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CONCEPT AND PRELIMINARY CALCULATIONS OF AN OPTIONALLY PILOTED RESEARCH PLATFORM

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Abstract

Along with the technological progress, unmanned aerial vehicles have found application not only in a military, but also in civil applications. The article presents Concept and preliminary calculations of an optionally piloted research platform. A literature review revealed a small number of existing aircraft of similar design. The analysis began with basic analytical calculations for airplanes, and more specifically their wings. The initial concept of the external shape of the designed aircraft was determined, and then the initial optimization of the structure was carried out on the basis of mathematical and computer analysis. Another goal of the research will be the construction of a demonstrator and its analysis.

Introduction

In recent years, Unmanned Aerial Vehicles have attracted the attention of scientists and engineers who have been working on their design and development to increase these vehicles autonomy and flight capability. Along

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with the technological progress, UAVs have found application in military aviation and civil applications. In particular, they are used in remote sensing and surveillance, material transport, research purposes, search and rescue, and military operations.

The concept presented in this article would be an optionally controlled research platform, which, after being called to the right place, would carry one passenger to the intended destination or be taken over by a pilot who would travel like an ordinary plane. The Blended Wing Body configuration was chosen to maximize the size of the aircraft's upper surface. The use of such a solution allows for the installation of a relatively large number of photovoltaic panels. The use of this type of structure also allows for a significant reduction in the aerodynamic drag of the aircraft.

Literature review of existing solutions

A literature review revealed a small number of existing aircraft of similar design. Most of this type of aircraft of a similar size are newly developed unmanned aerial vehicles for cargo transport or observation flights (Lyu, Martins 2014, Okonkwo, Smith 2016). Nowadays, aircraft with a similar arrangement are used as small unmanned platforms. Their undoubted advantages related to the simplicity of construction and the number of structural elements have resulted in the widespread use of electrically powered Blended Wing Body structures. Due to dimensions and method of use, the aircraft with the closest design are small planes based on platforms in the form of a flying wing. The considered structures capable of human piloted flight together with their flight parameters are presented in the Table 1.

Table 1

Review of existing solutions

Name of the aircraft	Horten Ho 229 (*Horton Ho 229.* 2017)	Verhees D-Plane 1 (*D1 single seater.* 2024)	Verhees Delta D2 (*D1 single seater.* 2024)
Wingspan [m]	16.8	4.5	5.4
Wing area [m^2]	51.8	10	15.5
Type of drive	Internal combustion engine	Internal combustion engine	Internal combustion engine
Empty weight of the plane [kg]	4,800	210	275
Max payload [kg]	2,715	130	325
Number of passengers	1	1	2

Methodology of calculations and structure optimization

Research on the presented object began with basic analytical calculations regarding flight capabilities based on the aerodynamic parameters of the aircraft (Abzug, Eugene 2002, Stafiej 2000). Due to the type of structure under consideration, the wing constitutes the entire aircraft, which simplifies performing calculations because there is no need to consider the impact of additional surfaces such as the tail and fuselage on the designed object. However, the main problem is to determine correctly the controllability and select the wing profiles so that the aircraft is stable and the control surfaces are in a neutral position during horizontal flight.

To determine the optimal flight parameters, it was necessary to develop a research methodology combining aerodynamic parameters with the assumed mass parameters of the designed object (*Airfoil Tools*. 2023, Zenowicz 2023). Due to the regulations regarding flying objects and the early stage of design work, the analyses carried out took into account the legal requirements developed for structures of this type. This action aims to use recommendations and legal requirements to shorten the design process (Szymański 2020, *Access Rules for Unmanned…* 2022, *Certification Specifications for Sailplanes…* 2008, *Easy Access Rules for Unmanned Aircraft…* 2022, Paturski 2024).

The initial concept of the external shape of the designed aircraft was determined and then the initial optimization of the structure was carried out based on mathematical analysis. The calculations started with determining the basic flight parameters, such as wingspan, wing area, and the aspect ratio (AR) parameter.

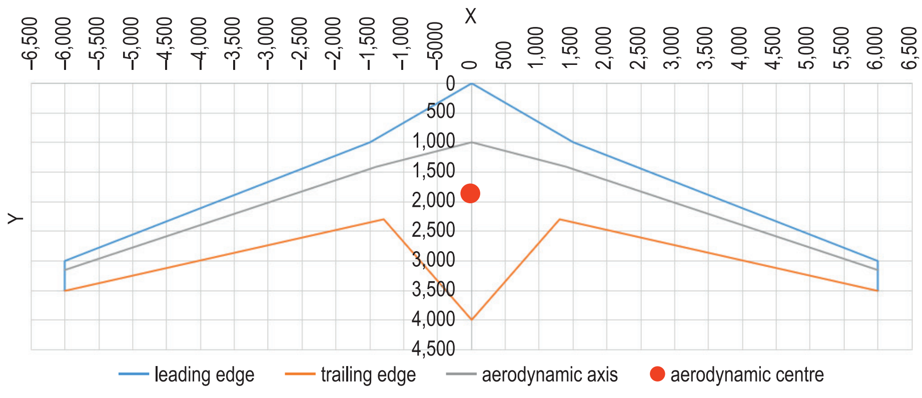

Fig. 1. Initial concept of the outer contour used for calculations

The data was determined based on a developed spreadsheet allowing for quick optimization of external shape parameters. The designed facility is presented in the Figure 1. The results of the first stage of analysis of the presented concept are presented in Table 2. The presented parameters were determined analytically and were used in further stages of analyses of the presented object.

Table 2

Predefined wing parameters

Calculated parameters		
Wing span [m]	b	12
Wing chord in airplane symmetric axis [m]	C_0	4
Wing tip chord [m]	C_k	0.5
Wing area [m^2]	S	15.95
Mean aerodynamic chord [m]	C_a	2.704
Taper ratio [-]	λ	0.125
Aspect ratio [-]	Λ	9.028

At this stage of the works, a decision was also made on the method of powering the aircraft and the method of obtaining this energy. An analysis model was adopted for electric aircraft with the use of the sailplane capabilities of the designed structure and photovoltaic panels on the surface of the wings and partially on the surface of the central part.

The next stages of work were carried out in parallel. They were:

– optimization of the shape and selection of aviation profiles based on calculations using the XFLR5 software;

– tests of flight capabilities based on simulation and autopilot prepared for the structure under consideration using Gazebo software;

– flight stability analysis performed with the AID extension of MATLAB;

– confirming the correctness of the assumptions and specifying the basic flight parameters, it was decided to proceed to the implementation of the first concept models of the aircraft, considering the internal structure and the place intended for the passenger.

Determining the parameters of the wing profiles

In order to determine the aerodynamic parameters and prepare an accurate conceptual model, it is necessary to determine the airfoils used on main wing and central part of presented aircraft.

For this purpose, were used the Direct Foil Design module in the XFLR5 program. Based on the literature review, available solutions and preliminary analysis of many aviation profiles, two profiles were selected for further work on the model (*xflr5.tech*. 2021, MEGSON 2010, DRELA 1989, ZENOWICZ et al. 2022):

– NACA 0010;
– NACA 4418.

These profiles were selected based on main aerodynamic parameters for the airfoil. The drag coefficient, lift coefficient and torque coefficient parameters available online in the AirfoilTool database of aviation profiles (*Airfoil Tools*. 2023). The analysis was also performed using the XFLR5 software (PATURSKI 2024). The imported wing profile is presented in Figure 2.

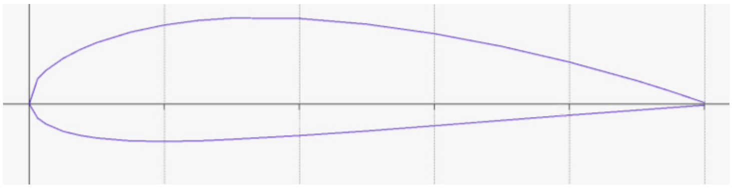

Fig. 2. Presentation of the NACA 4418 profile in the XFLR 5 software

Selected profiles were imported into the XFLR5 software, and then the quality of their mapping was improved by the software developer guidelines. Due to corrections to the imported profiles, it was necessary to carry out numerical analyzes to determine the basic aerodynamic parameters. This task was also performed in the XFLR5 software in the “Xfoil Direct Analysis” module. Partial results regarding the Airfoil NACA 4418 analyzes are shown in Figure 3.

The parameters of the adopted profiles obtained in this way were then used for the preparation of the model of a designed airplane in the XFLR5 environment.

Numerical aerodynamic analyses of the developed aircraft

The aircraft design in the XFLR 5 software was made with the use of the Wing and Plane Design module. The result of the work related to the preparation of the initial model of the tested object is presented in Figure 4.

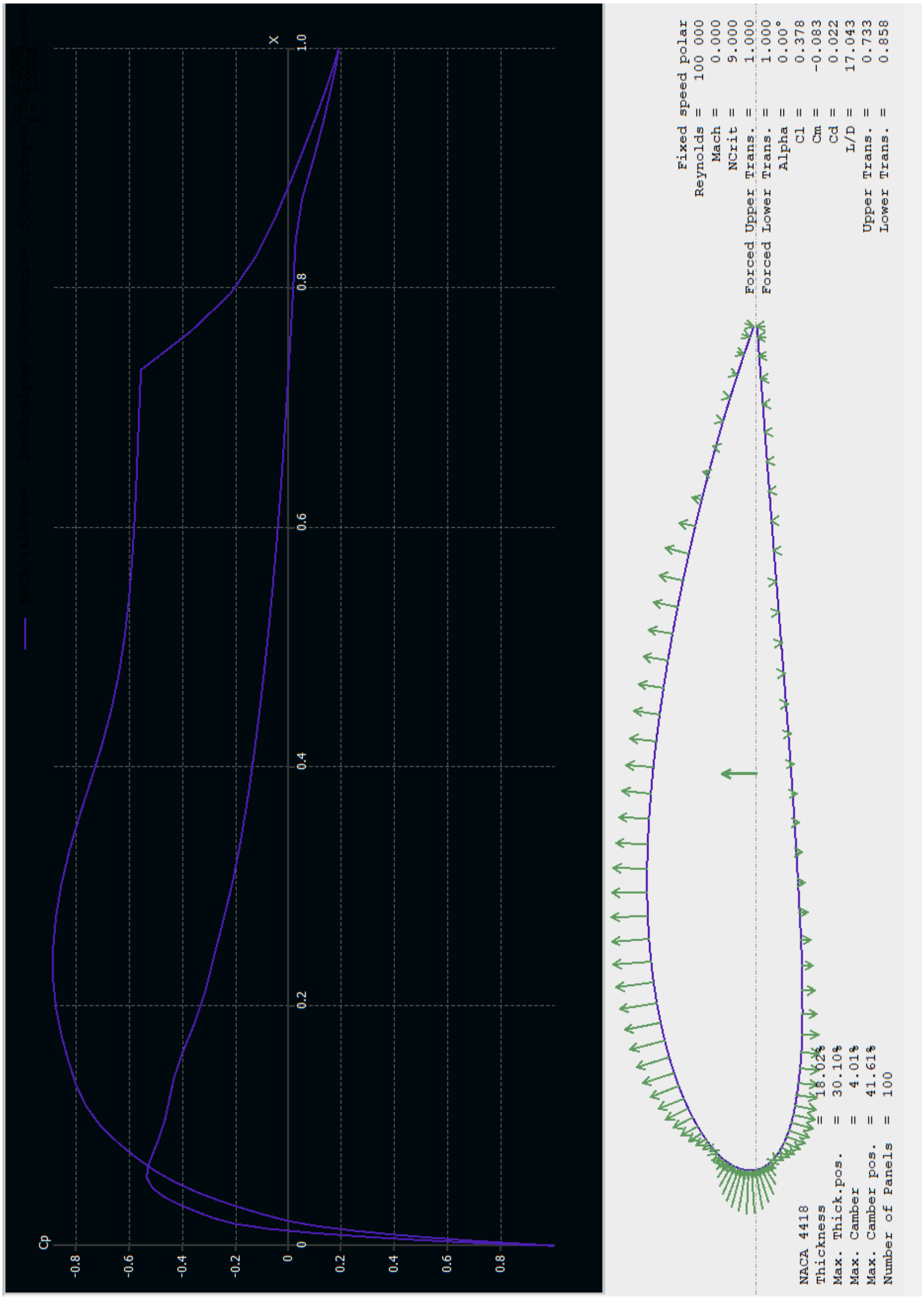

Fig. 3. XFoil Direct Analysis resultsNumerical aerodynamic analyses of the developed aircraft

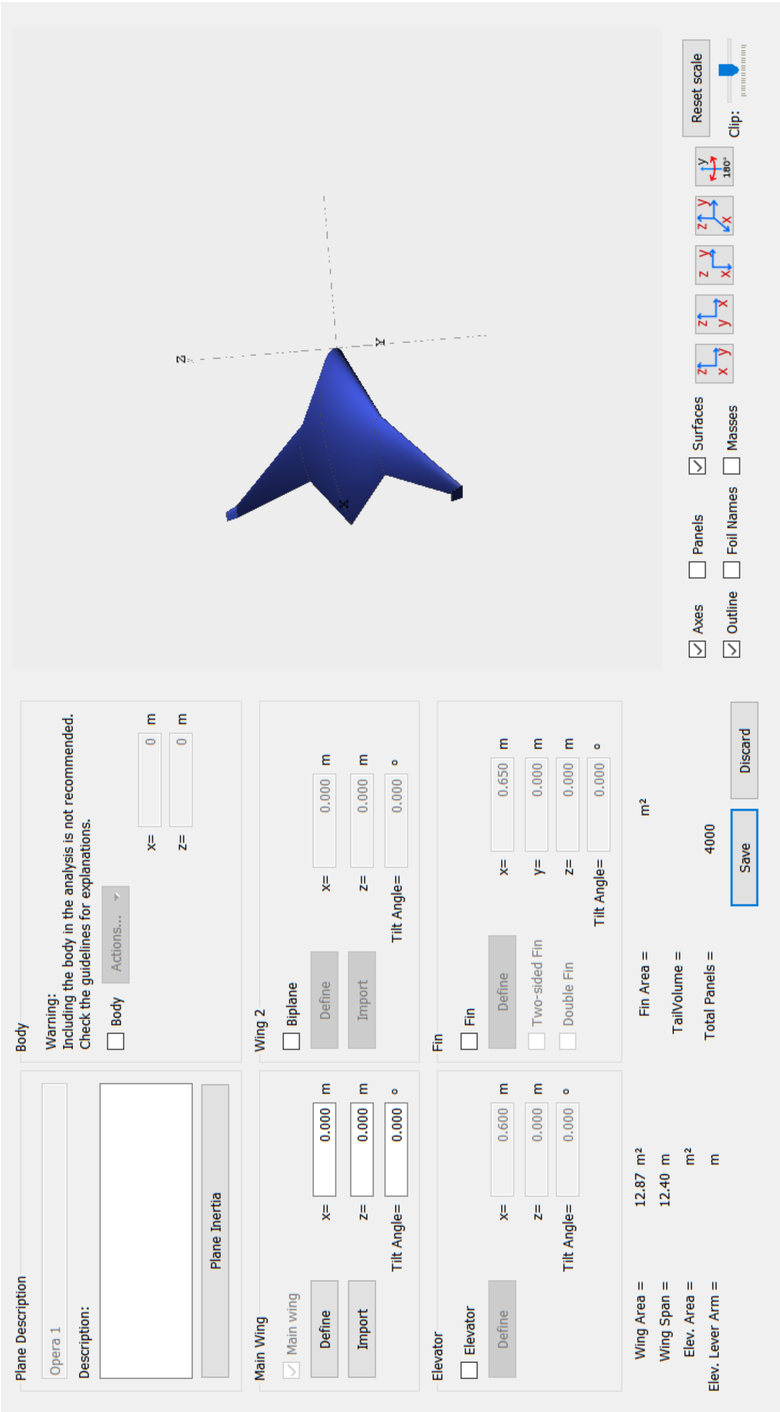

Fig. 4. Aircraft design window

The mentioned tool has many functions, but due to the designed geometry, some of them have not been used. The planned aircraft does not have a classic tail unit, therefore the Fin and Elevator options are unselected. The second wing will also not be used. The Body option is responsible for creating the fuselage of the aircraft, while according to the software developer information, it is used only for visualization and analysis should be performed without the fuselage. Only the option responsible for the main wing remains, and it will be the main object during the analysis of the flying wing aircraft.

The facility was made up of three sections. The first one, with the pilot's cabin, is designed so that it is possible to place a person in it with luggage. The next section is a standard wing like in standard airplane construction. The last part consists wing tips as the vertical parts of the wing, which can be used as stabilizers and rudders.

The last element of the structure is the hull, which was designed, although it will not be used in the calculations. The default options for the construction of the fuselage were used here and it was only enlarged so that the external dimensions resemble the cabins of modern single-seat gliders. The final effect of the first model of concept is presented in Figure 5.

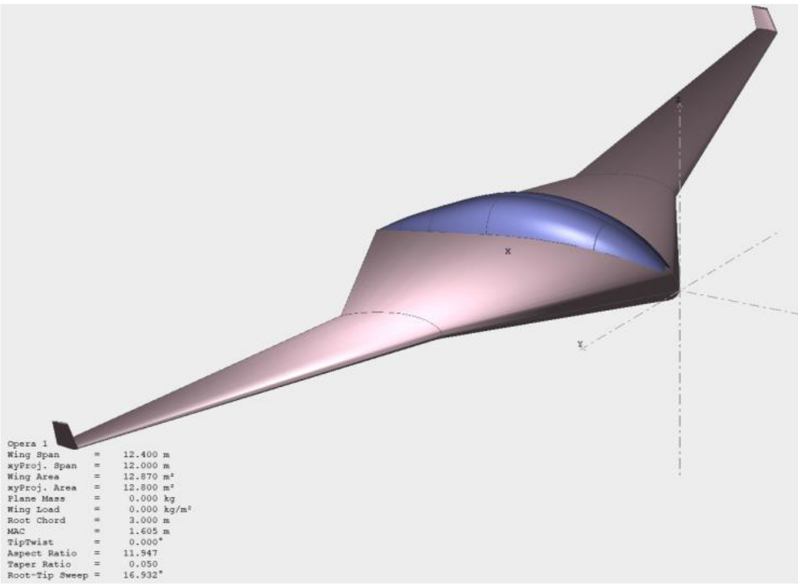

Fig. 5. First aircraft concept in XFLR 5 software

The next step, as in the case of a single airfoil design and analysis, is to determine the range of angles of attack and the step of angle by which the geometry will be tilted for each iteration of the calculations. Based on the recommendations of the software developer, these options were selected in the way presented in Table 3.

Table 3

Analysis results for the first aircraft concept

Angle of attack [°]	Speed required to maintain altitude [m/s]	Lift coefficient generated for fixed speed of 27 [m/s]	Drag coefficient generated for fixed speed of 27 [m/s]
-3	50.60	-0.15302	0.00513
-2	37.37	0.01772	0.00671
-1	30.99	0.10433	0.00694
0	27.06	0.19107	0.00783
1	24.32	0.27779	0.00941
2	22.29	0.36425	0.01163
3	20.69	0.45021	0.01449
4	19.40	0.53535	0.01798
5	18.33	0.61964	0.02210
6	17.42	0.70483	0.02687
7	16.64	0.79240	0.03243
8	15.96	0.87801	0.03867
9	15.36	0.95747	0.04525
10	14.83	1.03473	0.0547
11	14.35	1.11008	0.06022
12	13.92	1.18287	0.06844
13	13.53	1.25014	0.07687
14	13.18	1.31320	0.08568
15	12.85	1.37176	0.09479

Analyzes conducted in the XFLR5 software allowed for the determination of aerodynamic parameters for the initially developed concept. The model was subjected to the first stage of optimization aimed at determining the size of the control surfaces, the angle of attack and the achievable lift forces.

An example of the results obtained for a specific flight speed of 27 m/s and an angle of attack of 0 degrees is shown in Figure 6.

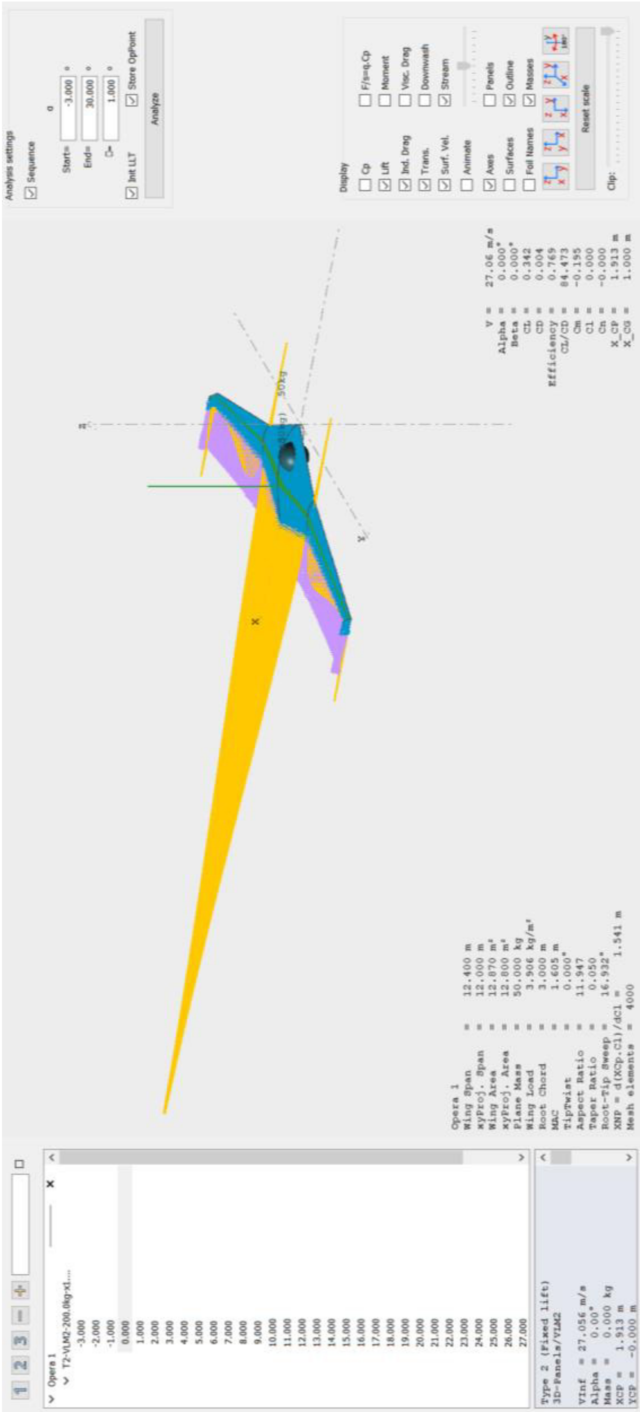

Fig. 6. First analysis resultsDevelopment of the initial concept of the internal structure

Development of the initial concept of the internal structure

Based on the analysis of the ergonomics of the pilot during the flight adopted. Due to the convenience of observing the direction of flight and the possibility of a side view during the flight, the pilot's position has been designed as in Figure 7.

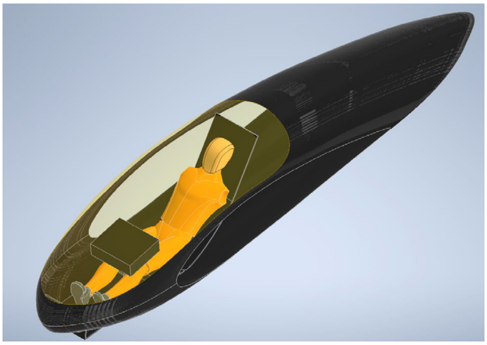

Fig. 7. Seat of the pilot in the designed structure

The location of the pilot in the designed machine is shown in Figure 8. Due to the average size of a person, the height of the middle part of the plane was selected. Taking this size into account, another model was made, showing the external outline of the designed structure. The description of the pilot placement analysis and the location of the piloting apparatus is a further research topic regarding the development of the internal structure.

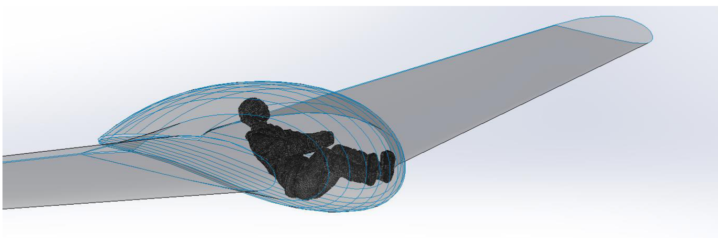

Fig. 8. Initial placement of the remote control in the structure

Due to the previously conducted analyzes and the determined forces acting on the structure during flight, an analysis of possible solutions for the internal structure of the aircraft was made. The literature review showed the possibility of using several proven structures. Possible solutions include:

– full honeycomb structure;
– large-format 3D printing as a core using a composite sheathing;
– standard aviation structure in the form of spars and ribs.

Due to the initial stage of designing the analyzed structure, several types of internal structure were developed, allowing the use of an electric drive system and the placement of photovoltaic panels on the upper surface of the presented concept. See Figure 9.

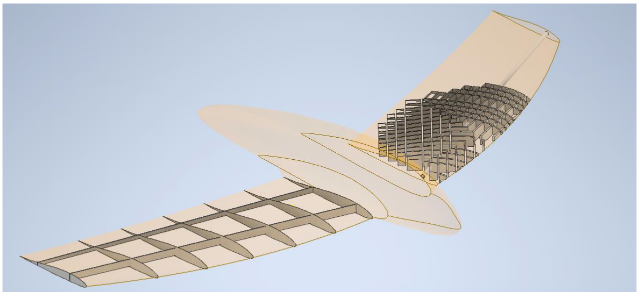

Fig. 9. Initial analysis of possible internal structures

The adopted structures are mainly based on the use of the main wing spar and various types of wing filling as well as many types of wing skin. Figure 10 shows a wing using a tubular wing spar and mesh infill.

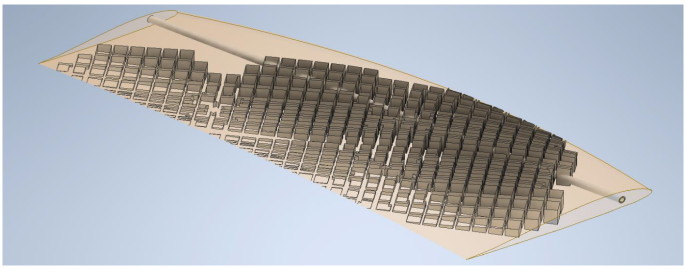

Fig. 10. Honeycomb structure reinforced with girder bars

The initial results of strength based on reduced stress analysis showed the possibility of improving the ratio of mass to strength parameters by using a gradient mesh size of the honeycomb structure. The analysis involved testing the proposed structure concepts for the unchanged external shape of the designed aircraft. The loads were constant and determined based on numerical aerodynamic analyses of the presented object. The loads in the form of pressure distribution obtained in this way were applied to the surface of the tested object. Further development of the designed structure will be developed in the next stages of work. The results obtained for the gradient structure of the filling can be enormous development potential of aviation structures.

Conclusions

Aircraft design requires a tremendous number of iterations and approximations. Later stages of project development often show that the initial assumptions and pre-adopted data are incorrect. The development and methodology of the development of optionally piloted aircraft is extremely complex and at present not clear. The methodology presented in the article has been developed directly for the aviation facility under development.

Due to the initial stage of work, the provisions on aircraft design were only briefly considered. Further stages of the development of the presented structure will use detailed legal analyzes for structures with given dimensions and masses. It will also be necessary to develop the exact method of control during the flight and allow the pilot to take the helm. The autonomous control system is another of the problems considered for the presented structure.

The project shows great development potential. Its main advantages are the size, low assumed take-off weight, the ability to fly without a pilot, allowing the machine to be moved to the place where it is needed, and a small amount of control surfaces, which contributes to the low level of complexity of the structure. The number of control surfaces also has a huge impact on the detectability of the aircraft in flight. This can be considered an advantage for military purposes and a disadvantage for civilian use. The absence of a recorded flight can be completely invisible to those responsible for air traffic.

The structure with a gradient filling of the wing allows for an increase in the stiffness of the structure where it is required and reduces the weight in places where stiffness is not so required. The problem with this structure is the bending strength along the wing. This problem was initially solved by the use of carbon fiber rods as the main wing spar. The discussed issue can also be solved by the use of carbon fiber tapes placed on the upper and lower parts of the wing skin. However, this solution is at the research development stage.

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