Light Civil Turboprop Airplane Take-Off Weight Preliminary Design Estimation Method

A. G. Grebenikov(✉), A. M. Gumenniy, L. Y. Buival, A. S. Chumak, and A. A. Sobolev

National Aerospace University "Kharkiv Aviation Institute", Kharkiv, Ukraine
l.buival@khai.edu

Abstract. A method for preliminary design estimation of civil light turboprop airplane take-off weight, taking into account the requirements of aviation rules Part 23 "Airworthiness standards for civil light airplane" AP-23 (CS-23, FAR-23), has been developed. The analysis of statistical parameters and characteristics of civil light turboprop airplane has been held. New parameters changing ranges are established. Statistical parameters and characteristics of existing civil light airplanes are specified. A method for light civil turboprop airplane take-off weight preliminary design estimation in three approximations according to the Technical Requirements Specification and recommendations for its implementation is presented. Minimum take-off weight is the accepted as effectiveness criterion. An algorithm for light civil airplane take-off weight calculation in first approximation has been developed. To implement the take-off weight calculation method, software has been developed. It allows studying the influence of the wing geometric parameters (such as aspect ratio (λ), taper ratio (η), airfoil relative thickness ($\bar{c}$) and sweep angle (χ)) on aerodynamic performance, power-to-weight ratio and airplane mass characteristics and parameters. The software was tested in the calculation of modern light airplane, namely: A-Viator, Rysachok, King Air C90 GTx, Cessna 441, as well as An-14 and was used in the development of the preliminary design of the KhAI-90 civil light turboprop airplane.

Keywords: Civil light airplane · Take-off weight · Preliminary design

1 Introduction

Light airplanes are used for transportation of passengers, goods and mail, patrol the terrain and communications, and providing medical services to the population; initial pilot training, performing training flights, as well as for aerial acrobatics, providing various types of leisure activities, etc. The main characteristic feature of such airplanes is their operation from both paved and unpaved runways, especially in small and remote places, without airports and equipped runways. Because of rapid development of science and technology which is strongly dictated by modern requirements of the industry, affecting the development of small airplane international market statistical analysis of the parameters and performances of civil light airplanes which is carried out.

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Airplane application in the wide range of human activity areas leads to the search for new ways to improve the efficiency of aviation technology (AT). At the same time, the AT is constantly being upgraded on the basis of accumulated experience, engineering and design investigations, modern science computer integrated technologies that allow providing high quality design, production preparation, engineering analysis, testing, certification, and information support for the life cycle engineering. The degree of their implementation in the design process, the development of new methods and the improvement of existing ones lead to the integration of technical, humanitarian, natural sciences and modern technology, theory and practice, which is a determining factor in safety, ergonomics and economy at civil light airplane operating.

The aim of this article is to develop take-off weight estimation method for light civil turboprop airplane with a take-off weight from 2,200 to 5,700 kg and a payload from 600 to 2,000 kg, respectively.

The evolution of the airplanes basic parameters and characteristics was accompanied by constant complication and detailed elaboration of their structure, aerodynamic, internal and load-charring layout of units, systems and equipment.

Significant changes in socio-economic activity, information and statistical support of research as well as new analytical capabilities for processing statistics have contributed to demand for existing statistical airplane data clarification from organizations that are related to the creation, development and operation of aviation complex.

Summary and systematization of light civil airplane parameters and characteristics changes [5–7, 11] and conducted researches [3, 7] contributed to identification of distinctive and essential light civil airplane design features.

Based on modern requirements of the aviation industry and its fields of application, the light civil turboprop airplane with a take-off weight from 2,200 to 5,700 kg and a payload from 600 to 2,000 kg respectively was chosen as the type of airplane for the investigations [3, 4].

2 Light Civil Turboprop Airplane Take-Off Weight Preliminary Design Estimation Method Development

At the preliminary design stage information about the designed airplane is mainly limited by performance requirements and existing similar purpose airplane designing experience. Semi-empirical methods for calculating the take-off weight of light civil airplanes are used, which are based on simplified theoretical analytical expressions and approximations that display the most important parametric dependencies. To improve results accuracy correction coefficients obtained from the processing of statistical and experimental data are introduced into these formulas [5–7, 9].

Estimating the take-off weight of an airplane and its components is one of the central tasks of the design process. Results of this stage allow to clarify the mass, energy, and geometric parameters of the airplane and, in the iterative process, coordinate them according the airplane existence equation, as well as the specified requirements and restrictions [15].

The developed method for light civil turboprop airplane take-off weight estimation on preliminary design stage is shown in the Fig. 1.

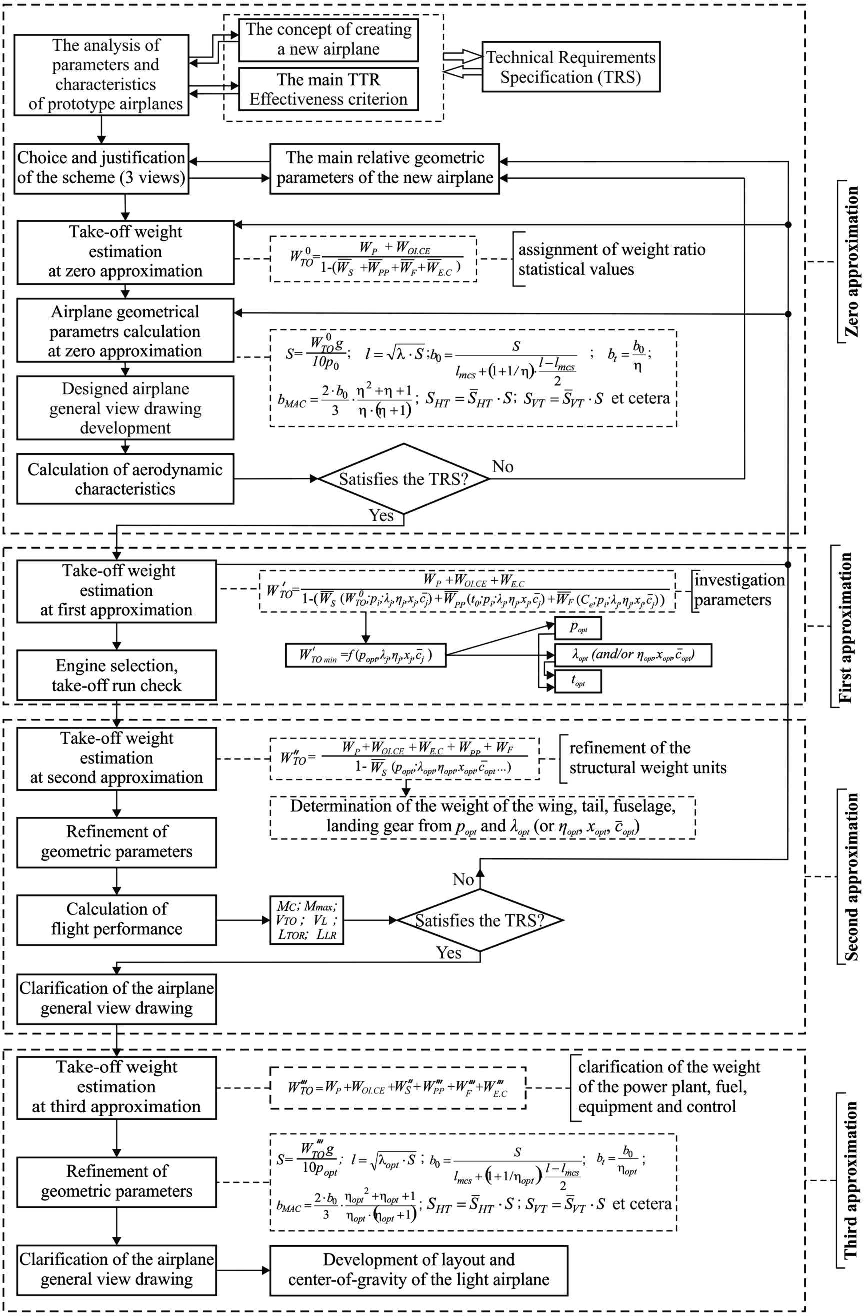

Fig. 1. Method for light civil turboprop airplane take-off weight estimation on preliminary design stage

2.1 Zero Approximation Stage

The initial data for the new light civil airplane design are:

- Technical Requirements Specification (TRS);
- the results of the prototype airplanes statistical data analysis;
- the concept of new airplane creating.

Technical Requirements Specification. In the TRS the following data are set:

- airplane designation;
- general requirements for engines, equipment, components, operational documentation, training aids and training programs for flight and engineering personnel, processing and analysis of flight information;
- expected operating (meteorological) conditions;
- requirements for airplane performance and economic characteristics: cruising flight speed V_C; cruising flight altitude H_C; ceiling H_{max}; range L; payload W_P; take-off run L_{TOR}; life cycle T;
- special requirements for airplane structure;
- requirements for functional systems and equipment;
- environmental requirements;
- physiological and hygienic requirements;
- requirements for operational manufacturability, testability, technical repair;
- ground support equipment and;
- operational documentation requirements;
- requirements for means of evacuation from damaged airplane;
- promotion of safety;
- requirements for metrological support for the airplane development, manufacture, testing and operation;
- requirements for operation of the airplane at international airports.

Statistics Analysis. Prototype airplanes statistical data analysis allows:

- new competitive airplane creating concept developing;
- complementing technical task principal tactical and technical requirements (TTR) to satisfy the requirements for a modern civil light airplane;
- establish expected operational factors.

At this stage, a statistical research of more than 30 civil light airplanes' parameters and characteristics has been conducted. Some of considered airplanes are: Cessna 441 Conquest II, Cessna 425 Corsair, Commander Jetprop 840, EMB-121 Xingu, Merlin IIIB, Mu-2B-60 Marquise, PA-42 Cheyenne III, Beech Model 200 Super King Air, King Air F90, Cessna Caravan, TBM-850, Rysachok, Piaggio P-166, M 101T Gzhel, SM-92 T Turbo-Finist, Piper Cheyenne I (PA-31T-500I), Piper Meridian 500, A-Viator, etc. It consists of three stages: "Statistical observation"; "Grouping of statistical data"; "Analysis of statistics" [3, 9–11]. Bar graphs, pie charts, scatter charts and the methods of mathematical statistics were used to analyze the parameters and characteristics dependencies.

The features of light civil airplanes aerodynamic layouts and their engines with the prevailing percentage of use in a given research range have been considered accordingly to the ongoing aviation science and technology development stage. They are low wing – 60%; two tractor propeller engines, normal aerodynamic layout, horizontal tail attached to the rear part of the fuselage, retractable landing gear – 80%; high lift devices consist of flaps and ailerons – 60%; control surfaces equipped with horn balance – 60%.

The statistical ranges of the wing parameters (Table 1), fuselage, horizontal and vertical tail (Tables 2 and 3) were determined. The wing loading range p_0 is from 98.7 to 313.85 daN/m^2, initial power-to-weight ratio is t_{TO} = 0.2585 (± 0.1055), payload ratio $\overline{W}_C$ equals to 0.271 (± 0.192), fuel weight ratio $\overline{W}_F$ equals to 0.255 (± 0.171) [3].

Table 1. Statistical ranges the wing geometric parameters [3, 14]

λ	η	χ_{LE}, degree	$\bar{c}$	S, m^2	$\overline{S}_{flap}$,	Dihedral wing V_{wing}	
						For low-winged airplane $V_{low\text{-}wing}$, degree	For high-winged airplane $V_{high\text{-}wing}$, degree
7.2...12.3	1.0...3.24	0...5	0.12...0.19	16...33	0.0177...0.362	+4...+8	−1...+4

The statistical range of the fuselage height is $h = (1.38...2.0)$ m , and its width is $b = (1.22...2.0)$ m.

Table 2. Statistical ranges of the horizontal tail relative geometric parameters [3, 14]

λ_{HT}	η_{HT}	$\chi_{LE\,HT}$, degree	$\bar{c}_{HT}$	$\overline{S}_{HT}$	$\overline{L}_{HT}$	A_{HT}
3.68...6.8	1.0...6.88	0...42	0.09...0.12	0.177...0.345	2.816...4.719	0.562...1.155

The value of dihedral horizontal tail V_{HT} depending on the place of its location has different values: for an airplane with horizontal tail located on the rear part of the fuselage, (deck tail), – 0... + 11°; for an airplane with horizontal tail located on the fin (at different distance from the fuselage axis), – 0, + 13°; for a T-tail airplane – 0, −5°.

Table 3. Statistical ranges of the vertical tail relative geometric parameters [3, 14]

λ_{VT}	η_{VT}	$\chi_{LE\,VT}$, degree	$\overline{S}_{VT}$	$\overline{L}_{VT}$	A_{VT}
0.765...1.78	1.34...3.68	0...49	0.09...0.319	0.241...0.548	0.0268...0.116

The statistical ranges of the control surfaces relative area are for elevator – $\overline{S}_E = 0.34\ldots0.472$; for rudder – $\overline{S}_R = 0.211\ldots0.491$ [3, 14].

In case of airplanes comparison at constant values of range, cruise speed, payload, etc. economic criteria are transformed into the generally accepted and more accessible criterion – the airplane take-off weight. Determination of the criteria making possible objective evaluation of the design results at each hierarchical level, finding parameters of each unit and system of the light airplane ensuring high efficiency of the airplane as a whole, is an important stage in the formalization of the design task [5, 8, 12, 13, 15].

Take-Off Weight Approximation. Light civil airplane Take-off weight zero approximation is calculated by the formula [3, 16]

$$W_0^0 = \frac{W_P + W_{OI.CE}}{1 - \left(\overline{W}_S + \overline{W}_{PP} + \overline{W}_F + \overline{W}_{E.C}\right)}, \tag{1}$$

where

W_P – payload weight, kg;
$W_{OI.CE}$ – operational items, crew and equipment weight, kg;
$\overline{W}_{E.C}$ – zero approximation equipment and control weight ratio;
$\overline{W}_S$ – zero approximation structure weight ratio;
$\overline{W}_{PP}$ – zero approximation power plant weight ratio;
$\overline{W}_F$ – zero approximation fuel weight ratio.

Zero approximations of structure weight ratio $\overline{W}_S$, power plant weight ratio $\overline{W}_{PP}$, fuel weight ratio $\overline{W}_F$, equipment and control weight ratio $W_{OI.CE}$ are assumed accordingly to the statistical range [3, 6].

The initial data are taken from requirements specified in aviation regulations, technical task (TT), tactical and technical requirements (TRS) and researches recommendations.

The numerical values of the payload weight W_P are taken from TRS or calculated by the formula

$$W_P = \left(W_{pas} + \Delta W_{lug}\right) \cdot n_{pas}, \tag{2}$$

where

W_{pas} – accepted passenger weight according to AP-23 (FAR-23, CS-23) [1, 2];
ΔW_{lug} = 14 kg – accepted passenger luggage weight.

Operational items, flight crew and equipment weight calculated by the formula [1, 2]

$$W_{OI.CE} = W_{crew} \cdot n_{crew} + \Delta W_{OI}, \tag{3}$$

where

W_{crew} – accepted crew weight according to AP-23 (FAR-23, CS-23) [1, 2], kg;
$n_{эк}$ – number of crew, pers.;
ΔW_{OI} – operational items and equipment weight, kg.

The operational items weight ΔW_{OI} is set by the designer according to the requirements of the Customer and the airworthiness standards of light civil airplane AP-23 (FAR-23, CS-23) [1, 2]. ΔW_{OI} includes personal items of flight personnel; unusable fuel reserve, technical fluids; seat covers, first-aid kit, literature for passengers, inboard repair tools, covers for units; rescue equipment, flares, containers for luggage, cargo, mail, etc. [16].

On this basis, the development of the designed airplane general view and its aerodynamic characteristics calculation can be considered as results of the zero approximation. Thus, it will make possible the most important decision to continue working on the project if technical requirements are met or to change basic relative geometric parameters if they are not satisfied.

2.2 Light Civil Turboprop Airplane Take-Off Weight First Approximation

The take-off weight of civil light airplane first approximation is made by studying the influence of its geometric parameters on the aerodynamic, energy and weight characteristics and parameters in order to determine the minimum airplane take-off weight and its optimal parameters (wing loading; aspect ratio, taper ratio, sweep, airfoil thickness ratio; power-to-weight ratio, etc.) at first approximation (see Fig. 2).

The airplane take-off weight at this stage is calculated by the formula

$$W'_{TO} = \frac{W_P + W_{OI.CE} + W'_{E.C}}{1 - \left(\overline{W}'_S\left(W^0_{TO}, p_i, \lambda_j, \eta_j, \chi_j, \bar{c}_j \ldots\right) + \overline{W}'_{PP}\left(t_{TO}, p_i, \lambda_j, \eta_j, \chi_j, \bar{c}_j \ldots\right) + \overline{W}'_F\left(C_e, p_i, \lambda_j, \eta_j, \chi_j, \bar{c}_j \ldots\right)\right)}, \quad (4)$$

where

$\overline{W}'_S$ – structural weight ratio at first approximation;
$\overline{W}'_{PP}$ – power plant weight ratio at first approximation;
$\overline{W}'_F$ – fuel weight ratio at first approximation;
$W'_{E.C}$ – equipment and control weight at first approximation, kg.

Accordingly to the developed method the calculation is performed in preliminary defined ranges of the geometric parameters, while the change in the output values is checked by the statistical ranges, actual values and behavior of the output curves of the corresponding dependencies [3, 4].

Achieving the criterion of minimum mass is possible by developed take-off weight approximation method. The introduction of the statistical correction coefficients, allows obtaining results close to the actual values of the modern civil light airplane parameters [4, 5].

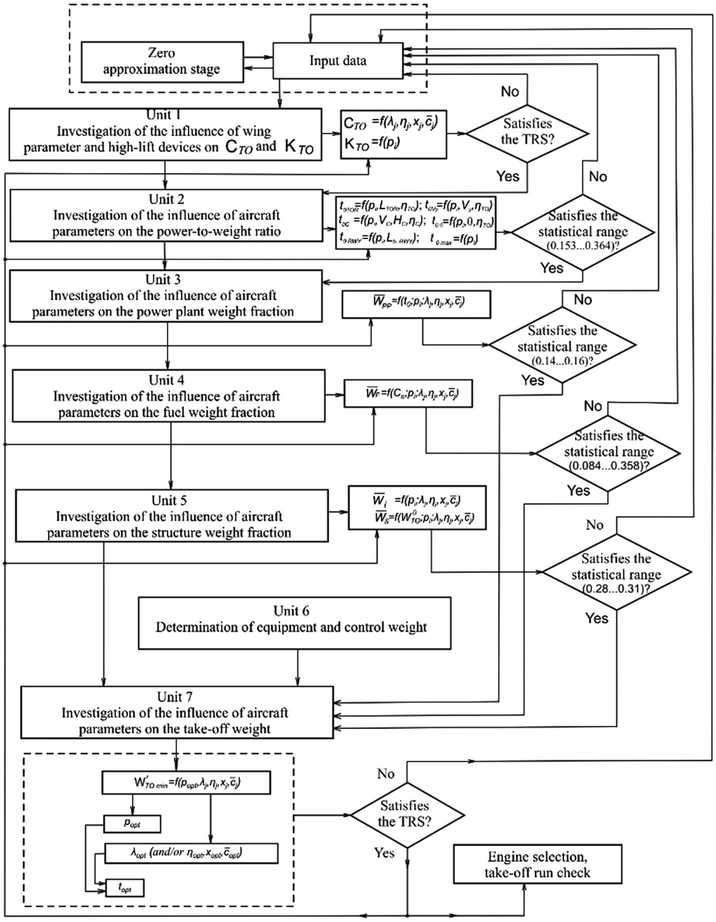

Fig. 2. The algorithm for calculation of light civil turboprop airplane take-off weight at first approximation

2.3 Estimation of the Take-Off Weight of Civil Light Airplane at Second Approximation [14]

The second approximation airplane take-off weight is determined by the formula

$$W''_{TO} = \frac{W_P + W_{OI.CE} + W'_{E.C} + W'_{PP} + W'_F}{1 - \overline{W}''_S\left(p_{opt}, \lambda_{opt}, \eta_{opt}, \chi_{opt}, \bar{c}_{opt}\ldots\right)}, \tag{5}$$

where

$W'_{E.C}$ – equipment and control weight at first approximation, kg;
$\overline{W}''_S$ – second approximation structural weight ratio;
W'_{PP} – power plant weight at first approximation, kg;
W'_F – fuel weight at first approximation, kg.

The estimation of the take-off weight of civil light airplane at second approximation is to clarify the relative masses of the units of the airplane structure. According to the graphical dependencies constructed at the first approximation $\overline{W}'_w = f(p)$, $\overline{W}'_t = f(p)$, $\overline{W}'_f = f(p, \lambda_f, d_f)$, obtain the mass parameters of the wing, tail, fuselage and landing gear at the optimal values of the wing loading p_{opt} and the investigated wing optimal geometric parameters λ_{opt} (and/or η_{opt}, $\chi_{LE\ opt}$, $\bar{c}_{opt}$). Further it is necessary to clarify the second approximation structural weight $\overline{W}''_S = \overline{W}''_w + \overline{W}''_f + \overline{W}_t + \overline{W}''_{l.g}$ and take-off weight.

2.4 Estimation of the Take-Off Weight of Civil Light Airplane at Third Approximation

The method of estimation the take-off weight of civil light airplane at third approximation refines weight of equipment and control, power plant weight and fuel.

Airplane take-off weight W'''_{TO} is determined by the formula [14, 17]

$$W'''_{TO} = W''_S + W'''_{PP} + W'''_F + W'''_{E.C} + W_P + W_{OI.CE}. \tag{6}$$

Weight of Equipment and Control [17]

$$W'''_{E.C} = k_C \cdot k_E^{e.l} \left[500 + 0.12 \cdot W''_{TO} + 0.04 \cdot W''_{TO} \cdot \sqrt{\frac{n_{pas} + n_{crew}}{100}} - 0.0011 \cdot \left(W''_{TO} \right)^{1.333} \right], \tag{7}$$

where

$k_C = 1 - 0.015 \cdot \Delta t$ – weighting factor improvement equipment,
Δt – future review period;
$k_E^{e.l}$ – factor depending on the engine layout.

Weight of Power Plant. Weight of power plant W'''_{PP} is determined by the formula

$$W'''_{PP} = R \cdot \mathrm{n}_e \cdot (m_e + m_b \cdot \mathrm{n}_b + m_h), \tag{8}$$

where R – coefficient taking into account the increase in power plant weight compared with the weight of engines and propellers combined. The value of coefficient R is determined by the formula [4, 14, 17]

$$R = 1.3 + \frac{1.5 \cdot \left(0.1 + \frac{0.9}{\sqrt[3]{N_0}} \right)}{\gamma_e}, \tag{9}$$

where

N_0 – one engine initial power, kW;

γ_e – engine specific weight, daN/kW [17].

$$\gamma_e = \frac{W_e + W_b \cdot \mathrm{n}_b + W_h}{N_0}, \tag{10}$$

where

W_e – one engine weight, kg;
W_b – blade weight, kg;
n_b – number of blades on one propeller, pieces;
W_h – propeller hub weight, kg.

Weight of Fuel. It is determined by the formula

$$W_F''' = \overline{W}_F''' \cdot W_{TO}'', \tag{11}$$

where

W_{TO}'' – second approximation take-off weight, kg;
$\overline{W}_F'''$ – fuel weight ratio at third approximation, which is determined by the formula [17]:

$$\overline{W}_F''' = \overline{W}_{F\,TOC}''' + \overline{W}_{F\,DL} + \overline{W}_{F\,ER} + \overline{W}_{F\,GTT} + \overline{W}_{FC}''', \tag{12}$$

where $\overline{W}_{F\,TOC}'''$ – fuel weight ratio, consumed during take-off and climb [14, 17]

$$\overline{W}_{F\,TOC}''' = 0.00477 \cdot \frac{C_e \cdot V_C \cdot \sqrt{A \cdot C_{d\,0\,C}} \cdot \tau_{ER}}{\eta_{b \cdot C}}, \tag{13}$$

where

C_e – specific fuel consumption at cruise flight mode, kg/kW h;
V_C – cruise speed, km;
A – drag-due-to-lift factor;
$C_{d\,0\,C}$ – airplane drag coefficient at zero lift for M_C corresponding cruising speed;
τ_{ER} – estimated time for the usable en-route fuel reserve, h;
$\eta_{b.\,C}$ – propeller efficiency at cruise flight mode.

Fuel weight ratio for the engine ground run-up, taxiing and trapped fuel $\overline{W}_{F\,GTT} = 0.006$.

$\overline{W}_{F\,DL}$ – fuel weight ratio for the descent and landing;
$\overline{W}_{F\,ER}$ – fuel weight ratio for the en-route fuel reserve [17]:

$$\overline{W}_{F\,ER} + \overline{W}_{F\,DL} = 0.00833 + 0.00144 \cdot H_C + 0.000222 \cdot H_C^2, \tag{14}$$

where

H_C – cruise altitude, km;
$\overline{W}'''_{FC}$ – fuel weight ratio consumed during cruise flight mode [14, 17]

$$\overline{W}'''_{FC} = k_F \cdot \frac{C_e \cdot L_{cal} \cdot \sqrt{A \cdot C_{d\,0\,C}}}{\eta_{b.\,C}}, \tag{15}$$

here k_F – statistical coefficient taking into account the influence of the calculated range to the value of fuel weight ratio consumed in cruise flight mode is determined from the dependence [14, 17]

$$k_F = 6.0379 \cdot L_{cal}^{-0.852}, \tag{16}$$

$$L_{cal} = L - L_{CD} = L - \left(2.6 \cdot H_C^2 + 24.8 \cdot H_C - 10\right), \tag{17}$$

where

L – range, km;
L_{cal} – calculated range, km.

3 Testing the Method for Estimation of Take-Off Weight of Civil Light Turboprop Airplane on the Preliminary Design

To implement the method for estimation of take-off weight of civil light turboprop airplane, the “CLA-TOW” (Civil Light Airplane – Take-off Weight) software of a cyclic steps has been developed [4, 14]. It allows to set the source data, edit it during the process, perform calculations, display the results in *xml* format and move them to tabular processors, build graphical dependencies for direct evaluation of the source data during calculation process.

The software package was tested by the authors with calculating modern light airplanes: A-Viator, Rysachok, King Air C90 GTx, Cessna 441.

A comparison (Table 4) of the actual and calculated minimum take-off weights, optimal aspect ratios and optimal wing payload, according to the developed method of the KhAI-90 new civil light turboprop airplane and prototypes airplanes has been made.

The method for estimation of take-off weight of civil light turboprop airplane taking into account the most important features of integrated design, was tested in the development of an advance project of the KhAI-90 new civil light turboprop airplane.

Table 4. Actual and calculated values of take-off weights, optimal aspect ratios and optimal wing payload of prototypes airplanes and KhAI-90

Airplane name	Name of quantity	Initial data	Estimated data according to the developed method	Δ, %
A-Viator	λ_{opt}	7.74	9	16.28
	$W'''_{TO\,min}$, kg	3000	3600	20.00
	p_{opt}, daN/m^2	158.2	160	1.10
Rysachok	λ_{opt}	9	10.6	15.09
	$W'''_{TO\,min}$, kg	6820	5800	17.00
	p_{opt}, daN/m^2	170	186.5	8.90
King Air C90 GTx	λ_{opt}	8.11	9	10.97
	$W'''_{TO\,min}$, kg	4756	4600	3.00
	p_{opt}, daN/m^2	141	160	19.20
Cessna 441	λ_{opt}	9.6	11	14.58
	$W'''_{TO\,min}$, kg	4468	4650	4.00
	p_{opt}, daN/m^2	160.1	200	24.90
An-14	λ_{opt}	12.15	13	7.00
	$W'''_{TO\,min}$, kg	3500	4000	14.00
	p_{opt}, daN/m^2	82.33	90	9.30
KhAI-90	λ_{opt}	9.6	8.8	9.00
	$W'''_{TO\,min}$, kg	2914	3123	7.00
	p_{opt}, daN/m^2	143.6	150	4.45

The main TTR, which are the most consistent with the Airworthiness Standards of civil light airplane AP-23 (CS-23, JAR-23) [1, 2], are given in Table 5.

Table 5. The main TTR of the KhAI-90 civil light turboprop airplane

M_{max}	L_{max}, km	n_{pas}, people	n_{crew}, people	V_C, km/h	t_{climb}, min	H_C, m	H_{max}, m	L_{TOR}, m	T, h
0.35	1 500	5–6	1–2	350	5	3 500	7 000	300	20 000

According to the results of the method for estimation of take-off weight of KhAI-90 civil light turboprop airplane, the general drawing was developed (Fig. 3).

The KhAI-90 civil light turboprop airplane is a freestanding monoplane with a high wing, single vertical tail, horizontal tail located in the rear of the fuselage, and a retractable tricycle landing gear with a nose strut.

The power plant of the designed airplane consists of two turboprop tractor engines mounted under the wing. By the decision of the Customer, one of the considered two types of power plants with modern engines can be installed. They are the AI-450C gas turbine engine of the Ukrainian production of "Motor Sich" enterprise with take-off

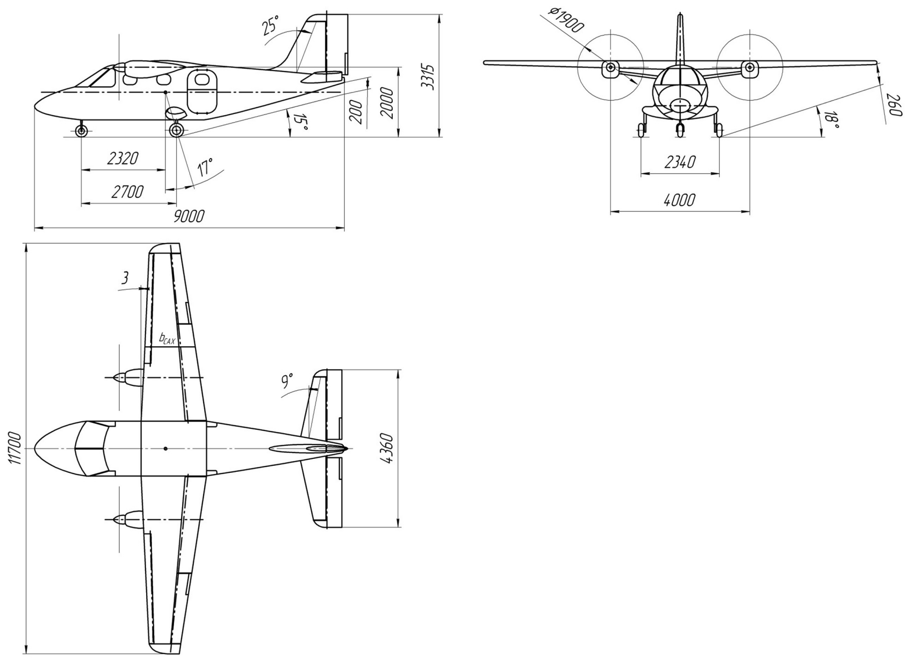

Fig. 3. Fragment of a general view drawing of the KhAI-90 airplane

power N_0 = 450 hp each and the RR 250-B17F turboprop engine of British company "Rolls-Royce" with take-off power N_0 = 420 hp each.

The application of the classical scheme of the KhAI-90 airplane with high lift devices (ailerons, flaps, slats) and controls (elevators and rudders) provides high stability and controllability in all flight modes.

The implementation of the high-wing airplane with engines located in the wing, allows operating both concrete, and grass or dirt runway surfaces. In this case, the elements of the power plant are protected from contaminants and small particles from the ground surface, which increases the life cycle and reliability of their operating. The use of modern engines designed for light airplane, reduces the specific fuel consumption and noise level on the ground.

4 Conclusions

The method for estimation the take-off weight of civil light turboprop airplane with a take-off weight from 2,200 to 5,700 kg and a payload from 600 to 2,000 kg, respectively has been developed.

The calculation at the zero approximation is based on existing methods developed by Arepiev (Moscow, 2006) [7], Badyagin - Mukhamedov (Moscow, 1978) [6], Chumak - Kryvokrysenko (Moscow, 1991) [18] and taking into account compliance with the Airworthiness Standards of civil light airplane AP-23 (FAR-23, CS-23) [1, 2, 12, 13].

The first approximation stage allows us to calculate the optimal wing payload p_{opt}, the power-to-weight ratio $t_{0\,opt}$ and the optimal geometric wing parameters λ_{opt} (or η_{opt}, $\chi_{LE\,opt}$, $\bar{c}_{opt}$), corresponding to the minimum take-off weight $W'_{\mathrm{TO}\,min}$, taking into account restrictions on landing speed $p_{limit}^{V_L}$ and normal g-factor during flying in turbulent atmosphere $p_{limit}^{n_y}$.

Based on the results of the investigation, graphical dependencies as $t_{0\,max} = f(p)$, $\overline{W}_{PP} = f(p)$, $\overline{W}_S = f(p)$, $\overline{W}_w = f(p)$, $\overline{W}_t = f(p)$, $\overline{W}_f = f(p, \lambda_f, d_f)$, $\overline{W}_F = f(p)$, $C_{TO} = f(p)$, $K_{TO} = f(p)$ are built, according to which the energy, weight and aerodynamic parameters of a civil light airplane are determined, namely, the structural units weight ratio are specified at the second approximation stage.

At third approximation weight of equipment and control, power plant weight and fuel are refined. According to these the W'''_{TO} take-off weight of civil light airplane at third approximation are determined.

The main design features of a civil light turboprop airplanes at the preliminary design stage are identified as:

– The analysis of changes parameters and characteristics of civil light airplanes made it possible to establish and clarify their limits of change and statistical ranges;
– The most important decisions in designing a light airplane on the continuation of the project makes it possible to get the results of the preliminary stage of the approach developed by the method of estimation the take-off weight;
– $W_{TO} \rightarrow \min$ minimum take-off weight is the accepted effectiveness criterion. Its value is achieved by investigation the influence of its geometric parameters on the aerodynamic, energy and weight characteristics and parameters;
– The introduction of correction statistical coefficients into the investigation using the method of successive approximations [3, 4], expressed by regression equations, allows us to obtain the values of the parameters of a new civil light airplane that satisfy the TRS;
– The geometrical, aerodynamic, energy and weight characteristics and parameters of a civil light airplane at three approximations are determined using the developed cyclic "CLA-TOW" (Civil Light Airplane – Take-off Weight) software;
– The testing of method for estimation the take-off weight was carried out during the design and development of preliminary design of KhAI-90 new civil light turboprop airplane. The value of its take-off weight is 1.3 times less than that of the prototypes, which corresponds to nearly 4%. The average error of calculation by the developed method relative to the actual values of prototype airplane is nearly 12%.

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