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# THE KhAI-90 LIGHT CIVIL TURBOPROP AIRPLANE PILOT PROJECT

**Oleksandr Grebenikov**[1] 0000-0002-1509-0665
**Vasyl Loginov**[2*] 0000-0003-4915-7407
**Andrii Humennyi**[1] 0000-0003-1020-6304
**Liliia Buival**[1] 0000-0002-3374-7720
**Anton Chumak**[1] 0000-0003-2913-7038
[1] Kharkiv Aviation Institute – National Aerospace University, 17 Chkalov Str., Kharkiv, 61070, Ukraine
[2] JSC FED, 132 Sumska Str., Kharkiv, 61023, Ukraine

* login_w@ukr.net

**Abstract**

The pilot project of new light civil turboprop aircraft, called the KhAI-90, featuring a cruising speed of 350km/h, payload of 600 kg at 500 km range, and equipped with two turboprop Rolls-Royce 250-B17F engines each with power of 420 hp (alternatively, two AI-450C engines each with power of 450 hp may be installed) is presented herein. Based on the developed technical task, the concept for creating the KhAI-90 new competitive light civil aircraft, and the analysis of prototypes' aircraft parameters and characteristics, the main tactical and technical requirements are assigned. The take-off weight of the new aircraft is determined in three approximations at the preliminary design stage of light civil turboprop aircraft, using the iterative software "CLA-TOW", studying the influence of the wing geometric parameters and lift devices on aerodynamic performance, the power-to-weight ratio and the airplane weight parameters. The following parameters are calculated for the design: minimum take-off weight $W_{TO\ \min}$ = 3,600 kg, optimal wing loading $p_{0\ opt}$ = 130 daN/m$^2$, optimal aspect ratio 9.6, taper ratio 2.25, sweep angle at leading edge 3 degrees, airfoil relative thickness 10.6%. A general view and three-dimensional parametric models of the master-geometry and passenger cabin space distribution are constructed for the KhAI-90 by means of the SIEMENS NX computer integrated system. More broadly, this pilot project has also demonstrated the viability of the method we developed and previously reported for determining light civil turboprop airplane parameters.

**Keywords:** pilot project, aircraft design, light civil airplane, method, take-off weight, Three-Dimensional Parametric Modelling
***Type of the work:*** *Research Article*

## 1. INTRODUCTION

Civil light aircraft development is a promising sector for Ukraine's aviation industry, which is almost not covered by potential investors. In the local and regional air service, the use of such aircraft has not yet been fully developed. Therefore, a light civil aircraft pilot project may be important for the development of small aircraft in Ukraine, as well as significant for the broader Ukrainian economy.

The domestic design and production of such light civil aircraft in Ukraine will lead to lower costs of their manufacture, maintenance and repair as compared to that of airplanes currently in service, and also create jobs in the country.

Important aspects in the design of civil light aircraft include minimal weight, minimal operating and production costs, better aerodynamic performance and durability [1, 2]. These can be achieved through the development of concepts for the aerodynamic layout, strength and weight improvement of the designed aircraft, which meet the long-term needs of the light aircraft market [1, 3].

The essential transportation properties of a new aircraft type, its overall system concept, design data and detailed geometry – including the generation of aircraft concept proposals, including the technical, technological, competitive and commercial aspects – and the preliminary design stages have been discussed in [4–6]. Some representative studies describing the airplane design methodology, including summaries of the preliminary design process using CAD software for investigating the geometrical parameters of airplane units, are listed in [7–10]. Advanced transport systems are generally characterized by various infrastructural, technical/technological, operational, economic, environmental, social, and policy performance indicators, and can be classified in terms of their level of potential commercialization [11, 12].

A "light civil aircraft" is a multi-purpose category with a number of seats, excluding pilots, not more than nine, with a maximum certified take-off weight of not more than 5,700 kg [13, 14]. Comparative analysis of 5- to 19-seater aircraft has shown the economic viability of using gas turbine aircraft engines use for airplanes of local airlines (carrying 5-6 passengers) [15]. The evolution of the basic parameters and characteristics of such aircraft, involving the continual complication and detailed elaboration of their structure, the aerodynamic, internal and load-charring layout of units, systems and equipment, is described shown in [1, 16]. Based on the modern requirements of Ukraine's aviation industry, potential fields of application, and the previous research on parameters and statistical characteristics of light civil airplanes reported in [17–21], as the type of airplane for this pilot study we selected a 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 [2].

One of the most important tasks in designing a new aircraft is to determine its take-off weight. The main task is to ensure the necessary flight and tactical characteristics of the aircraft at its minimum value, because any unjustified overstatement of the take-off weight always reduces the efficiency and competitiveness of the aircraft. The difficulty of solving this problem, however, lies in the fact that some components of the take-off weight depend on its magnitude and therefore there is a contradiction: the take-off weight cannot be determined without determining the weight of all its components, and the weight of components cannot be found without the take-off weight. This is usually solved by using a method of successive approximations, first using approximate methods, and then more accurate methods and formulas for calculating the aircraft weight.

The main factor hampering this process is the confidentiality maintained by commercial enterprises and also (in Ukraine) the insufficiently modernized domestic public methodological base for the design of civil light aircraft with turboprop engines. 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 the safety, ergonomics and economy of light civil airplane operation.

The existing literature did not describe any investigation of aircraft parameters or detailed calculation at the stage of zero approximation for a light turboprop aircraft of the specified type – namely: the criterion is not the minimum weight, does not take into account the amount of fuel consumption, does not allow to determine the mass of the structure, fuel and equipment in the calculation process, in the method of calculating takeoff mass, do not specify the components of the target load, workload and crew equipment in the zero approximation. In a previous publication we developed a new method for light civil turboprop airplane take-off weight estimation at preliminary design stage [2]. The present article, in turn, presents an implementation of the developed method and a demonstration of its viability.

**The overall aim of this article** is to develop a pilot project of KhAI-90 light civil turboprop airplane, using the new method we previously published [2] for light turboprop civil airplane take-off weight estimation at the preliminary design stage. The more **specific objectives** of this article are as follows:

- to develop the Technical Requirements Specification and the Concept of Light Civil Airplane Creation;
- to assign modern tactical and technical requirements for the designed airplane;
- to determine aerodynamic, masses and geometric parameters and characteristics of the KhAI-90;
- to develop a general drawing and a three-dimensional model of the new light civil airplane.

**List of Symbols**

| | |
|---|---|
| $f$ | Friction coefficient |
| $m_z^{C_y}$ | Margin of static stability |
| $M_{\max}$ | Maximum Mach number |
| $L_{\max}\,(W_{f\,\max})$ | Maximum range with maximum weight of fuel |
| $L_{\max}\,(W_{p\,\max})$ | Maximum range with maximum weight of payload |
| $T$ | Life cycle |
| $W_{TO}^{0}$ | Zero approximation take-off weight |
| $W'_{TO}$ | First approximation take-off weight |
| $W''_{TO}$ | Second approximation take-off weight |
| $W'''_{TO}$ | Third approximation take-off weight |
| $\bar{W}_{PP}$ | Power plant weight ratio |
| $\bar{W}_{S}$ | Structure weight ratio |
| $\bar{W}_{W}$ | Wing structure weight ratio |
| $\bar{W}_{t}$ | Tail unit structure weight ratio |
| $\bar{W}_{f}$ | Fuselage structure weight ratio |
| $\bar{W}_{F}$ | Fuel weight ratio |
| $C_{TO}$ | Take-off lift coefficient |
| $K_{TO}$ | Take-off lift to drag ratio |
| $W_{OI.CE}$ | Operational items, crew and equipment weight |
| $W_{P}$ | Payload weight |
| $\bar{W}_{E.C}$ | Equipment and control weight ratio |
| $l$ | Wing span |

| | |
|---|---|
| $l_{mcs}$ | Wing center section span |
| $p_o$ | Wing loading (W/S) |
| $\eta$ | Taper ratio |
| $\chi_{LE}$ | Leading-edge sweep angle |
| $\overline{c}$ | Airfoil relative thickness |
| $d_f$ | Diameter of fuselage |
| $\lambda_f$ | Fuselage fineness ratio |
| $h$ | Aircraft height |

The method for determining the parameters of the light civil turboprop airplane is presented in Fig. 1. It can be used to develop light civil turboprop airplane pilot project for aircraft with a take-off weight from 2,200 to 5,700 kg and a payload from 600 to 2,000 kg. Approximations with explanations of their names are shown in four large rectangles drawn in dotted lines. The solid-lined rectangles, in turn, show successive steps with explanations in the form of basic calculation formulas within each approximation. The diamonds indicate conditions, the fulfillment or non-fulfillment of which will lead to an intermediate assessment of the approximation results and a decision to proceed to the next step or approximation. The links between approximations and between steps within the same approximation are shown in Fig. 1.

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

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

In the zero approximation, the estimated take-off weight $W_{TO}^{0}$ and geometrical parameters, and also a general drawing of the designed airplane are used to calculate its aerodynamic characteristics.

The first approximation of the take-off weight of a light civil airplane is made by studying the impact of its geometric parameters on the aerodynamic, power and weight parameters and performance indicators to estimate the minimum airplane take-off weight $W'_{TO\min}$ and its optimal parameters (wing loading; aspect ratio, taper ratio, sweep angle, airfoil thickness ratio; power-to-weight ratio, etc.). The first approximation stage allows us to calculate the optimal wing loading $p_{opt}$, the power-to-weight ratio $t_{0\,opt}$ and the optimal geometric wing parameters $\lambda_{opt}$ (or $\eta_{opt}$, $\chi_{LE\,opt}$, $\overline{c}_{opt}$), corresponding to the minimum take-off weight $W'_{TO\min}$, taking into account restrictions on landing speed $p_{\text{limit}}^{V_L}$ and normal g-factor during flying in turbulent atmosphere $p_{\text{limit}}^{n_y}$. Based on these results, graphical dependencies such 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 devised, according to which the weight, power and aerodynamic parameters of the new light civil airplane are determined, the engine selected, and the take-off run length checked.

At the second approximation stage, the structural unit weight ratio, take-off weight $W''_{TO}$, geometric parameters are specified, to calculate flight technical characteristics and to specify the general drawing.

At the third approximation, the weights of equipment and control, power plant and fuel, take-off weight $W'''_{TO}$, geometric parameters; general drawing are refined and three-dimensional layout and centering of the aircraft are developed.

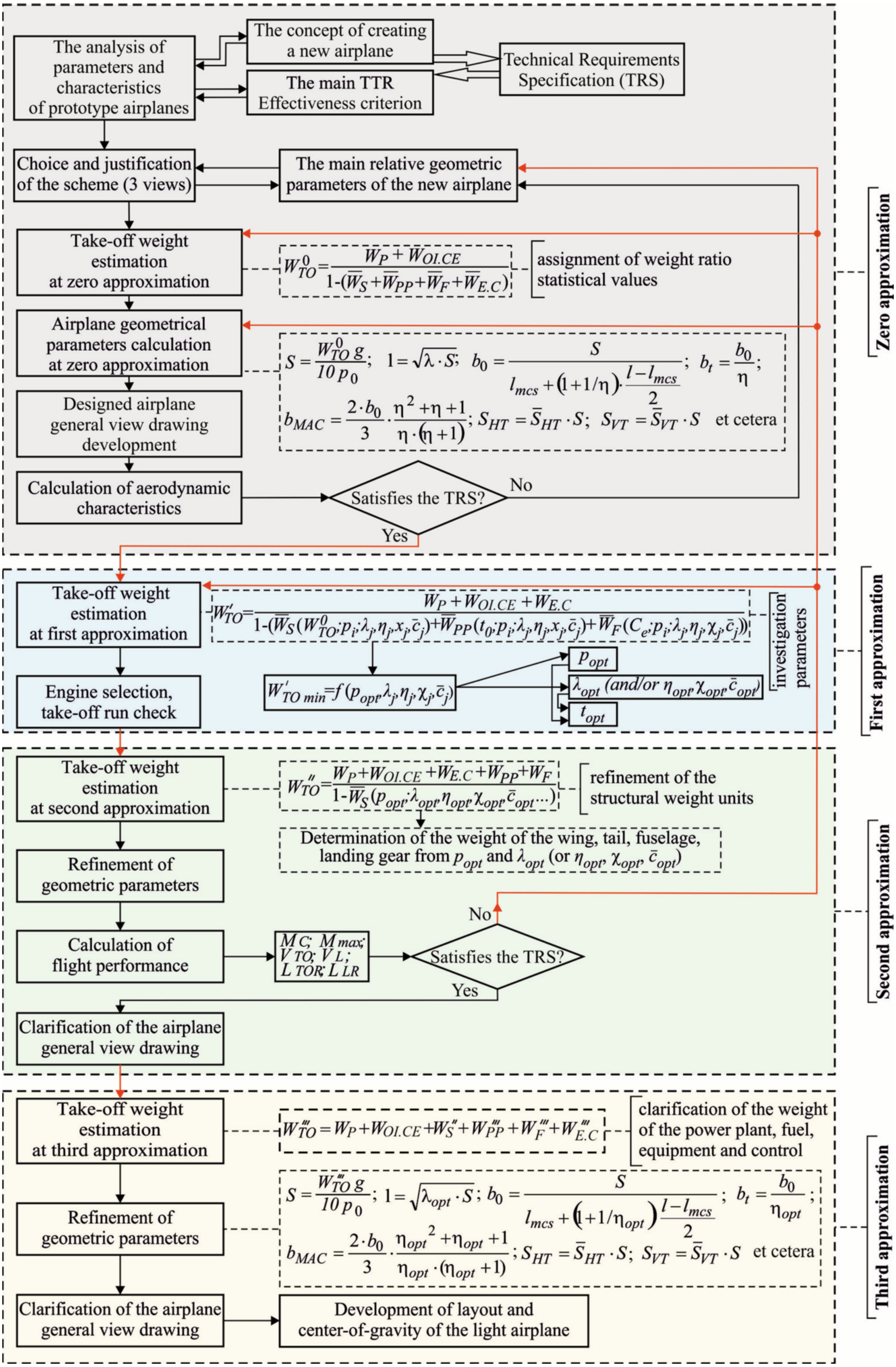



Fig. 1. Method for determining the parameters of a light civil turboprop airplane.

The preliminary design stage involves the choice of the aircraft scheme, determination the combination of the main parameters of the aircraft and its systems that ensure compliance with the specified requirements, or justify the need for their adjustment [16, 22].

## 2. DEVELOPMENT OF THE KHAI-90 LIGHT CIVIL AIRCRAFT PILOT PROJECT AT THE PRELIMINARY DESIGN STAGE

### 2.1. Technical Requirements Specification for the KhAI-90 light civil airplane's development

*Assignment*

The KhAI-90 light civil airplane is designed to perform civil tasks and to be used in such variants:

- transportation of six passengers;
- three passengers and 300 kg of cargo;
- two passengers and 400 kg of cargo;
- 800 kg of cargo;
- as a VIP option.

The KhAI-90 designed aircraft can be used to provide such services:

- passenger, cargo, passenger-cargo transportation;
- "air taxi" service;
- patrolling and reconnaissance of geographical landscape sites and of national economy sites;
- search and rescue operations and evacuations of people;
- transportation of the wounded or individuals with musculoskeletal disabilities ;
- execution of tourist and wedding routes, air walks;
- delivery of hunters and fishermen to remote destinations;
- transportation of athletes and tourists (including with long equipment).

*Expected operating conditions:*

- mass density, barometric pressure, kinematic viscosity, outside air temperature compliant with DSTU GOST (ДСТУ ГОСТ) 4401: 2009;
- air temperature near the ground – from minus 35°C to +35°C;
- relative humidity of the outside air near the ground at +35°C ≤ 70%;
- direction and wind speed near the ground according to AP (АП)-23 (CS-23, FAR-23):
  - counter component ≤ 3.2 m/s;
  - associated component ≤ 9.3 m/s;
  - lateral component at an angle of 90° to the runway varies in the range of 3 to 6.3 m/s according to the friction coefficient $f$.

Acceptable runway conditions:

- dry, wet;
- wet, with areas of water;
- filled with water up to 10 mm;
- covered with a layer of slush up to 15 mm;
- snow-covered (snow layer up to 50 mm).

The aircraft must provide the following flights:

- according to the rules of visual flight and devices;
- day and night;

- in simple and complex weather conditions;
- in conditions of icing;
- on domestic and international air routes;
- over the plain, hilly and mountainous terrain;
- over bodies of water.

## 2.2. Concept of the KhAI-90 Civil Light Airplane Creating

The new aircraft must satisfy the specified long-term requirements, the relevant tasks for various spheres of society, and provide a higher level of economic and operational performance among similar-purpose domestic and foreign light aircraft . Achieving this goal is possible by implementing the following concepts [1, 4]:

– aerodynamics: to obtain aircraft lift-to-drag ratio of not less than 14 in flight cruise mode and of not less than 8 in take-off mode and to develop an aerodynamic layout of the aircraft which will provide take-off and landing speeds of no more than 135 km/h. These requirements can be fulfilled through the use of a classical aerodynamic scheme with a high-mounted wing, which has a lower resistance to interference compared to the aerodynamic scheme of a low-wing airplane. A retractable chassis also helps to reduce drag;
– airframe structure and aircraft systems: the weight return in accordance with the payload must be higher than that of modern aircraft designs and exceed 60%, or not more than 27% for the airframe structure;
– power plant: should employ more economical engines;
– stability and controllability: the plane must provide a harmonious combination of stability criteria and controllability in all flight modes, regulated by a margin of static stability $m_z^{C_y} = (0.1...0.12)\ b_{MAC}$;
– airplane systems: systems and equipment complexes must satisfy the specified requirements for aerobatic and navigation characteristics, the level of reliability and flight safety. The magnitude of the command lever effort in all flight modes should be within the following ranges: pitch from 2.5 to 25 kgf; roll from 1.5 to 15 kgf; rate from 3 to 50 kgf;
– life cycle: airframe structure and aircraft systems with the required weight return must ensure a given life cycle of at least 20,000 flight hours;
– aircraft layout: should provide passenger comfort, safety and efficiency of operation, convenient and fast boarding and disembarking of passengers (loading and unloading of cargo) by using a removable step and wide doors in both passenger and cargo options, respectively. The aircraft structure should allow for rapid inspection and preparation of the aircraft for flight without additional maintenance staff.

## 2.3. Basic tactical and technical requirements and efficiency criteria

Based on the adopted technical tasks and the envisioned concept for the KhAI-90 aircraft, the basic tactical and technical requirements (TTR) were adopted, best meeting all the requirements for a modern civilian light aircraft, shown in Tab. 1.

Tab. 1. The main TTR for the KhAI-90 light civil turboprop airplane [2, 3].

| $M_{max}$ | $L_{max}(W_{f\max})$, km | $L_{max}(W_{p\max})$, km | $n_{pas}$, pers. | $L_{TOR}$, m | $H_{\max}$, m | $V_C$, km/hr | $n_{crew}$, pers. | $H_C$, m | $T$, hr |
|---|---|---|---|---|---|---|---|---|---|
| 0.35 | 1,500 | 500 | 6 | 300 | 5,000 | 350 | 1 | 3,500 | 20,000 |

The airframe structure, systems, power plant and equipment must be operated within the designated life cycle. The functional capabilities and technical level of the aircraft and equipment must provide the specified flight and technical requirements and certification requirements in compliance with the Aviation Rules for Civil Light Aircraft (AP-23 (АП-23) and CS-23), aircraft engines (AP-33 (АП-33), aviation rules of aircraft certification for noise in the field (AP-36 (АП-36), aviation certification procedures for equipment (AP-21 (АП-21), airworthiness standards for propellers (AP-35 (АП-35). Design documentation must be performed using modern computer integrated technologies: the aircraft is designed using CAD\CAM\CAE systems. $W_{TO}$→min – minimum take-off weight is the accepted effectiveness criterion.

Next, based on the above assumptions, the design of KhAI-90 civil light aircraft was developed according to the method for light civil turboprop airplane parameters estimation at the preliminary design stage in three approximations [2].

## 2.4. Zero approximation

### 2.4.1. Analysis of parameters and characteristics of prototype aircraft

We studied a chosen group of civil light turboprop aircraft based on a classical aerodynamic scheme, with a horizontal tail in the tail part of fuselage, with take-off weight from 2,200 to 5,700 kg and with payload from 600 to 2,000 kg. The aerodynamic schemes of the following light aircraft of the studied type were chosen for the analysis: Cessna 441 Conquest II [17], Cessna 425 Corsair, Commander Jetprop 840 [18], EMB-121 Xingu, Merlin IIIB [20], Mu-2B-60 Marquise [21], PA-42 Cheyenne III, Beech Model 200 Super King Air, King Air F90, Cessna Caravan [19], TBM-850, Rysochok [17], Piaggio P-166, M 101T Gzhel, CM-92 T Turbo-Finist, Piper Cheyenne I (PA-31T-500I), Piper Meridian 500 [23], and A-Viator [4, 6, 14, 15, 17, 22]. Based on the Technical Requirements Specification and analysis of the parameters and characteristics of prototype aircraft [17], the concept for creating a new competitive KhAI-90 civil light aircraft was developed and the basic tactical and technical requirements (TTR) were identified.

### 2.4.2. Selection and justification of the aircraft scheme

The scheme selected for the KhAI-90 light civil turboprop airplane is that of 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 straight trapezoidal wing with a straight wing center section offers good aerodynamic, structural and technological characteristics. As wing lift devices it uses simple flaps, as controls, it employs ailerons located along the wing to increase their efficiency. The wing is equipped with two turboprop engines with traction propellers and fuel tanks that unload it in flight.

The fuselage is unpressured. Dimensions of the fuselage are calculated in accordance with the layout of the passenger cabin for five passengers, crew cabin for one pilot and one passenger and the required amount of cargo space depending on the task, which allows for more efficient use of cabin space.

The landing gear has a tricycle configuration and is retractable, with a nose strut. Under the action of lateral forces on the wheels of the main struts, it is stable at the stage of takeoff and run. To increase the speed and improve aerodynamic characteristics, the design uses retractable landing gear, while the nose strut is removed forward into the fuselage, the main struts – in the fairings, made as a small wing and located on the fuselage, and partially in the fuselage.

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

The implementation of the high-wing airplane, with engines located on the wing, allows it to be operated from concrete, as well as grass or dirt runway surfaces. In this case, the elements of the power plant are better protected from contaminants and small particles from the ground surface, which increases their operation life cycle and reliability. The use of modern engines designed for light aircraft reduces the specific fuel consumption and noise level on the ground [2, 3].

### 2.4.3. The main relative geometric parameters

Based on the analysis of the parameters and characteristics of modern prototype aircraft, the main relative geometric parameters of the designed aircraft were calculated, as shown in Tab. 2.

Tab. 2. The main relative geometric parameters of the KhAI-90 civil light aircraft.

| $\lambda$ | $\chi_{LE}$, degree | $\eta$ | $\bar{c}_{mid}$, % | $\bar{b}_{flap}$ | $\delta_{flap}$, degree | $d_f$, m | $\lambda_f$, m |
|---|---|---|---|---|---|---|---|
| 9.6 | 3 | 2.25 | 10.6 | 0.271 | 20/40 | 1.58 | 5.69 |

| $\bar{S}_{HT}$ | $\bar{S}_{VT}$ | $\lambda_{HT}$ | $\lambda_{VT}$ | $\chi_{0.25\,HT}$, degree | $\chi_{0.25\,VT}$, degree | $\bar{c}_{HT}$ | $\bar{c}_{VT}$ | $\eta_{HT}$ | $\eta_{VT}$ |
|---|---|---|---|---|---|---|---|---|---|
| 0.26 | 0.15 | 4.2 | 1.04 | 9 | 25 | 0.1 | 0.12 | 1.54 | 1.8 |

Determination of take-off weight and geometric parameters of the aircraft in the zero approximation is performed using software “CLA-TOW” [2, 3], as follows:

$$W_{TO}^{0}=\frac{W_P+W_{OI.CE}}{1-\left(\bar{W}_S+\bar{W}_{PP}+\bar{W}_F+\bar{W}_{E.C}\right)}=2,683\,\text{kg}.$$

### 2.4.4. Calculation of aerodynamic characteristics

The calculations were performed using analytical methods and a program developed at the Department of Aerohydrodynamics of the Kharkiv Aviation Institute (KhAI), taking into account the Airworthiness Standards for civil light aircraft AP-23 [2, 4, 11, 13].

The construction of the graphical dependence of the coefficient of lift on the angle of attack and the polar in different configurations of flight is shown in Fig. 2 and 3.

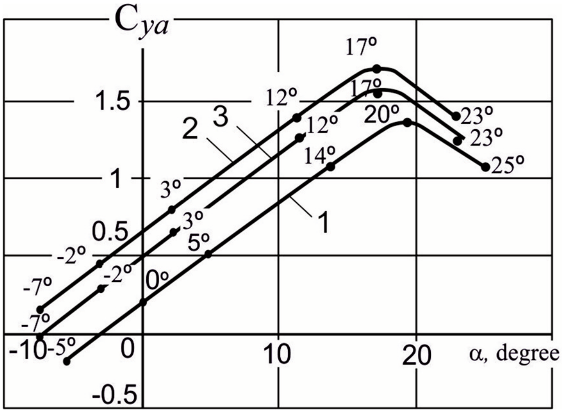



Fig. 2. The influence of the angle of attack on the lift coefficient KhAI-90. 1– cruising mode; 2 – take-off; 3 – landing.

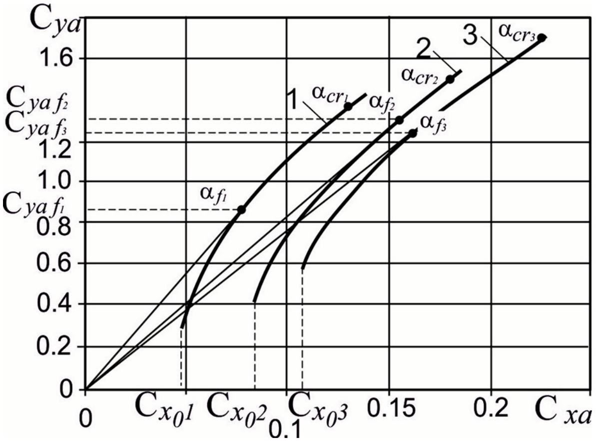


Fig. 3. The polars of the aircraft KhAI-90. 1– cruising mode;
2 – take-off; 3 – landing.

The figures determine the maximum, most favorable lift coefficients, critical and most favorable angles of attack, drag coefficients and lift-to-drag ratio of the aircraft in cruising, take-off and landing modes.

### 2.5. The first approximation

#### 2.5.1. Determination of the take-off weight of the aircraft in the first approximation

The determination of the take-off weight in the first approximation was performed using software "CLA-TOW" [2, 17, 23] by studying the influence of wing parameters and lift devices on aerodynamic, power and weight parameters. The study of the effect of wing loading and its aspect ratio on the take-off weight of the KhAI-90 aircraft is shown in Fig. 4 and 5.

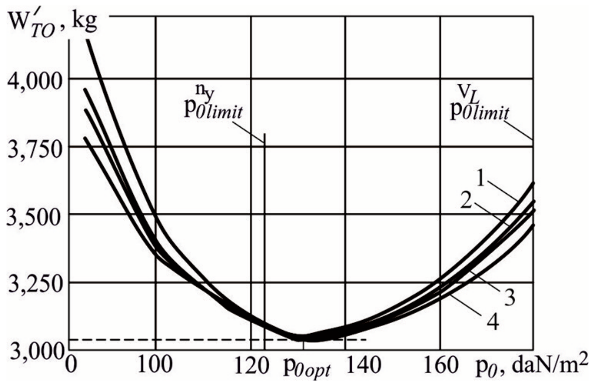


Fig. 4. The effect of wing aspect ratio on the take-off weight of the aircraft KhAI-90 when changing the wing loading.
1 – $p_0$ = 115 daN/m²; 2 – $p_0$ = 130 daN/m²;
3 – $p_0$ = 143.6 daN/m²; 4 – $p_0$ = 145 daN/m²;
5 – $p_0$ = 160 daN/m².

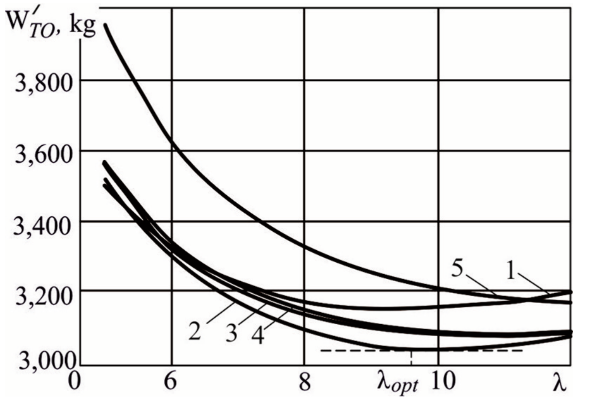



Fig. 5. Influence of wing loading on the take-off weight of the KhAI-90 airplane at change of wing aspect ratio.
1 – λ = 9; 2 – λ = 9.6; 3 – λ = 10; 4 – λ = 11.

Minimum calculated weight $W'_{TO\min}$ = 3,037 kg the corresponding optimal parameters are as follows: wing loading $p_{opt}$ =130 daN/m$^2$, aspect ratio $\lambda_{opt}$ = 9.6, power-to-weight ratio $t_{0\ opt}$ = 0.1893.

### 2.5.2. Selection of the engine

To select the engine, the total required power is calculated taking into account the calculated optimum size of the maximum starting power equipment, according to the formula:

$$N_0 = t_{0onm} \cdot m_0 = 0.1893 \cdot 3,037 = 564\,\text{h.p.}$$

This requires power of one engine:

$$N_{01} = N_0/n = 564/2 = 282\,\text{h.p.}$$

On similar civil light aircraft in the world market, turboprop engines of various engine companies are installed to increase the competitiveness: these include the AI-450C (JSC "Motor Sich", Ukraine) or Rolls-Royce 250-B17F (Rolls-Royce, UK). Their main technical characteristics are given in Tab. 3.

Tab. 3. The main technical characteristics of AI-450C and Rolls-Royce 250-B17F engines [24].

| Name | AI-450C | Rolls-Royce 250-B17F |
|---|---|---|
| Dry engine weight $W_{en}$, kg | 115 | 93 |
| Take-off power $N_0$, h.p. | 450 | 420 |
| Cruise power $N_{0cruise}$, h.p. | 300 | 380 |
| Specific fuel consumption $C_e$, kg/h.p.·hr | 0.31 | 0.285 |

The KhAI-90 aircraft is equipped with two turboprop engines located in the wing, which allows the technical task requirements to be met and satisfies the concept and safety requirements for the operation of the passenger aircraft.

## 2.6. The second approximation

### 2.6.1. Determination of the take-off weight of the aircraft in the second approximation

According to the graphical dependencies shown in Fig. 6 i 7, wing weight ratio $\bar{W}''_w = 0.1423$, fuselage weight ratio $\bar{W}''_f = 0.1263$, tail weight ratio $\bar{W}''_t = 0.0315$, landing gear weight ratio $\bar{W}''_{l.g} = 0.0599$.

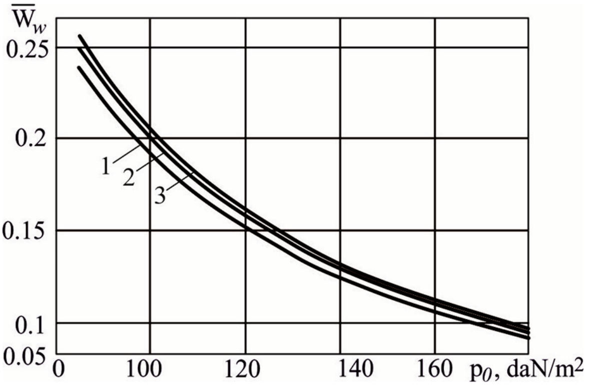



Fig. 6. Influence of wing loading on the value of the wing weight ratio when changing wing aspect ratio.
1 – λ = 9; 2 – λ = 9.6; 3 – λ = 10; 4 – λ = 11.

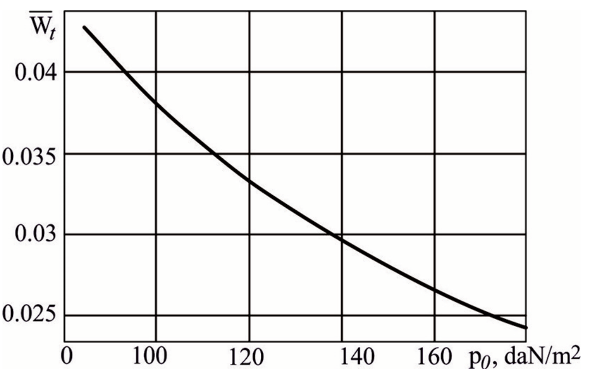



Fig. 7. Influence wing loading on the value of the tail weight ratio when changing the wing aspect ratio.

The relative weight of the aircraft design was specified, taking into account the placement of the maximum fuel supply at a range of up to 1500 km. Then the take-off weight of the second approximation is as follows:

$$W''_{TO} = \frac{W_P + W_{OI.CE} + W'_{E.C} + W'_{PP} + W'_F}{1 - \bar{W}''_S\left(p_{opt}, \lambda_{opt}, \eta_{opt}, \chi_{opt}, \bar{c}_{opt} \ldots\right)} = 3{,}139\,\text{kg}.$$

### 2.6.2. Calculation of flight characteristics

The calculation of flight characteristics was performed using the methods of thrust and power [1, 5, 13, 26]. The results are shown graphically on Fig. 8 i 9.

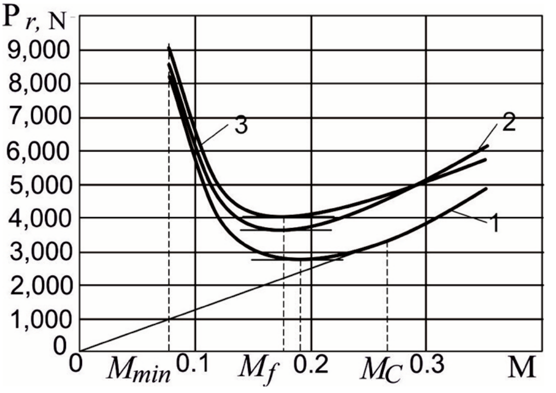



Fig. 8. Influence of Mach numbers on the required thrust of KhAI-90 aircraft engines. 1– cruising mode; 2 – take-off; 3 – landing.

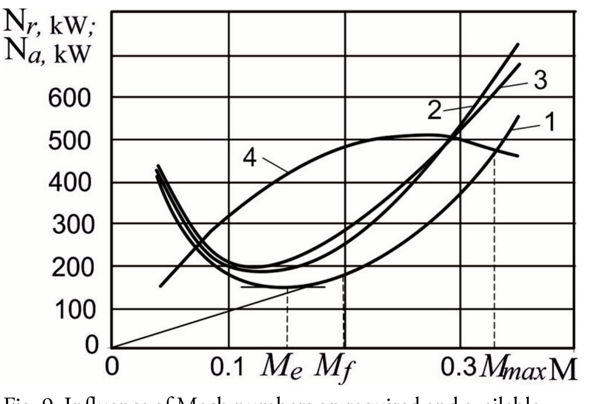



Fig. 9. Influence of Mach numbers on required and available power. 1, 4 – cruising mode; 2 – take-off; 3 – landing; 4 – available power.

The figures determine the minimum, maximum and cruising Mach numbers, as well as the area of existence of the aircraft in cruising, take-off and landing modes.

## 2.7. The third approximation

### 2.7.1. Determination of the take-off weight of the aircraft in the third approximation

The determination of the take-off weight in the third approximation was performed using software "CLA-TOW" [1, 2, 7]. Calculated value:

$$W'''_{TO} = W''_{S} + W'''_{PP} + W'''_{F} + W'''_{E.C} + W_{P} + W_{OI.CE} \approx 3,600\,\text{kg}.$$

### 2.7.2. Clarification of geometric parameters and general drawing of the aircraft

Clarification of the geometric parameters of the wing, tail, fuselage and landing gear of the KhAI-90 aircraft was performed using software "CLA-TOW" [2, 9, 17]. The main parameters are listed in Tab. 4. Based on the geometrical parameters, a general view of the designed aircraft, a fragment of which is shown in Fig. 10.

Tab. 4. Basic geometric parameters of the KhAI-90 aircraft.

| $l$, м | $L_f$, m | $d_f$, m | $h$, m | $l_{HT}$, m | $b_0$, m | $b_t$, м | $b_{0\,HT}$, m | $b_{t\,HT}$, m | $b_{0\,VT}$, m | $b_{t\,VT}$, m |
|---|---|---|---|---|---|---|---|---|---|---|
| 11.7 | 9.0 | 1.58 | 3.315 | 4.36 | 2.24 | 0.995 | 1.3 | 0.838 | 2.54 | 1.42 |

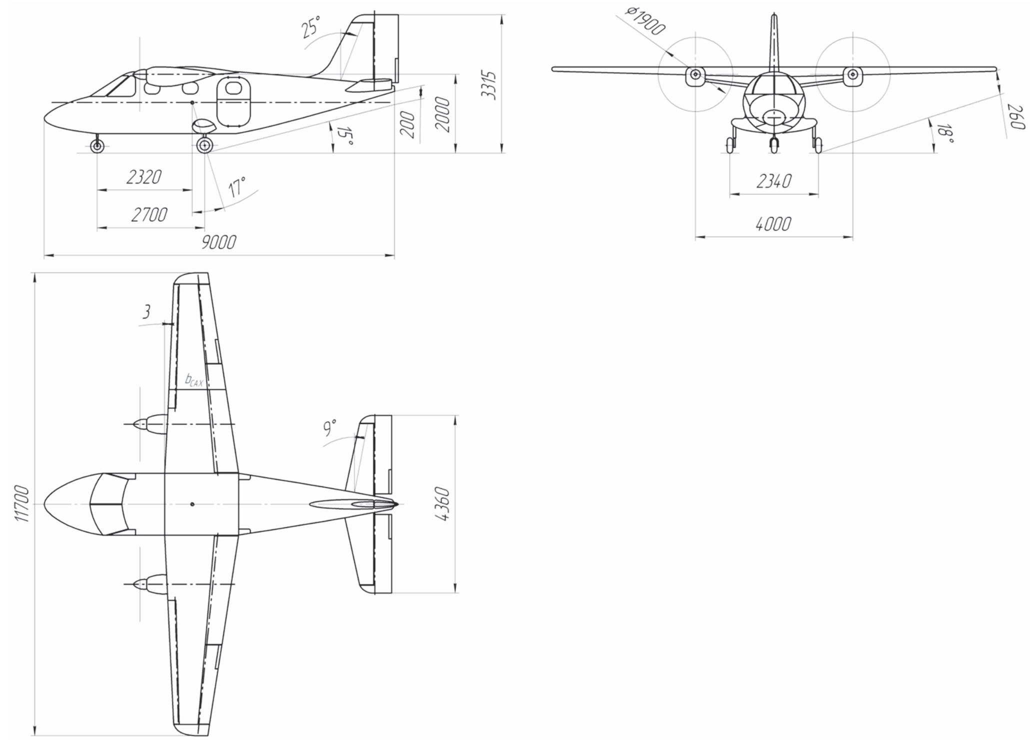


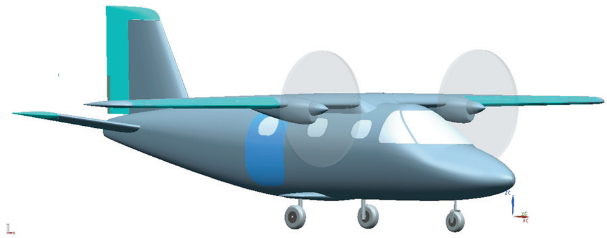

Fig. 10. Fragment of KhAI-90 airplane general view drawing.

The remainder of this article presents the results of the KhAI-90 designed civil light aircraft with Rolls-Royce 250-B17F engines, laid out for the basic purpose – the transportation of passengers over a distance of 500 km.

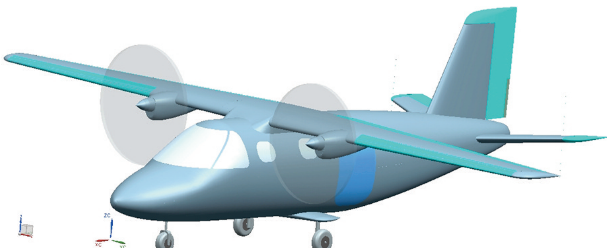
## 2.8. Development of layout and center-of-gravity of KhAI-90 civil aircraft

To develop the layout of the KhAI-90 aircraft, the method of three-dimensional parametric model is used, which allows the model of the aircraft to be transformed, the elements devised in the early stages to be changed, and all the geometry created later to be automatically rearranged. The computer design of the aircraft was developed using the Siemens NX system, including models of master-geometry and space distribution [1, 2, 23, 25]. Fragments of KhAI-90 airplane general view drawing is shown in Fig. 11.

The cross-section parameters of the fuselage depend on the size of the seats and the width of the aisle, the height of the floor, the thickness of the inner walls. Analysis led us to install passenger seats in three rows, two seats in the first two rows and one in the third (for a total of five passengers). Passenger seats are mounted on rails, allowing the intervals between them to be modified.



a)



b)

Fig. 11. Fragments of the master-geometry of the aircraft KhAI-90, a) view from the left side of the fuselage; b) view from the right side of the fuselage.

The chairs have the following dimensions: distance between the armrests – 380 mm; back deflection angle – 13°. The minimum width of the passage between the seats of a light aircraft is limited by the Airworthiness Standards AP 23.815 (АП 23.815). For the KhAI-90 aircraft, this means 380 mm at a height of less than 635 mm from the floor and 430 mm at a height of 635 mm from the floor. Under the seats there are mooring nets for small passenger belongings (bags, purses, cosmetic bags, folders with documents, briefcases and backpacks no larger than 270 × 290 × 400 mm), fixed at the rear, and passenger-adjustable from the front. Sliding tables are installed on the sides near each chair. To ensure sufficient free space for passengers' heads, the inner wall of the cabin is at a distance of 335 mm from the conditional point of the passenger's eyes.

The outer diameter is obtained by adding 80 mm of wall thickness to the inner diameter of 1,580 mm. The floor has a horizontal surface 100 mm high from the lower perimeter of the fuselage.

The pitch of the seats is 1,100 mm, which according to the general classification belongs to the first class, and the obtained length of the cabin 4,350 mm allows it to be modified for other types of operation without changing the length of the fuselage. On the port side is a container for passengers' luggage.

On the sides of the fuselage after the second row of seats, the passenger door is situated. The left door consists of two sections: the top opens up, while the bottom, with a built-in folding step, opens down. The right passenger door is an emergency exit that opens outwards in the direction of flight. For external inspection and lighting of the cabin during the day in the design of the aircraft provides glazing – crew cabin windows and windows of the passenger compartment. Portholes measuring 300 × 400 mm are located two on each side of the fuselage and one in the emergency exit.

An appropriately equipped first aid kit is provided for, in the event of medical care. The aircraft also has two portable fire extinguishers (one in the cockpit, the other in the passenger compartment). For information and cultural purposes, places can be provided for placement and storage of periodicals, advertising, radio and television equipment, the inclusion of PVM, Internet access and other amenities, depending on customer requirements.

Fig. 12 and 13 show fragments of cross sections and models of the distribution of space in the passenger cabin of the KhAI-90 aircraft, created in the Siemens NX system. Using the command Tools → Human Modeling → Human, a mannequin was used as a human model with generally accepted average body parameters: height – 1.754 m, weight – 78.45 kg (according to aviation rules, the estimated weight is 86 kg), in the position "seated relaxed".

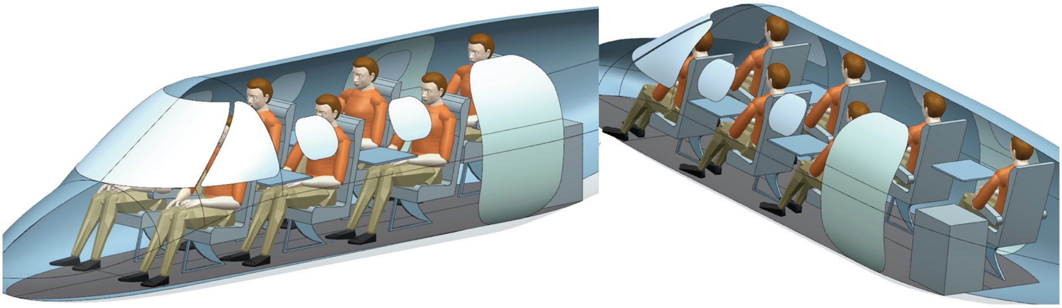


Fig. 12. Fragments of the space distribution model of the KhAI-90 passenger cabin.

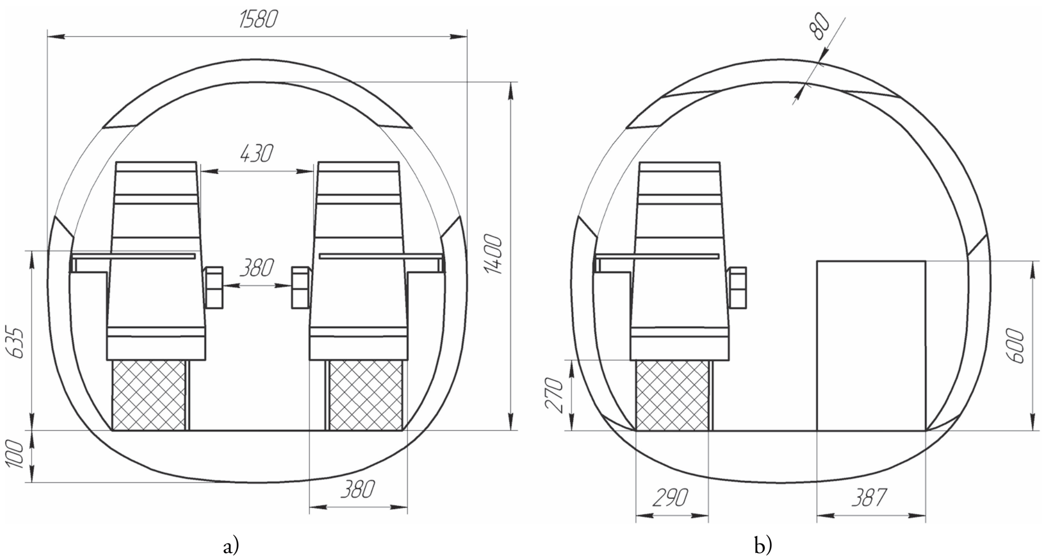



Fig. 13. Fragments of cross sections of the KhAI-90 passenger cabin, a) cross section at the location of the seats in the second row, b) cross section at the location of the front door and emergency exit.

*Determination of static stability and controllability*

The calculation of the center of mass of the designed aircraft was performed for the following operational case: aircraft weight – take-off, landing gear – retractable, payload – maximum, fuel weight – maximum.

Given the constructed torque diagram of the dependence of the $m_Z$ longitudinal moment coefficient on the $\alpha$ angle of attack, shown in Fig. 14, the KhAI-90 aircraft is statically stable because it is a derivative

$$\frac{dm_Z}{d\alpha} = \frac{dm_Z}{dC_y} < 0.$$

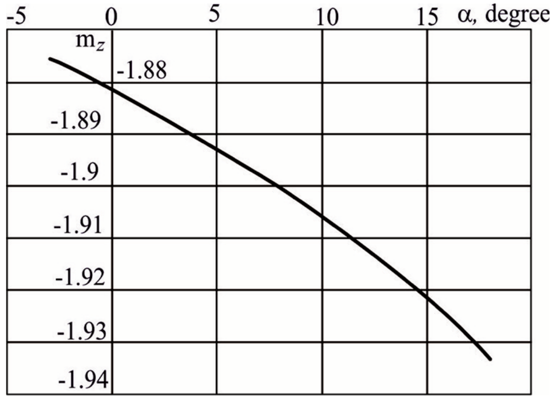



Fig. 14. The dependence of the $m_Z$ longitudinal moment coefficient on the $\alpha$ angle of attack.

Relative to the mean aerodynamic chord is the relative coordinate of the center of gravity $\bar{x}_m = \frac{x_m}{b_{MAC}} = \frac{0.341}{1.53} = 0.22.$

Limit front center of gravity $\bar{x}_{l.f} = 0.157 \cdot b_{MAC}$.

Limit rear center of gravity $\bar{x}_{l.r} = 0.318 \cdot b_{MAC}$.

A detailed comparison of the actual data and minimum take-off weights, optimal aspect ratios and optimal wing specific load calculated in line with the developed method for the KhAI-90 new light civil turboprop airplane and prototypes airplanes has been performed [2], showing that the value of the KhAI-90's take-off weight is 1.3 times less than that of prototypes.

## 3. CONCLUSIONS

The KhAI-90 Light Civil Turboprop Airplane Pilot Project at the preliminary design stage has been developed. The design was developed using a new method for light civil turboprop airplane take-off weight estimation at the preliminary design stage [2], and as such serves as a demonstration of the viability of that method.

The technical tasks posited for the new aircraft and the overall concept of light civil aircraft creating performing civil tasks and satisfying the adopted perspective requirements were described. Based on the analysis of prototype aircraft schemes, a classic high-altitude scheme with a horizontal tail located behind the wing and retractable landing gear was chosen. Modern tactical and technical requirements (TTR) were presented for the aircraft, with the basic purpose of transporting six passengers across a distance of up to 500 km with a cruising speed of 350 km/h.

The aircraft using CAD\CAM\CAE systems in accordance with the criterion of optimality: assuming a minimum take-off weight and a given life cycle of 20,000 flight hours. The KhAI-90's minimum take-off weight value was investigated using CLA-TOW (Civil Light Aircraft – Take-Off Weight) software at $W_{TO\,\min}$ = 3,600 kg, with optimal wing loading $p_{0\,opt}$ = 130 daN/m$^2$. A general view drawing, a three-dimensional parametric model of the master-geometry and a distribution model of the KhAI-90 light civil turboprop airplane's passenger cabin space were using SIEMENS NX integrated computer system. The calculations were based on existing methods and provide for compliance with the Airworthiness Standards for light civil airplane AP-23 (АП-23), FAR-23, CS-23.

The main ways in which the KhAI-90 civil light aircraft differs from other modern prototypes in the world are as follows: the orientation of all passenger seats in the direction of flight; the increased pitch of seats, aisle width, and overall dimensions of passenger doors; and a new design and technological solution for the placement of small passenger belongings under each passenger seat. Because there is no partition between the passenger compartment and the cockpit, the volume of the passenger compartment has been increased. The design offers ease of maintenance, operation and transportation, comfortable conditions for the crew due to the size of the cabin and efficient ventilation and heating, the use of new light and economical engines, and operation without runway.

This pilot project for the new KhAI-90 light civil turboprop airplane, using developed the new method for light civil turboprop airplane take-off weight estimation at the preliminary design stage, has demonstrated that the parameters and characteristics of the aircraft are comparable with existing modern prototypes. More broadly, this pilot project has also demonstrated the viability of the developed method for determining light civil turboprop airplane parameters.

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# PROJEKT PILOTAŻOWY LEKKIEGO CYWILNEGO SAMOLOTU TURBOPROPOWEGO KhAI-90

**Abstrakt**

Przedstawiono projekt pilotażowy nowego lekkiego cywilnego samolotu turbośmigłowego o nazwie KhAI-90, charakteryzującego się prędkością przelotową 350 km/h i ładownością 600 przy zasięgu 500 km, wyposażonego w dwa silniki turbośmigłowe Rolls-Royce 250-B17F, każdy o mocy 420 KM (alternatywnie w dwa silniki AI-450C, każdy o mocy 450 KM). Na podstawie ustalonego zadania technicznego, koncepcji stworzenia nowego wyczynowego lekkiego samolotu cywilnego KhAI-90 oraz analizy parametrów i charakterystyk prototypów samolotu określono główne wymagania taktyczno-techniczne. Masa startowa nowego samolotu określono w trzech przybliżeniach na etapie wstępnego projektowania lekkiego samolotu przy użyciu iteracyjnego oprogramowania „CLA-TOW" (analizując wpływ parametrów geometrycznych skrzydła i urządzeń nośnych na osiągi aerodynamiczne, stosunek mocy do masy i parametry masy samolotu). Obliczono następujące parametry projektu: minimalna masa startowa $W_{TO\,\min}$ = 3600 kg, optymalne obciążenie skrzydła $p_{0\ opt}$ = 130 daN/m2, optymalny współczynnik kształtu 9,6, współczynnik zbieżności 2,25, kąt natarcia na krawędzi natarcia 3 stopnie, grubość względna profilu 10,6%. Przedstawiono ogólny widok oraz trójwymiarowe modele parametryczne geometrii głównej i rozkładu przestrzeni kabiny pasażerskiej wygenerowane dla KhAI-90 za pomocą zintegrowanego systemu komputerowego SIEMENS NX. Niniejszy projekt pilotażowy wykazał również przydatność wcześniej opracowanej przez autorów metody określania parametrów lekkich cywilnych samolotów turbośmigłowych.

**Słowa kluczowe:** projekt pilotażowy, projektowanie samolotów, lekki samolot cywilny, metoda, masa startowa, trójwymiarowe modelowanie parametryczne.