18. Apparatus for selectively injecting diesel oil and igniting fuel into the combustion chamber of a reciprocating internal-combustion engine using as main fuel diesel oil or gas: Pat. No. CH669015. No. CH19860000562; declareted: 12.02.1986; published: 15.02.1989.
19. Ivanov O. M. Hidravlichnyi korektor systemy palyvopodachi dyzelia: Pat. No. 44504 UA. No. u200903104; declareted: 02.04.2009; published: 12.10.2009, Bul. No. 19.
20. Ivanov O. M. Sposib korektuvannia kuta vyperedzhennia vporskuvannia palyva v tsylindry dyzelia: Pat. No. 113738 UA. No. u201608645; declareted: 08.08.2016; published: 10.02.2017, Bul. No. 3.
21. Astahov I. V. Podacha i raspylivanie topliva v dizelyah. Moscow, 1971. 359 p.
22. Voronov N. A. Primenenie raschetnyh metodov k analizu dinamiki elektromagnitnogo privoda v forsunkah elektroupravlyaemyh sistem toplivopodachi // Dvigatelestroenie. 1985. Issue 5. P. 25–27.
23. Fomin Yu. Ya. Metodika rascheta toplivopodachi v nasose s nagnetatel'nym klapanom dvoynogo deystviya // Dvigatelestroenie. 1982. Issue 9. P. 39–41.
24. Fomin Yu. Ya. Gidrodinamicheskiy raschet toplivnyh sistem dizeley s ispol'zovaniem ECVM. Moscow, 1973. 144 p.

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ANALYSIS AND SELECTION OF THE PARAMETRIC PROFILE OF A POWERPLANT ENGINE FOR A LIGHT TRAINER AIRCRAFT

V. Loginov
Doctor of Technical Sciences, Senior Researcher
Department of Aircraft Engine Design
National Aerospace University
Kharkiv Aviation Institute
Chkalov str., 17, Kharkiv, Ukraine, 61070
E-mail: flightpropulsion@gmail.com

Ye. Ukrainets
Doctor of Technical Sciences, Professor
Department of Design and Strength
of Aircraft and Engines
Ivan Kozhedub Kharkiv National
University of Air Force
Sumska str., 77/79, Kharkiv, Ukraine, 61023

I. Kravchenko
Doctor of Technical Sciences,
Associate Professor, Director*

A. Yelanskiy
PhD
Department of Advanced Development
and Gas Dynamic Calculations*
*State Enterprise «Ivchenko-Progress»
Ivanova str., 2, Zaporizhia, Ukraine, 69068

Актуальність проведених досліджень обумовлена поліпшенням паливної ефективності літака і, як наслідок, зменшенням вартості життєвого циклу авіаційного двигуна у складі силової установки навчально-тренувального літака типу DART-450. Теоретично обґрунтовано льотно-технічні та економічні характеристики сучасного легкого літака для навчання льотного складу. В основі методів дослідження використовується набір параметрів, характеристик і показників, що в цілому відображають техніко-економічну досконалість двигуна силової установки технічної системи «силова установка – планер» легкого навчально-тренувального літака.

Наукова новизна одержаних результатів полягає у формуванні нового параметричного обрису турбогвинтових двигунів силової установки для легкого навчально-тренувального літака типу DART-450 з урахуванням моделювання заданого польотного циклу літака та життєвого циклу двигуна.

Чисельними дослідженнями встановлено, що максимальна дальність польоту літака з різними двигунами при однаковій злітній масі визначається, в основному, запасом палива, а не економічністю витрати палива. Тому двигун найменшої потужності має перевагу у всіх характеристиках, крім злітної дистанції, яка найменша у літака з двигуном найбільшої потужності.

Результатами обгрунтовано, що для виконання задач по навчальному тренуванню льотного складу доцільно встановлення двигуна АІ-450СР, який має найменшу вартість життєвого циклу. Очевидно, що даний літак із встановленим двигуном буде мати найнижчу вартість льотної години. Однак для виконання розвідувальних та ударних задач на літаку типу DART-450 доцільно встановлення двигуна АІ-450СР-2. Для виконання тільки ударних задач на літаку типу DART-450 доцільно встановлення двигуна МС-500В-С, який має більшу потужність, ніж розглянуті двигуни

Ключові слова: навчально-тренувальний літак, життєвий цикл, льотно-технічні характеристики, турбогвинтовий двигун

1. Introduction

At present, much attention is paid to the creation of light aircraft, designed to perform training tasks, to monitor the Earth's surface, for business flights, etc. The capability to land at an aerodrome of any class, easy flight operation and maintenance, elegance of interior design, make these light aircraft a reasonable choice for business meetings, recreation, as well as to train flight personnel. An important stage in the creation of such an aircraft (AC) is a conceptual research during which the aerodynamic and technical-economic characteristics of the aircraft are examined [1–3].

The relevance of studying the technical and economic characteristics of light training aircraft (TAC) predetermines the need to substantiate the required flight-technical and economic characteristics of modern aircraft to train flight personnel. The importance of the task on examining AC operational characteristics is predetermined by the relevance of the task to improve fuel efficiency and, consequently, to reduce the cost of engine life cycle (LC) in the structure of an aircraft powerplant (PP) [4–6].

Since of the greatest interest is the reduction of engine fuel consumption (FC), at the forefront of research is a study into improving the integrative properties of PP and AC airframe [7]. Exploiting aircraft with turboprop engines (TPE) makes it possible to significantly reduce FC. When carrying out the research, it is necessary to analyze the features of AC PP with TPE, to evaluate the technical and economic characteristics of TPE as part of an aircraft and to assess the results obtained. Thus, this work reports such a study related to light TAC.

2. Literature review and problem statement

Flight training is the most expensive of all types of training of aviation specialists, which defines special responsibility of approaching the choice of means of flight training, first and foremost, TAC and training procedures [8–11]. Flight personnel training in different countries may typically vary in the number of flying hours during training process, the content and programs of each particular stage of training, as well as the types of TAC. A modern TAC must meet the highest echnical and economic requirements and be of interest to potential international customers.

At present, characteristics of prospective light TACs are actively explored. Paper [12] shows that a light multipurpose aircraft for general purpose should ensure flights at a distance to 2.5 thousand kilometers. In this case, the composition of equipment and the structure of an aircraft must enable smooth operation at ambient air temperatures from –55 up to +40 °C, with the mandatory practical possibility to take-off and land from dirt, snow, and ice. Article [13] substantiated the relevance of the task on estimating an aircraft's flight-technical and operational characteristics, with special focus on the cost of its LC. However, the integrative properties of an aircraft and its PP with a new engine are not examined.

Papers [14, 15] reveal basic directions in the development of aviation science and technology, but they do not specify particular means and approaches to reducing the cost of engine's LC as part of TAC. It is known that the high cost of experimental studies into aircraft characteristics complicates the stages of its design and production. The issue on choosing optimum operational modes for key subsystems requires solving the interrelated tasks of mathematical modelling of PP working process and an aircraft flight cycle, the optimization of aerodynamic characteristics and composition of the equipment. The remaining unresolved issues include defining the function of modeling objective as the problem is a multiparameter one [16, 17].

Methodological and theoretical foundations of research into the utilization of engines at AC were laid by leading scientists in aviation science [18–23]. The authors widely apply methods of systems analysis, scientific forecasting, mathematical statistics, mathematics modeling of workflows. However, the issues related to determining the integrative properties of engine as part of the aircraft PP remain unsolved. The papers do not describe procedures to create a parametric profile of the engine with respect to the flight cycle of TAC.

To substantiate the choice of TAC PP engine, different techniques for agreeing on the characteristics of a airframe and an engine for PP [24, 25] are used, based on the principles of comparison of AC and engines characteristics, and the developments by a series of research organizations are applies. Underlying the calculations is the notion of the tie parameters – specific load on the wing and the relative size of PP. At present, these principles are developed and supplemented, they form the basis of a procedure for choosing parameters of GTE working process, to approve of PP and a airframe, part of the systems for the automated design of PP and AC airframe elements. However, most modern research is not comprehensive and does not take into consideration a change in the cost of development, production, and operation of PP and airframe. Such studies produce a one-way effect and are not appropriate. First of all, this relates to the comparative evaluation of AC using indicators for technical perfection.

The most common approach to the assessment of technical-economic perfection of AC PP engine is to examine the magnitude of AC LC cost [26], which also includes operational factors. The concept of LC cost was introduced to account for all costs and includes expenditures on research and development work, bringing a sample of aviation equipment to production, investment in mass production, the cost of operation, maintenance, withdrawal from production and disposal of an object. However, most studies do not take into consideration a change in the aircraft flight cycle during its operation, which affects the resource and cost characteristics of engine [27].

The leading aviation countries are intensively undertaking research into advanced engines and airframes of airplanes using such software as, for example, FLUENT [28], ANSYS [29], CFX, FlowVision HPC, IOSO NM, CAMCTO, ECOMI, CASE, Piano-X, APP, CAD/CAM/CAE, PDM, STEP and others. However, the calculation and justification of the magnitude of cost of an hour during engine or aircraft airframe LC is not always carried out jointly and considering a flight cycle of the aircraft, which complicates analysis of influence of one subsystem to another at a predefined flight cycle. Studying the integrative of properties of an aircraft implies the assessment of mutual influence of characteristics for PP engine and the elements of an aircraft airframe at a certain flight cycle.

It is known that the leading engine-building firms spend huge sums on the development and implementation of automated design systems adapted to their conditions [30]. The basis of universal tool kits is Unigraphics, Euclid, Cimatron, CATIA, CADDS 5, Pro/Engineer, and others. However, studies into operational characteristics for a new-generation engine prove ineffective without a joint research into characteristics of the object at which it is to be installed [31, 32].

Therefore, there is a need to solve a problem that relates to determining the possibilities to reduce the cost of LC of PP and AC airframe based on the substantiation of a parametric profile to improve their integrative properties.

3. The aim and objectives of the study

The aim of this study is to analyze and select a parametric profile of PP engine for light TAC, which is a relevant scientific and technical task.

To accomplish the aim, the following tasks have been set:

– to select a light TAC among the world fleet of light general-purpose aircraft, which has many modifications and the prospect of development;

– to assess changes in TAC flight-technical characteristics based on the mathematical modeling of its flight cycle.

To analyze the efficiency of application of an aircraft with appropriate PP during a flight cycle, it is necessary to give recommendations on selecting the type and parameters for the engine as part of PP.

4. Materials and methods to examine PP and AC characteristics

When conducting this study, we used methods of system engineering, methods of statistical analysis, a retrospective method, methods of mathematical modeling of a working process, and numerical methods. It is known that capital investments in AC are calculated now based on the price of engine's elements and an airframe for the aircraft of a given type. However, it is problematic to obtain accurate information related to these data. Therefore, taking into consideration statistical information, estimation of PP LC is carried out depending on the size of the engine, its purpose, the level of technical sophistication, succession of design, and structural-circuit layout of engine and its unification [20, 24]. It is believed that reducing AC operation cost requires the assessment of LC as early as the first stage of design. The design parameters of an aircraft or engine are chosen based on the minimum cost of LC for all ACs of a given type.

Specifying the project data for an aviation training complex at different stages over its life cycle opens up a possibility for a detailed enough consideration of all the features in the operation of existing TAC. That involves the consideration of the degree of AC use during predefined flight tasks, such as flying in a circle, the flight to perform aerobatics, flying at a distance, and others.

For a comprehensive assessment of the TAC technical-economic excellence, an indicator was proposed [6, 33], which includes the flight-technical and economic components:

$$\Pi_{AC} = \frac{\sum_{1}^{m}\left(k_{flight\ cycle} \cdot k_{util\ AC}\right)}{\dfrac{C_{LC}^{new}}{C_{LC}^{basic}}}, \tag{1}$$

where m is the number of typical flight tasks performed by AC; $k_{util\ AC}$ is the AC utilization factor over LC at a specific distribution of share of flight tasks, such that $\sum_{i=1}^{m} k_{util\ AC_i} = 1.0$; $k_{flight\ cycle} = \prod_{k=1}^{s}\left(\frac{A_k^{new}}{A_k^{basic}}\right)_k$ is the characteristic coefficient of AC flight cycle; A_k^{new} is the value for a parameter or a characteristic for new AC (weight and size parameter, the flight-technical or techno-economic characteristic); A_k^{basic} is the value for a parameter or a characteristic for basic AC (weight and size parameter, the flight-technical or techno-economic characteristic); s is the number of parameters or characteristics for AC; C_{LC}^{new} is the magnitude of the value for the cost of LC of new AC; C_{LC}^{basic} is the magnitude of the cost of LC of basic AC.

For a research, the input data are the structural, weight, technical, resource, and economic data on AC and on PP propulsion engine. Estimation of technical and economic excellence of existing and new aircraft engines employs methods based on short-term and long-term forecasts taking into consideration the actual parameters and characteristics.

In papers [6, 33], the proposed indicator is used to study the flight-technical and technical-economic characteristics of a prospective training-combat aircraft with turbojet two-circuit engines. The authors investigated variants of existing training and training-combat aircraft, as well as variants for prospective training-combat aircraft with new two-circuit engines. However, a given work improved the existing procedure taking into consideration the application of TPE as part of PP. To simulate a flight cycle of an aircraft, they used a system of differential equations of motion of the center of mass of TAC in the form of projections of forces onto the axis of the trajectory coordinate system [7]. Papers [6, 19] applied a node-based mathematical model of PP with TPE, which is built mainly on the aviation TPE working process, using a base of static characteristics for nodes, which makes it possible to employ experimental data.

To account for peculiarities of air that flows around AC with TPE, it is necessary to know the geometry of the air propeller, nacelle, wing, and empennage, as well as throttle characteristics for TPE. Improving the aerodynamic characteristics for aircraft at the expense of air blowing from the propeller adjusts certain aircraft parameters, for example: the speed of separation reduces by 15...20 %, the length of run – by 25...30 % [22].

An increase in the flight speed reduces the gain of aerodynamic forces. The more powerful the PP the greater an increase in aerodynamic forces. To account for the influence of air blow over an air propeller on the aerodynamic forces and their coefficients, one performs their recalculation for the most characteristic operational modes of PP engine.

In TPE, an increase in airspeed leads to an increase in reactive power. In addition, a decrease in the degree of throttling, along with an increase in full power, leads to an increase in the engine efficiency coefficient and reduces fuel consumption. An analysis of dependences of kilometer FC on flight speed at different altitudes [6, 21, 22] reveals that an increase in the flight altitude leads to a decrease in the kilometer FC. An increase in flight speed leads to an increase in the magnitude for kilometer fuel consumption.

When conducting a research, determining the required amount of fuel is substantiated for the two recommended modes of flight. In the case of short runs, when the required amount of fuel is small and does not reduce the payload, it is recommended that maximum cruising mode should be applied. At longer runs, when such amount of fuel is needed that it is required that a payload should be reduced, it is appropriate to use an economy flight mode. In this case, the cruising speed is lower, while the weight of a payload is greater than in the case when a maximum cruising mode is employed. To improve the efficiency of a cruising flight, it is advisable to perform it under the operational mode of engines up to 80 % of maximum long mode. In the range of altitude of 2.300...3.200 m, an indicated airspeed is 190...230 km/h. In special cases during cruising flight, it is allowed to use the emergency operational mode of PP engine.

Based on the developed procedure, the existing modular software system for the evaluation of technical and economic characteristics of TPE as part of light TAC was improved [35]. The structure of a modular software system to conduct parametric studies into the performance of engine for AC powerplant is shown in Fig. 1. The designed modular software system has been logically built based on the procedure for estimation of life cycle of an aircraft engine in the system of the aircraft and includes all required technical and economic indicators [7, 35]. All estimation units are interconnected, thereby making it possible to study characteristics of aircraft at both subsonic and supersonic flight speed.

At systemic designing and refinement of aviation engines, it is expedient to use a unified research algorithm based on the approach to forming a multilevel model of the system «aircraft – powerplant». The initial projects of an aircraft and PP engine are either formed from a database built on the basis of statistical information or downloaded as a finished technical object. After the end of project examination, each object is formed, structured, and submitted to the library of objects, separately for an aircraft airframe and an engine.

The module of initial data on AC airframe, PP engine, aviation weapons (geometry, mass, resource, maintenance, cost) is built by the user based on the targeted tasks for aircraft. There, one can assign predictive values for parameters and characteristics similar to those for the objects examined by world companies. A great advantage of this software system is a possibility for the user to assign a profile of the aircraft flight.

For military AC, this is the compulsory research phase when investigating new tactical techniques applying existing weapons and equipment. The integrated evaluation of AC flight-technical and technical-economic characteristics can be supplemented with a module of expert assessment if it is necessary for the organization.

Thus, the improved procedure and the improved software system make it possible to conduct comprehensive parametric study into characteristics of light TAC with TPE. The novelty of the improved procedure is in obtaining a methodological tool, using which has made it possible to conduct comprehensive research into characteristics of existing and prospective TAC with TPE considering their flight cycle. Application of an indicator for the technical-economic excellence of TAC makes it possible to evaluate the technical and economic perfection of a new AC or its upgraded variant taking into consideration the utilization factor of AC, which is very important for TAC.

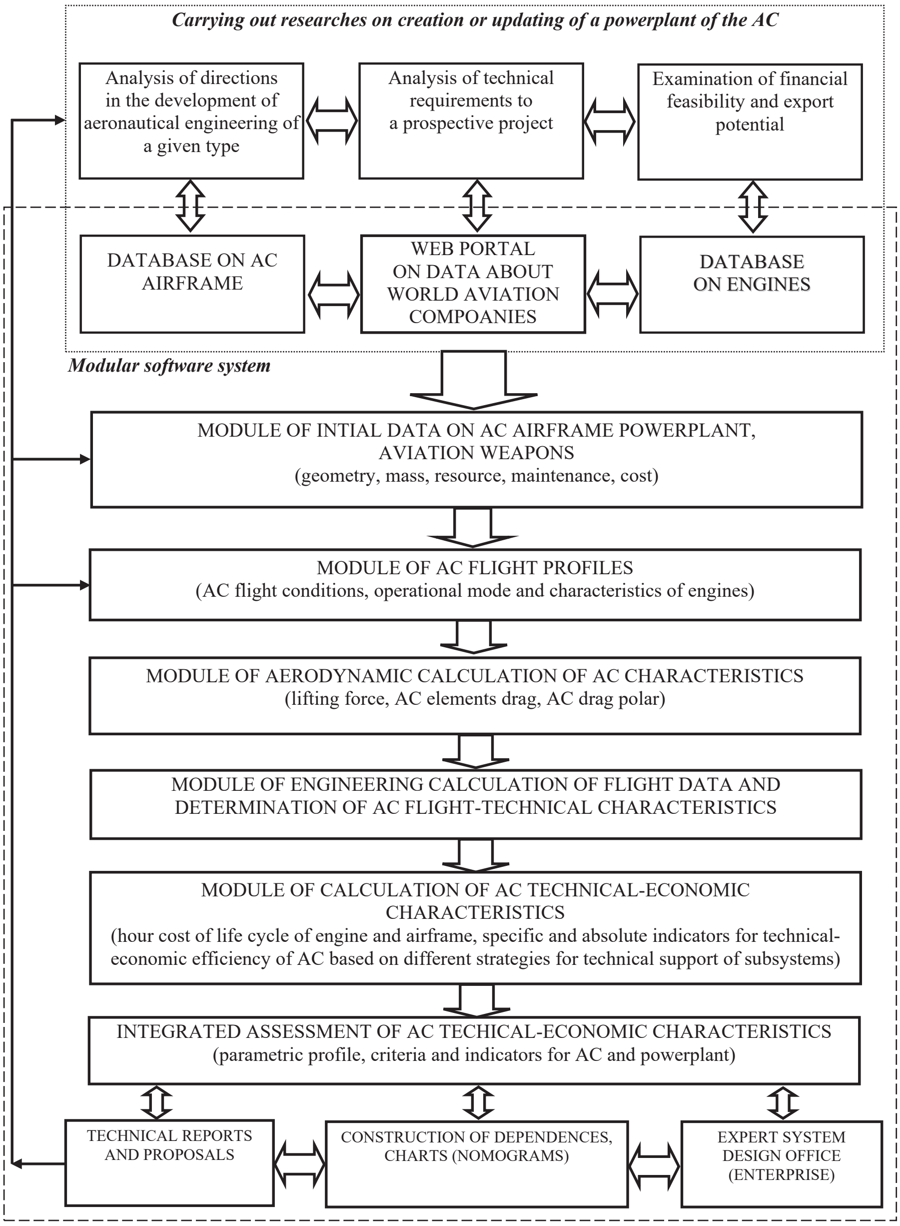

Fig. 1. Structure of modular software system

5. Results of studying the flight-technical characteristics of TAC at various flight tasks with different TPE as part of PP

It is known that a modern aircraft must be sufficiently agile and possess reasonable thrust-to-weight ratio, have low landing and takeoff speed, be equipped with on-board radio-electronic equipment for flights during day and night. An analysis of existing world fleet of light aircraft for general purpose [7] makes it possible to draw a conclusion on that of great interest are the aircraft made by company Diamond Aircraft Industries, which have many modifications and the prospect of development. Research into prospective structural-assembly schemes should be conducted taking into consideration a comprehensive evaluation of the parameters and characteristics of PP and AC.

To conduct a research into the formation of TAC PP parametric profile, it is necessary to know features of flight tasks (typical flights) of AC, the scope and content of these tasks. Such features of a flight task indicate the duration of the engine operation mode (resource characteristics) and aircraft maneuverability (speed and overload). Therefore, in this work we analyzed and investigated 5 main types of flight tasks:

- flying in a circle;
- a flight to perform aerobatics;
- flying at a distance;
- flight to duration;
- a strike task (simulation of bomb dropping).

To construct and study a flight profile over a flight cycle, we shall consider particularities of programs related to basic training at TAC and a training program to perform certain combat tasks. It is known that a flight task includes a graphical model of the flight, respective information and calculations, represented textually or in tables (charts). Consider the basic flight tasks at TAC for further modeling of an aircraft flight and an engine operation.

Flying aerobatics in the zone and in a circle is performed under simple meteorological conditions at a range of altitudes from 1,000 m to 5,000 m. The following aerobatics figures must be performed: turns with different angles of roll (45° or 60°); diving at angle 30°; slide at angle 30°; combat turn-around; downward spiral at roll 45°; approach (from the line).

Flying aerobatics in the zone at low altitudes is performed under simple meteorological conditions in a range of altitudes from 200 m to 2,500 m with the mandatory performance of aerobatics: turns at different angles of roll (45° or 60°); the acceleration of an aircraft to the maximum instrument speed $V_{instrum\,\max}$ at altitude 200 m; the acceleration of an aircraft and the execution of the Nesterov loop; a sighting dive; slide at angle 30°; combat turnaround; visual approach to landing at an altitude of 200 m.

A flight to drop bombs from a horizontal flight is performed under simple meteorological conditions in a range of altitudes from 300 m to 500 m. A maneuver and bomb dropping from a horizontal flight is performed from an altitude of 300–500 m under the automated mode of sighting complex operation.

A demonstration flight of combat maneuvering at overcoming air defense on the route, using the means of radio-electronic warfare, is performed under simple meteorological conditions in a range of altitudes from 200 m to 5,000 m. The following aerobatics figures are performed: an anti-missile «snake» with a roll of 60° using the individual means of active interference; a maneuver to escape from the issued missile of the «earth-air» class, which comes from the front hemisphere, or follows in pursuit.

Thus, taking into consideration the basic requirements to the content of flight cycles, we have developed typical flight profiles for TAC, based on which the mathematical modeling of AC flight is carried out.

We report part of the research results and show basic conditions to perform the estimation. For example, a flight to range and duration was calculated under two conditions:

a) fuel consumption G_{FC} = const and maximum take-off weight of the aircraft $M_{AC\,TO}$ = var;

b) fuel consumption G_{FC} = var and maximum take-off weight of the aircraft $M_{AC\,TO}$ = const.

To conduct further research, we have selected, as the object of research, the aircraft DART-450 [36], which is designed as a training aircraft, as well as an intelligence and surveillance aircraft. The PP composition of the aircraft DART-450 is set as follows:

- with engine AI-450CP [37] equipped with air propeller MTV-5-l/210-56 (5 blades, diameter of 2.1 m);
- with engines AI-450CP-2, MS-500-C [38] equipped with air propeller MTV-27/210-58D (5 blades, diameter of 2.1 m).

The aircraft's maximum flight range is obtained under the following assumptions: cruising speed of the aircraft with engine AI-450CP at an altitude of 3.200 m – 352 km/h. An increase in the power of the applied engine led to an increase in the cruising speed. Cruising speed of the aircraft with engine AI-450CP-2 at an altitude of 3.200 m – 410 km/h, cruising speed of the aircraft with engine MC-500B-C at an altitude of 3.200 m – 434 km/h. The guaranteed fuel margin in calculating amounted to 3 % of the total fuel capacity. The results of research obtained under various conditions of aircraft flight with different engines are given in Table 1.

The flight of TAC to perform a strike task was calculated under two conditions:

a) tactical radius R_{tac} = const, G_{FC} = var, $M_{AC\,TO}$ = var;

b) tactical radius R_{tac} = var, G_{FC} = const, $M_{AC\,TO}$ = var.

Table 1

Characteristics of AC during flight to range and duration

Engine type	AC take-off mass, kg	Total route length, km	Average kilometer FC by AC PP under cruising mode, kg/km	Hourly FC by AC PP, kg/h	Hourly FC by AC PP under cruising mode, kg/h	Time to perform a task, min.
Flight to range (G_{FC}=const; $M_{AC\,TO}$=var)						
AI-450CP	1,600	1,220	0.2243	74.63	78.90	233
AI-450CP-2	1,633	945	0.2733	107.32	112.17	162
MC-500B-C	1,715	803	0.3107	127.55	136.61	134
Flight to range (G_{FC}=var and $M_{AC\,TO}$=const)						
AI-450CP	1,600	1,220	0.2243	74.63	78.90	233
AI-450CP-2	1,600	820	0.2730	106.62	112.04	151
MC-500B-C	1,600	460	0.3012	119.26	131.03	107
Flight to duration (G_{FC}=const and $M_{AC\,TO}$=var)						
AI-450CP	1,600	1,174	0.2218	51.15	51.48	324
AI-450CP-2	1,633	1,050	0.2285	69.27	69.30	238
MC-500B-C	1,715	828	0.2921	93.51	94.16	176
Flight to duration (G_{FC}=var and $M_{AC\,TO}$=const)						
AI-450CP	1,600	1,174	0.2218	51.15	51.48	324
AI-450CP-2	1,600	910	0.2276	69.46	66.00	209
MC-500B-C	1,600	441	0.2891	92.35	93.20	104

The results from simulation of performing a strike task were received under the following assumptions: flying at a limit of low altitude, which is necessary to ensure the hiding of an aircraft that does not have a complex of defense. We considered a bombarding variant with bombs OFAB-100M on two nodes of a suspension, since this variant is most often used to simulate the performance of a strike task at TAC the type of L l-39. Take-off mass of the aircraft was increased by the weight of bombs (2×125 kg), underwing holders (2×17 kg), starters (2×21 kg). When modifying the aircraft into a strike one, in addition to increasing the aircraft take-off mass by the mass of bomb load, pylons and launching devices, it is necessary to strengthen the structure of the wing and an aircraft fuselage, and to install sighting equipment. We took into account an increase in the aircraft take-off mass carried out in accordance with the condition for the existence of the aircraft [20, 21]. A weaponry suspension increases the aircraft drag by about 20 %, which leads to increased kilometer and hourly fuel consumption. A change in the aircraft balancing and a change in the wing bearing capacity were not taken into consideration. A guaranteed fuel margin during calculation is a 30-minute flight without external components.

An analysis of the flight data of TAC the type of DART-450 suggests that the action tactical radius R_{tac} is approximately 250 km. Uniformity of the tactical radius R_{tac} was ensured by decreasing the reserve of fuel at aircraft with engines AI-450CP and AI-450CP-2 (DP »Ivchenko-Progress», Ukraine). Characteristics of AC when performing a strike task with different engines at R_{tac}=const are summarized in Table 2, at R_{tac}=var – in Table 3.

Taking into consideration the available data on the aircraft DART-450, PP engine and propellers characteristics, which can be found from open sources, errors in the reliability of determining the basic flight-technical characteristics of the aircraft do not exceed 5 %. However, in some cases, evaluation of the technical or economic excellence of TAC may be limited to the consideration of separate partial criteria or even its functional properties [7, 25]. In other cases, for unambiguous evaluation, it is possible to use a comprehensive criterion, which combines values for individual partial criteria. This is typically the criterion of «cost-efficiency», which combines individual values for the criteria of cost and tactical capabilities of an aircraft.

Refining the project data on an aviation training complex at different stages of AC LC opens up a possibility for a sufficiently detailed consideration of all the features of operation of existing TAC. First of all, that refers to the comparative assessment of AC when using indicators for technical and economic excellence. To this end, we examined the degree of utilizing the AC during 11 flight tasks.

A comprehensive assessment of the perfection of an aviation training complex is based on the indicator for the technical-economic excellence of AC, which was reported earlier [7, 36]. We selected, as a standard variant of the basic aircraft, the airplane DART-450 equipped with engine AI-450CP. The following two assembly schemes of TAC include:

– aircraft DART-450 with engine AI-450CP-2;

– aircraft DART-450 equipped with engine MC-500B-C (AT «Motor Sich», Ukraine) and its modernized airframe.

An analysis of formula (1) reveals that at the same aircraft utilization factor we obtained different coefficients for an aircraft flight cycle, and assigning the aircraft utilization factor affects the total magnitude of TAC excellence indicator. An analysis of results shows that the magnitude of the indicator for TAC technical-economic excellence depends on the cost indicators and characteristics of aircraft LC with the selected engine. Formula (1) demonstrates that it is appropriate to install at TAC that perform most of the tasks on training or intelligence engines the type of AI-450CP, because they have the highest indicator for technical-economic excellence. However, only a significant increase in the AC utilization factor to perform strike tasks will lead to the improvement in the magnitude of excellence indicator for aircraft equipped with engines AI-450CP-2 and MC-500B-C.

In further studies, we carried out calculation of quantitative characteristics of such dependences. To calculate an indicator for the technical-economic excellence of TAC, the prototype taken was the aircraft DART-450 equipped with engine AI-450CP. The crew includes 2 people; PP is composed of a single engine, a propeller, and related systems.

Table 2

Characteristics of AC when performing a strike task (R_{tac} = const, G_{FC} = var, $M_{AC\ TO}$ = var)

Engine type	AC take-off mass, kg	Total length of the route in a straight line, km	Average kilometer FC by AC PP under cruising mode, kg/km	Hourly FC by AC PP, kg/h	Hourly FC by AC PP under cruising mode, kg/h	Required run distance, m	Time to perform a task, min
AI-450CP	2,231	500	0.3331	92.6	103.5	801	130
AI-450CP-2	2,361	500	0.4026	132.8	144.6	554	116
MC-500B-C	2,559	500	0.4378	152.5	166.8	525	111

Table 3

Characteristics of AC when performing a strike task (R_{tac} = var, G_{FC} = const, $M_{AC\ TO}$ = var)

Engine type	AC take-off mass, kg	Total route length, km	Average kilometer FC by AC PP under cruising mode, kg/km	Hourly-FC by AC PP, kg/h	Hourly FC by AC PP under cruising mode, kg/h	Required run distance, m	Take-off distance, m	Time to perform a task, min
AI-450CP	2,316	789	0.3355	96.15	91.48	831	1205	177
AI-450CP-2	2,386	618	0.4030	133.86	140.00	560	812	127
MC-500B-C	2,559	552	0.4378	152.50	153.75	525	761	111

We calculated economic characteristics of the aircraft equipped with different engines for the following initial data: designated resource of airplane airframe is 20,000 hours; inter-repair resource of airplane airframe is 4,000 hours; annual average flight time is 1,600 hours; initial price of the aircraft DART-450 equipped with engine AI-450CP (catalogue price) is USD ≈3.1 million.

The following initial data were taken for the engine: designated resource is 12,000 hours; inter-repair resource is 3,000 hours; mean time per 1 failure for all reasons that led to the premature removal of the engine is 3,000 hours; the cost of 1 kg of fuel is USD 1.3 per kg; the cost of 1 kg of oil is USD 14.2 per kg; the average price of 1 kW is USD 661. Calculation of the magnitude of maintenance and repair (MR) was adopted for the same number of hours of LC for all AC.

It should be noted that the conducted research implied installing engines in a different range of power. The derived magnitudes are preliminary results of the study; upon refining the technical and economical data on the aircraft and engines, the resulting magnitudes will be more accurate.

We report results of research into technical and economic characteristics of aircraft with different engines as part of PP at various flight tasks (Tables 4–6).

Comparison of the indicator for AC technical-economic excellence is given in Table 7.

Table 8 shows results from the calculation of AC technical-economic excellence indicator for the case of change in the AC utilization factor provided other values for LC parameters are stable.

Table 4

Comparative characteristics of aircraft at different flight tasks

Title and condition of flight task	Aircraft DART-450, engine **AI-450CP**, designated engine resource – 12,000 hours, inter-repair resource of engine – 3,000 hours					
	Average cost of an hour of operation per a fleet of engines, a.u.	Cost of PP LC per a single AC, a.u.	Cost of flying hour for AC PP, a.u./h	Cost of flying hour for AC, a.u./h	Cost of LC per a single AC, a.u.	Expenditures on MR over an entire LC, a.u.
Maximal range (G_{FC}=const, $M_{AC\ TO}$=var)	155	3,147,857	163	511	7,752,110	1,502,303
Maximal range ($M_{AC\ TO}$=const, G_{FC}=var)	155	3,147,857	163	511	7,752,110	1,502,303
Maximal duration (G_{FC}=const, $\mathrm{M}_{AC\ TO}$=var)	122	2,480,786	129	476	7,085,038	1,494,451
Maximal duration (G_{FC}=var, $M_{AC\ TO}$=const)	122	2,480,786	129	476	7,085,038	1,494,451
Strike task (R_{tac}=const, G_{FC}=var, $M_{AC\ TO}$=var)	182	3,705,837	190	535	8,316,886	1,522,754
Strike task (R_{tac}=var, G_{FC}=const, $M_{AC\ TO}$=var)	185	3,762,545	193	550	8,374,411	1,510,012
In a circle (G_{FC}=const, $M_{AC\ TO}$=var)	168	3,420,922	176	516	8,025,167	1,505,747
Maneuverability while flying near the ground	136	2,769,189	144	453	7,371,668	1,529,604
Flying (0.5G_{FC}=const, $\mathrm{M}_{AC\ TO}$=var, H=1,500 m)	167	3,403,189	175	517	8,005,687	1,502,539
Flying at maximum speed (mode «Take-Off»)	186	3,791,731	195	536	8,395,978	1,511,287
Flying at minimum speed (a strike task)	124	2,524,601	132	453	7,135,628	1,519,945

Table 5

Comparative characteristics of aircraft at different flight tasks

Title and condition of flight task	Aircraft DART-450, engine **AI-450CP-2**, designated engine resource – 12,000 hours, inter-repair resource of engine – 3,000 hours					
	Average cost of an hour of operation per a fleet of engines, a.u.	Cost of PP LC per a single AC, a.u.	Cost of flying hour for AC PP, a.u./h	Cost of flying hour for AC, a.u./h	Cost of LC per a single AC, a.u.	Expenditures on MR over an entire LC, a.u.
Maximal range (G_{FC}=const, $M_{AC\ TO}$=var)	214	4,346,068	224	565	8,950,716	1,928,892
Maximal range ($M_{AC\ TO}$=const, G_{FC}=var)	213	4,335,310	223	560	8,939,551	1,933,773
Maximal duration (G_{FC}=const, $M_{AC\ TO}$=var)	160	3,246,355	169	514	7,851,005	1,916,156
Maximal duration (G_{FC}=var, $M_{AC\ TO}$=const)	160	3,245,375	169	508	7,849,619	1,919,727
Strike task (R_{tac}=const, G_{FC}=var, $M_{AC\ TO}$=var)	251	5104937	262	609	9717206	1942567
Strike task (R_{tac}=var, G_{FC}=const, $M_{AC\ TO}$=var)	252	5,119,653	262	614	9,732,153	1,938,041
In a circle (G_{FC}=const, $M_{AC\ TO}$=var)	234	4,754,636	244	580	9,359,278	1,933,327
Maneuverability while flying near the ground	141	2,861,081	150	461	7,464,066	1,957,294
Flying (0.5G_{FC}=const, $M_{AC\ TO}$=var, H=1,500 m)	222	4,511,065	232	543	9,114,050	1,959,325
Flying at maximum speed (mode «Take-Off»)	258	5,258,755	269	606	9,863,398	1,939,494
Flying at minimum speed (strike task)	246	5,002,305	257	598	9,614,566	1,920,243

Table 6

Comparative characteristics of aircraft at different flight tasks

Title and condition of flight task	Aircraft DART-450, engine **MC-500B-C**, designated engine resource – 12,000 hours, inter-repair resource of engine – 4,000 hours					
	Average cost of an hour of operation per a fleet of engines, a.u.	Cost of PP LC per a single AC, a.u.	Cost of flying hour for AC PP, a.u./h	Cost of flying hour for AC, a.u./h	Cost of LC per a single AC, a.u.	Expenditures on MR over an entire LC, a.u.
Maximal range (G_{FC}=const, $M_{AC\ TO}$=var)	268	5,451,151	276	619	10,160,438	2,661,798
Maximal range ($M_{AC\ TO}$=const, G_{FC}=var)	258	5,251,937	266	583	9,959,825	2,689,342
Maximal duration (G_{FC}=const, $M_{AC\ TO}$=var)	211	4,288,270	219	563	8,997,559	2,647,846
Maximal duration (G_{FC}=var, $M_{AC\ TO}$=const)	209	4,261,177	217	534	8,969,064	2,671,685
Strike task (R_{tac}=const, G_{FC}=var, $M_{AC\ TO}$=var)	295	6,012,762	304	661	10,730,465	2,668,010
Strike task (R_{tac}=var, G_{FC}=const, $M_{AC\ TO}$=var)	295	6,012,762	304	661	10,730,465	2,668,010
In a circle (G_{FC}=const, $M_{AC\ TO}$=var)	283	5,753,776	291	631	10,463,059	2,663,038
Maneuverability while flying near the ground	169	3,435,896	176	493	8,143,636	2,686,245
Flying (0.5G_{FC}=const, $M_{AC\ TO}$=var, H=1,500 m)	261	5,319,717	270	586	10,027,456	2,686,947
Flight at maximum speed (mode «Take-Off»)	303	6,169,102	312	652	10,878,386	2,671,267
Flight at minimum speed (a strike task)	213	4,334,592	221	552	9,052,269	2,662,717

Table 7

Comparison of the indicator for AC technical-economic excellence

No. of entry	Variant of AC compared to base	Designated resource of engine, hours	Inter-repair resource of engine, hours	Indicator for aircraft technical-economic excellence Π_{AC}
1	DART-450 equipped with engine AI-450CP	12,000	3,000	1.0
2	DART-450 equipped with engine AI-450CP2	12,000	3,000	0.8041
3	DART-450 equipped with engine MC-500B-C	12,000	4,000	0.7683
4	DART-450 equipped with engine MC-500B-C	15,000	5,000	0.7909

Table 8

Comparison of the indicator for AC technical-economic excellence

No. of entry	Type and condition of flight task	DART-450 equipped with engine **AI-450CP-2**		DART-450 equipped with engine **MC-500B-C**		DART-450 equipped with engine **MC-500B-C**	
		$k_{util\ AC}$	Π_{AC}	$k_{util\ AC}$	Π_{AC}	$k_{util\ AC}$	Π_{AC}
1	In a circle (G_{FC}=const, $M_{AC\ TO}$=var)	0.3	**0.80405**	0.3	**0.76833**	**0.1**	**1.20**
2	Range (G_{FC}=const, $M_{AC\ TO}$=var)	0.1		0.1		0.1	
3	Range ($M_{AC\ TO}$=const, G_{FC}=var)	0.1		0.1		0.2	
4	Duration (G_{FC}=const, $M_{AC\ TO}$=var)	0.05		0.05		0.1	
5	Duration (G_{FC}=var, $M_{AC\ TO}$=const)	0.05		0.05		0.1	
6	Flying	0.3		0.3		**0.1**	
7	Strike task	0.1		0.1		**0.3**	

An analysis of the data reveals that changing the target purpose of AC equipped with engine MS-500B-C to a light striker results in that its efficiency is better than other variants of AC.

By using the indicator for AC technical-economic execellence it is possible to esimate the perfection of new AC or its modernization taking into consideration the economic and flight-technical characteristics. An aircraft utilization factor takes into consideration the resource expenses of the engine, which is important for training and combat aircraft.

6. Discussion of results of studying the technical and economic characteristics of PP and AC

The choice of a variant for the structurally-assembly solution to a project of the aircraft with the best LC characteristics implies the features of scientific and methodical nature, which emphasize the importance and relevance of technical solutions at the stage of preliminary predictions. The received preliminary results on the choice of a parametric profile for PP engine for light TAC the type of DART-450 are given in Tables 1–3. The reported reseach results allow us to assert that the maximum range of the aircraft flight with different engines at the same take-off mass is determined mostly by a fuel reserve, rather than the efficiency of FC (Tables 4–6). Thus, the engine AI-450CP has the advantage in all characteristics except for the take-off distance, which is the shortest for the aircraft equipped with engine MC-500B-C.

It was established that the maximum range of the aircraft flight at the same fuel stock is the largest for the aircraft equipped with engine AI-450CP, it is shorter for the aircraft equipped with engine AI-450CP-2 (Table 5), and the shortest for the aircraft equipped with engine MC-500B-C.

The maximum flight speed is the largest for the aircraft equipped with engine MC-500B-C, which is explained by its greatest power under a take-off mode and the maximum take-off mode at the assigned altitude at a slightly larger take-off mass of the aircraft (Table 6).

The maximum flight duration is demonstrated by the aircraft equipped with the least powerful engine AI-450CP, which is predetermined by the lowest hourly consumption of fuel by this engine at its throttling.

When simulating the performance of a strike task, the advantage in the flight range was shown by the aircraft equipped with engine AI-450CP; the advantage in the takeoff performance and flight speed were demonstrated by the aircraft equipped with engines AI-450CP-2 and MC-500B-C.

When simulating a flight in a circle, the advantage in terms of distance and duration of flight was shown by the aircraft equipped with engine AI-450CP, capable of performing 18 complete 10-minute circles at full fueling. However, the aircraft equipped with engines AI-450CP-2 and MC-500B-C would show better speed and takeoff performance.

Preliminary evaluation of energy fast-lift capacity of the strike variant of the aircraft when performing a strike task at equal tactical radius made it possible to demonstrate a significant advantage of the aircraft equipped with engines AI-450CP-2 and MC-500B-C over the the aircraft equipped with engine AI-450CP.

A problem situation when using the software system could occur while determining the cost of LC for a prospective TAC, since those companies that design aircraft components do not reveal accurate technical and economic information. In this case, it is advisable to use statistical information.

In the further research, we plan to assess the impact of increasing the number of weapons and equipment at AC on AC utilization factor.

7. Conclusions

1. An analysis of existing world fleet of light aircraft for general purposes reveals that characteristics of aircraft the type of DART-450 are promising for its modification.

2. Based on the improved procedure for evaluating the technical-economic characteristics of TPE as part of light TAC, we performed a study into the flight-technical characteristics of the aircraft DART-450 at various flight tasks with different TPE as part of PP. The results of studying a parametric profile of PP in the system of TAC showed the feasibility of expanding the range of altitudes and speeds of AC.

3. Numerical calculation of the project for the aircraft DART-450 with different engines suggests that in order to fulfill tasks on training flight personnel it is advisable to install the engine AI-450CP, which has the lowest life-cycle cost. It is obvious that a given aircraft with the installed engine will have the lowest cost per flight hour. To perform intelligence and strike tasks by aircraft the type of DART-450, it is advisable to install the engine AI-450CP-2. To perform strike tasks only, an aircraft the type of DART-450 should be equipped with engine MC-500B-C, which has more power than the considered engines. However, when modifying TAC to a strike aircraft, in addition to increasing the take-off mass of the aircraft in proportion to the mass of a bomb load, pylons and starters, it is necessary to enhance the structure of the aircraft wings and fuselage, and to install sighting equipment. In addition, it is necessary to conduct a research into reduction of FC by the engine when integrating it to a TAC airframe.

References

1. Mialytsa A. K. Razrabotka avanproekta samoleta: uchebnoe posobye. Kharkiv: Nats. aэrokosm. un-t «KhAY», 2010. 233 p.
2. Skibin V. A. Raboty vedushchih aviadvigatelestroitel’nyh kompaniy v obespechenii sozdaniya perspektivnyh aviacionnyh dvigateley (analiticheskiy obzor). Moscow: CIAM, 2010. 678 p.
3. Mieloszyk J., Goetzendorf-Grabowski T. Introduction of full flight dynamic stability constraints in aircraft multidisciplinary optimization // Aerospace Science and Technology. 2017. Vol. 68. P. 252–260. doi: https://doi.org/10.1016/j.ast.2017.05.024
4. Sforza P. M. Propulsion Principles and Engine Classification // Theory of Aerospace Propulsion. 2017. P. 1–52. doi: https://doi.org/10.1016/b978-0-12-809326-9.00001-4
5. Donateo T., Spedicato L. Fuel economy of hybrid electric flight // Applied Energy. 2017. Vol. 206. P. 723–738. doi: https://doi.org/10.1016/j.apenergy.2017.08.229
6. Tereshchenko Yu. M. Intehratsiya aviatsiynykh sylovykh ustanovok i litalnykh aparativ. Kyiv, 2009. 344 p.
7. Loginov V. V. Metodologicheskie osnovy formirovaniya parametricheskogo oblika silovoy ustanovki perspektivnogo uchebno-boevogo samoleta: monografiya. Kharkiv: HUVS im. Ivana Kozheduba, 2016. 294 p.
8. On Exploring Method and Software for Evaluating Effectiveness of Military Training Aircraft / Min G., Jianliang A., Zhiwen L., Juan D., Jing W. // Chinese Journal of Aeronautics. 2009. Vol. 22, Issue 6. P. 607–611. doi: https://doi.org/10.1016/s1000-9361(08)60148-x
9. Sánchez-Lozano J. M., Serna J., Dolón-Payán A. Evaluating military training aircrafts through the combination of multi-criteria decision making processes with fuzzy logic. A case study in the Spanish Air Force Academy // Aerospace Science and Technology. 2015. Vol. 42. P. 58–65. doi: https://doi.org/10.1016/j.ast.2014.12.028

10. Plioutsias A., Karanikas N. Using STPA in the Evaluation of Fighter Pilots Training Programs // Procedia Engineering. 2015. Vol. 128. P. 25–34. doi: https://doi.org/10.1016/j.proeng.2015.11.501
11. Kontseptsiya trokhstupenevoi systemy lotnoi pidhotovky kursantiv Kharkivskoho universytetu Povitrianykh Syl imeni Ivana Kozheduba. Vinnytsia: Komanduvannia PS, 2012. 10 p.
12. Marketingovoe issledovanie rynka legkih samoletov, Rossiya 2009–2011 gg. Prognoz razvitiya do 2020 goda. URL: http://www.asmarketing.ru/marketingovyie-issledovaniya/marketingovoe-issledovanie-ryinka-legkih-samoletov-v-rf-2009-2011-gg.-prognoz-razvitiya-do-2020-goda.html
13. 2014 General Aviation Statistical Databook & 2015 Industry Outlook. URL: https://gama.aero/wp-content/uploads/GAMA_2014_Databook_LRes-LowRes.pdf
14. Geremes Yu. N., Grebenikov A. G., Gumenniy A. M. Koncepciya sozdaniya samoleta dlya mestnyh vozdushnyh liniy // Otkrytye informacionnye i komp'yuternye integrirovannye tekhnologi. 2010. Issue 47. P. 20–33.
15. Forsayt razvitiya aviacionnoy nauki i tekhnologiy do 2030 goda i dal'neyshuyu perspektivu. 2012. URL: http://xn--80ap5ae.xn--p1ai/
16. Trainer Aircraft. URL: http://www.globalsecurity.org/military/world/trainer-aircraft.htm
17. Yang X., Zhang W. A faster optimization method based on support vector regression for aerodynamic problems // Advances in Space Research. 2013. Vol. 52, Issue 6. P. 1008–1017. doi: https://doi.org/10.1016/j.asr.2013.05.030
18. Florov I. F. Metody ocenki effektivnosti primeneniya dvigateley v aviacii // Trudy CIAM. 1985. Issue 1099.
19. Nechaev Yu. N. Teoriya aviacionnyh dvigateley. Moscow: VVIA im. N. E. ZHukovskogo, 1990. 878 p.
20. Yugov O. K. Osnovy integracii samoleta i dvigatelya. Moscow: Mashinostroenie, 1989. 304 p.
21. Proektirovanie samoletov / S. M. Eger (Ed.). Moscow: Mashinostroenie, 1983. 616 p.
22. Torenbik E. Proektirovanie dozvukovyh samoletov. Moscow: Mashinostroenie, 1983. 648 p.
23. Kyuheman D. Aerodinamicheskoe proektirovanie samoletov. Moscow: Mashinostroenie, 1983. 656 p.
24. Della Vecchia P., Nicolosi F. Aerodynamic guidelines in the design and optimization of new regional turboprop aircraft // Aerospace Science and Technology. 2014. Vol. 38. P. 88–104. doi: https://doi.org/10.1016/j.ast.2014.07.018
25. Portnikov B. A. Kriterii tekhniko-ekonomicheskoy effektivnosti aviacionnoy specializirovannoy sistemy // Vestnik Orenburgskogo gosudarstvennogo universiteta. 2007. Issue 5. P. 171–180.
26. Pornet C., Isikveren A. T. Conceptual design of hybrid-electric transport aircraft // Progress in Aerospace Sciences. 2015. Vol. 79. P. 114–135. doi: https://doi.org/10.1016/j.paerosci.2015.09.002
27. Marinus B. G., Poppe J. Data and design models for military turbo-propeller aircraft // Aerospace Science and Technology. 2015. Vol. 41. P. 63–80. doi: https://doi.org/10.1016/j.ast.2014.12.009
28. Wang T.-C., Chang T.-H. Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment // Expert Systems with Applications. 2007. Vol. 33, Issue 4. P. 870–880. doi: https://doi.org/10.1016/j.eswa.2006.07.003
29. O'Regan M. S., Griffin P. C., Young T. M. A vorticity confinement model applied to URANS and LES simulations of a wing-tip vortex in the near-field // International Journal of Heat and Fluid Flow. 2016. Vol. 61. P. 355–365. doi: https://doi.org/10.1016/j.ijheatfluidflow.2016.05.014
30. Saltykov A. S. Using of ansys cfx software for calculate the characteristics of aviation combat aircraft powerplants to increase flight safety // Izvestiya Samarskogo nauchnogo centra Rossiyskoy akademii nauk. 2012. Vol. 14, Issue 4 (2). P. 751–757.
31. Klochkov V. V. Metody i programmnoe obespechenie ekonomiko-matematicheskogo modelirovaniya i optimizacii tekhnicheskogo obsluzhivaniya i remonta aviadvigateley. Moscow: MFTI, 2005. 167 p.
32. Ryerson M. S., Ge X. The role of turboprops in China's growing aviation system // Journal of Transport Geography. 2014. Vol. 40. P. 133–144. doi: https://doi.org/10.1016/j.jtrangeo.2014.03.009
33. Yelanskyi O. V. Evaluation of perfection an aviation combat-trainer complex at preliminary stages designing or subsequent modernisation // Systemy ozbroiennia i viyskova tekhnika. 2014. Issue 3. P. 33–36.
34. Nasir R. E. M., Kuntjoro W., Wisnoe W. Aerodynamic, Stability and Flying Quality Evaluation on a Small Blended Wing-body Aircraft with Canard Foreplanes // Procedia Technology. 2014. Vol. 15. P. 783–791. doi: https://doi.org/10.1016/j.protcy.2014.09.051
35. Loginov V. V. Software for forming of operational performance of engine aircraft power plant // Aviacionno-kosmicheskaya tekhnika i tekhnologiya. 2015. Issue 9 (126). P. 149–152.
36. Diamond DART-450. URL: http://www.airframer.com/aircraft_detail.html?model=DART-450
37. AI-450C/CD/CP Turboprop. URL: http://ivchenko-progress.com/?portfolio=%d0%b0%d0%b8-450%d1%81
38. MS-500V-S family engines. URL: http://www.motorsich.com/ukr/products/aircraft/tr/ms-500v-s/