the current emergency condition, which implies the need to determine the accident rate to clarify the calculations [12]. This value is determined by the ratio:

$$K_{acc} = \frac{B}{T} \tag{4}$$

where B – the number of breakdowns per unit of time; T – the time interval under study.

Taking into account all of the above, the model for calculating the economic feasibility of modifying the design of air transport is a function of many variables that are interrelated and determine both the current state of the aircraft and the potential opportunities for improving it by making changes to the design [13].

When assessing the cost-effectiveness of the aircraft modernisation, special attention should be paid to the operating time of the aircraft after the completion of its modernisation. In this context, the determining factor is the value of the coefficient of modification utility (Ω), which is the ratio of the actual service life of an aircraft, calculated based on the modernisation performed, and the planned one, determined directly during the design and construction works:

$$\Omega = \frac{T_{aot}}{D_{ini}} \tag{5}$$

where T_{aot} – the actual operating time of the aircraft, calculated taking into account the completed modernisation; D_{ini} – the planned service life of the aircraft, the value of the durability of the original design without modification.

For example, if, for the planned 40,000-60,000 flight hours, the Dini value is set to 30 years of operation, and after the aircraft modernization, the T_{aot} indicator was 45 years, the value of the coefficient Ω will be:

$$\Omega = \frac{45}{30} = 1.5 \tag{6}$$

Thus, with values of the coefficient Ω greater than 1, there is a practical benefit from the modernization, which is expressed in an increase in the service life of an aircraft.

This coefficient is used when calculating the economic efficiency indicator from the work on the modernization of transport aircraft. Assume D_{ini} = 30 years and the structural damage coefficient K = 0.25, the D_{mod} value will amount to 0.25×30=7.5.

In this case, the indicator of economic efficiency from the modernization of the transport aircraft can be presented in the form of the ratio:

$$\mathrm{E_{ef}} = 100\% \frac{\Omega}{D_{mod}} = 100\% \frac{1.5}{7.5} = 20\% \tag{7}$$

Thus, in this case, taken as an example, the economic efficiency of the modernization of the aircraft will be 20%.

The diagram presented in Figure 1 shows the dependence of the service life of an aircraft (Y-axis) on the coefficient Ω (X-axis) with a constant indicator of the accident rate (K_{acc}).

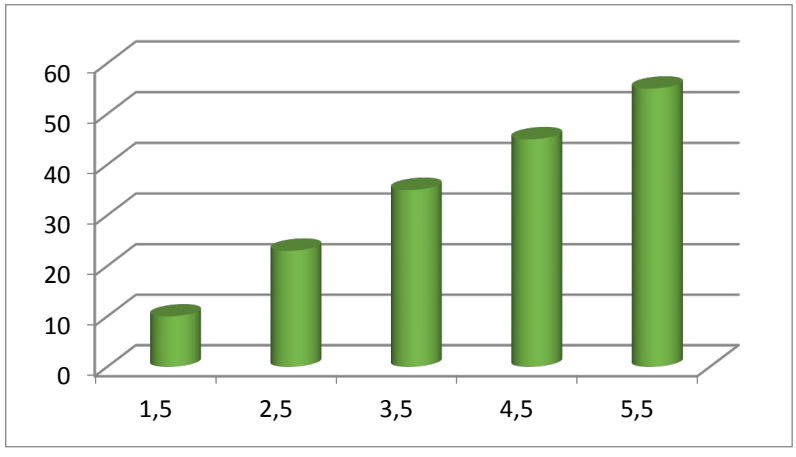

Fig. 1 – The dependence of the service life of the transport aircraft on the coefficient of modification utility

As can be seen from the data presented in Figure 1, an increase in the coefficient Ω invariably leads to an increase in the overall service life of the aircraft, and, consequently, has a positive effect on the economic component of this process. Thus, it can be concluded that when evaluating the economic feasibility of aircraft modification, it is necessary to take into account the final service life of the aircraft after its modification, since without increasing this indicator, it is not expedient to discuss the economic feasibility of this process [14].

An effective model for calculating the economic feasibility of aircraft design modification involves taking into account changes in many factors over time, as a mandatory component of the accuracy and timeliness of calculations [15]. Over the course of the operation of the transport aircraft, numerous changes in its design characteristics occur, which subsequently determine the indicators of the durability of the aircraft operation and the safety of transportation in general. Modifications of aircraft structures are possible at any stage of

operation, both after the identification of newly appeared defects, and as a result of scheduled work [16]. In any case, the work on improving the designs of the transport aircraft in operation is designed to contribute to the effective solution of the problems of improving their flight characteristics, regardless of the presence or absence of certain operational problems [17].

The creation of an effective economic model for improving the design of the operated air transport allows significantly reducing the costs of its subsequent operation with a parallel increase in the service life of the aircraft, provided that the specified aircraft is not repaired for a long time [18], [19]. The standards of airworthiness of the aircraft put forward such requirements for its design features that a wide range of loads, both mechanical and thermal, should not significantly affect the integrity of the aircraft structure and cause its premature destruction [8]. Admittedly, this can only be achieved if modern, high-tech and high-strength materials are used in the design of an air transport that can ensure strict compliance with the requirements of technical documentation standards [20]. Otherwise, it will be impossible to economically justify the need to modify the design of aircraft, taking into account all the variety of factors that affect the safety of their subsequent operation.

4. DISCUSSIONS

It has long been known that the aircraft industry and other high-tech industrial sectors act as an "innovative locomotive" of any economy without exception. At the same time, applied study of the economic feasibility of modernization of an already built aircraft equipment, as a rule, solves the problem of determining the most rational ways to improve the operated aircraft, taking into account their technological characteristics [21].

For each stage, based on the experience of operation, the results of laboratory tests of the full-scale design and the forecast of the expected operating conditions of the aircraft, the resource value and service life are established, as well as the conditions for their development, under which flight safety is guaranteed. During the aircraft operation, at each stage, certain information is collected about the operating conditions, about newly discovered design problems, additional tests of the full-scale design are carried out, and technical measures are developed in the form of additional conditions (or confirmation of existing conditions) for extending the service life and service life for the next stage of operation. Within the next stage of establishing the resource and service life, almost all the shortcomings of design, manufacture, maintenance and repair are identified. Further continuation of operation is possible only after the elimination of the detected shortcomings [22].

Modification of air transport implies the refinement of airframe structures and systems aimed at the qualitative solution of certain tasks, both technical and economic, as well as marketing. In addition, modifications can be aimed at improving the flight characteristics of the transport aircraft. For example, the redesign of an aircraft, the replacement of passenger seat models, the installation or modification of a passenger entertainment system are usually dictated solely by marketing considerations. The installation of pylons of an improved design, in terms of aerodynamic characteristics, the placement of optimized wingtips, or the reduction of the weight of a dry-loaded transport aircraft, pursues economic goals (as a rule, reducing fuel consumption). Replacing the unit with an analog with a higher average time to failure (a typical example of a modification performed for technical purposes) serves to increase the regularity and safety of flights [23].

Improving the performance of modern transport aircraft should be associated with the timely identification and elimination of various design defects that occur during the operation of transport aircraft, as well as with the qualitative implementation of design modifications

that improve it and thus extend the overall life of the aircraft without accidents [24]. In this context, an important factor is the evaluation of the economic feasibility of this process, in terms of the potential for reducing the cost of operating transport aircraft, as well as reducing the cost of carrying out its repairs and the frequency of repairs as such.

The annual cost savings allows to free up significant amounts, which can subsequently be used to develop fundamentally new models of transport aircraft, which in itself has a positive effect on the development of the entire industry. Transport aviation is developing mainly due to the introduction of the latest technological solutions into production, so obtaining cost savings by modifying the existing fleet of transport aircraft can significantly affect the quality of subsequent technological developments and become an important link in the development of aviation [25]. Modern aviation technologies allow quickly and efficiently performing operations to modernize the existing fleet of air transport aircraft, provided that all the necessary components are available. In this situation, the question of the economic feasibility of performing such operations comes to the fore, taking into account the fact that the significant cost of high-quality materials used in the modernization of modern aircraft can cause a subsequent increase in operating costs and have a negative impact on the economic prospects for their subsequent use in such works in general. This situation encourages the search for alternative ways to improve the design of modern transport aircraft, mainly by facilitating the design and reducing the requirements for the safety of an air transport [26].

Constant monitoring of the current state of the resources of the aircraft transport and their operational suitability, as well as the compliance of design details with the requirements of technical documentation, contributes to the qualitative solution of the problems of maintaining an appropriate level of airworthiness of the aircraft. The constructive resource laid down directly in the design of the aircraft and its construction is expressed in the requirements for matching the number of flight hours to the actual number of flights of the aircraft, including its full operating cycles. The introduction of certain technological changes in the design of the aircraft during the work on its modification can qualitatively change the situation with the resource of this aircraft, since the increase in such will contribute to both the appearance of additional opportunities to increase flight hours, as well as to strengthen the design of the aircraft. The overall survivability of the aircraft should also be significantly increased [27].

The reduction of operational costs for the maintenance of aircraft when making various modifications to their design is the most important criterion for the economic feasibility of modifications to aircraft structures. Moreover, in this aspect, the quality of work performance comes to the fore, since such modifications require high training of engineering team and a clear understanding of their duties by technical service personnel. In this context, the situation suggests the need for a high-quality solution to the issues of organizing special training for airport technical personnel, in the event that it is necessary to introduce certain technical innovations that specialists in this field have not yet had to deal with [28]. This implies the need to take into account the cost of training technical service personnel in assessing the overall cost-effectiveness of work on the modernization of existing transport aircraft, including in the construction of new models with improved flight characteristics and belonging to a new type of aircraft. Notably, with each round of technological development in aviation and the creation of new models of aircraft, the technological costs for their modernization and routine maintenance can significantly increase, which does not always have a positive impact on the aspect of economic feasibility of improving existing models of aircraft.

The operational cost of modern air transport is determined both by the duration of its life cycle, and the amount of expenses for its repair and improvement of the design, in the event that certain work was carried out to modernize the aircraft. Today, the aircraft is created in

conditions of fierce competition between companies, aircraft manufacturers, as well as large firms involved in the organization of air transportation. In this regard, both the quality of the development and construction of the aircraft and the quality of its subsequent flight operation is important, along with the professionalism and training of transport aviation pilots and airport maintenance personnel. A high-quality modernization of the design of a modern transport aircraft can significantly increase its load capacity, increase the flight time in the absence of additional refueling and reduce the risk of accidents, provided that the pilots of the aircraft comply with all the safety requirements of air transportation. In such a situation, it is quite possible to achieve a gradual reduction in the operational cost of a transport aircraft, which will invariably entail significant cost savings, both for the air carrier and for organizations directly responsible for the quality of construction of modern aircraft [29].

In the past few decades, there has been a tendency in the practice of world aircraft construction to reduce the cost of work on the construction of aircraft directly by reducing the cost of materials used in the construction of modern aircraft. This practice does not always justify itself and contributes to the preservation of high-quality standards for both newly built civil and cargo aircraft. This is confirmed by a series of aviation accidents in various parts of the world, which occurred due to the failure of certain parts of the aircraft design, conditioned by the poor quality of the components of the design or assembly of aircraft [30].

To ensure the proper level of safety of air transport operations, it is necessary to strictly monitor the current technical condition of aircraft with timely identification and elimination of detected technical and other malfunctions. The quality and timeliness of such monitoring largely determines the safety of air transport in general, since with an appropriate level of serviceability of the aircraft used for transportation on existing airlines, the risk of accidents due to technical problems is minimised [31].

In general, modern civil and transport aviation is subject to strict requirements for compliance with the principles of reliable and uninterrupted transportation, safe delivery of cargo and passengers, timely maintenance of aircraft, maintaining the full cycle of aircraft operation, taking into account all the above components [32], [33]. Ensuring all the stated requirements involves maintaining a high level of training, both for aircraft designers and builders, as well as for aircraft pilots and maintenance personnel, which is necessary to maintain a high level of professionalism throughout the industry.

The introduction of changes in the design of transport aircraft should contribute to the effective solution of the tasks of maintaining a high level of safety of aircraft, as well as ensuring the safety of air transport at all its stages [34]. Ensuring the permanent technical serviceability of aircraft in the conditions of making certain technological changes to the design is the responsibility of the representatives of the maintenance service, who, by the nature of their activity, decide on the issues of monitoring the current condition of aircraft and their serviceability. The professionalism of aircraft maintenance and repair services largely determines both the timeliness of making the necessary changes to the design of aircraft, and the features of their subsequent operation. And this, in turn, determines the compliance with economic standards of the feasibility of modernising aircraft, both operating on international and domestic airlines and planned for construction in the future.

5. CONCLUSIONS

Based on the results obtained in the course of this study, it is possible to draw conclusions about the economic feasibility of modifying the design of modern aircraft transport at any stage of its operation. Measures to modify modern air transport can qualitatively change the

situation in transport aviation, since the use of the latest technological solutions in the design of modern aircraft significantly increases its service life and reduces operating costs. There is a general economic effect from the modernisation of transport aircraft, expressed in a combination of a number of factors, both financial and technological.

Notably, the economic feasibility of modifications to the design of modern air transport is impossible without performing special calculations that take into account all possible components of this process. As the calculated data show, high indicators of economic efficiency of the considered process can be achieved only if the high-quality standards of work on the modernisation of transport aircraft are maintained and timely deliveries of components to the place of their implementation are ensured. Otherwise, it is not necessary to consider the economic feasibility of all the operations performed as a whole. In addition, the economic feasibility of design modifications involves mandatory accounting for the costs of retraining maintenance personnel, who are forced to face the need to study the latest technological solutions used in the modernisation of all types of air transport, as well as the practical application of new knowledge. The assimilation of new technologies is a long process and does not always proceed smoothly – at its initial stages, temporary problems associated with insufficient qualifications of service personnel may occur, which require timely and high-quality resolution.

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