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TEAM NAME: AGH SOLAR PLANE 2.0
VEHICLE TYPE: FIXED WING
UNIVERSITY: AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY IN CRACOW
TEAM CAPTAIN: MATEUSZ PRASKI

1. PROJECT SUMMARY

The final achievement of AGH SOLAR PLANE 2.0 team is the aircraft powered by solar energy. The UAV, which was constructed by our group, has fixed wings. Building such a vehicle demanded specific skills and involvement as the process was a bit challenging to us. The combination of modern technology and composite materials let us reach the features that allows us to take part in the competition. What is more, the final aircraft is able to perform missions, which finds many applications.

1.1. Method Followed in Design

The model is fully autonomous unmanned plane powered by solar energy. The center of gravity is located under the spar which is designed in 1/3 of the width of the wing. The construction relies on extruded polystyrene, carbon fiber and glass fabrics, which allows to obtain low-weight, but highly durable aircraft . The UAV's system is being charged only by energy generated by solar panels and excess of it is stored in battery, located inside the fuselage. Main part of control system is Pixhawk which allows flight stabilization, auto-return, flying with waypoints and many more. It is based on open software which allows updating.

1.2.Team organization

The organization chart of our team is presented below (Figure 1.). As it was mentioned earlier, our team consists of four sections. Every person in our team is responsible for various kind of actions that help to create the aircraft. Mateusz Praski is our captain and he is the person that manage other team's members. What is more, he is differentiated by comprehensive knowledge, so the rest of the team rely on his experience. Andrzej Rusinowski is responsible for construction section, he is also our pilot. Andrzej watches over all construction actions and gives the order to the rest of the section. Marcin Stępień fulfils a tasks given by Andrzej and also he provides our team with virtual projects of aircraft. When it comes to power system, Michał Dudziak is the head of it. He makes sure that power systems perfectly match our expectations. The person who helps Michał with power systems is Barbara Kaczorowska. She makes sure that our solar panels and batteries works properly. Iwo Plaza and Jakub Gajda are responsible for aircraft's software. They cooperate each other as it is very important to connect telemetry system with flight management system. Mateusz Wlekliński is responsible for our last section- documentation. He keeps guard on the paperwork related with our

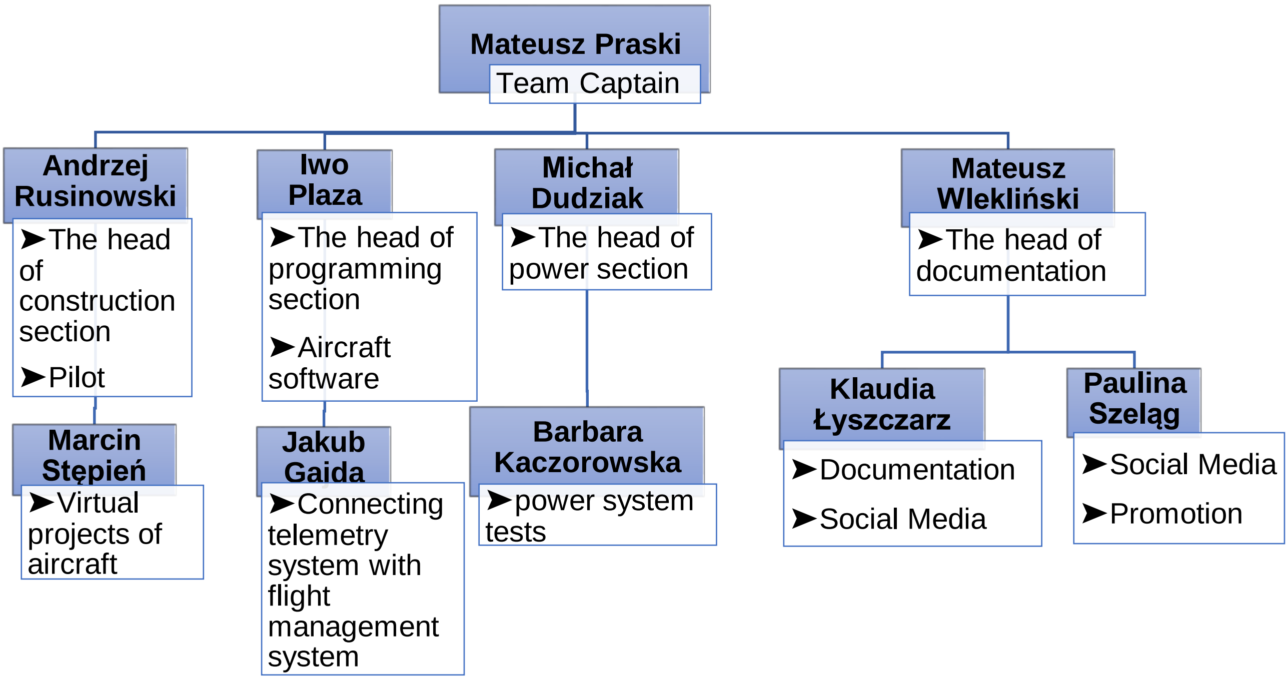

Figure 1. Organization chart

organization. Klaudia Łyszczarz and Paulina Szeląg assist him with it. What is more, both of them take care of our social media - Facebook and Instagram profiles and look after our promotion.

1.3.Milestone Chart: Planned and Realized

As it is presented on the schedule in the Attachment 1, our team had to perform many steps before building the final aircraft. Every step was planned very precisely as we buckled down to our UAV. Every subteam had huge involvement in creating our UAV. First of all, the construction subteam created the visualization of the aircraft in a SolidWorks program. As the visual project was ready, the team prepared the construction of the UAV. Our next step, which was kept up for 3 months, was designing the power system that can be applied in the built construction. Very important step was laminating the solar cells and locate them on the wings. This activity demanded time as it was necessary to provide special conditions that let us obtain high productivity solar cells. Moreover, it was crucial to create the system which allows performing the missions. As it can be seen we have spent lot of time on airplane tests. The final aircraft comes up to our expectations.

2. DETAIL DESIGN

2.1. Dimensional Parameters of the Design

The aircraft achieved the final weight about 4 kg with the wingspan 3.8 meters. The length of the UAV is 2.2 meters.

Construction and wiring make up the main and the most heavy part in the aircraft. Table 1. contains all components and their weight, including components of all systems.

Table 1. Fixed Wing UAV Part and Total Weight Table

No	Part Name	Weight [grams]	Pieces	Total Weight [grams]
1.	Construction and wiring	2 263	1	2 463
2.	Battery 5S 5000mAh 45C	480	1	480
3.	Engine AXI 2830/12 GOLD LINE V2 LONG	236	1	236
4.	Pixhawk 2.1 Cube Black	62	1	62
5.	Solar cell	8,75	48	420
6.	Raspberry Pi 4	66	1	66
7.	ESC	88	1	88
8.	Servo type 1	50	2	100
9.	Servo type 2	16	4	64
10.	Servo type 3	9	2	18
11.	Raspberry Pi Camera HD v2	3	1	3
	Total			4 000

2.2. Body and Mechanical Systems

Composite materials such as extruded polystyrene, glass fabric and carbon fibers were used to build the aircraft. The fuselage is made of glass fabric (front part) and carbon fiber. The wings of the plane were made of extruded polystyrene. The shape of the wings was designed in an appropriate program and then cut using plotter. The girders are made of carbon fibers. The wings have been laminated with solar panels using epoxy resin. Each of the composite materials has specific properties that affect the final appearance of the UAV. Traditional materials have given way to composite materials due to the properties guaranteed by the use of composites. Thanks to the materials mentioned above, it was possible to build and aircraft with a lower final weight, while increasing its mechanical strength.

Take-off, landing will be conducted manually by the pilot. The missions will be performed automatically. During landing, two flaps open giving the stability of the belly landing. Pixhawk will be receiving entire information about flight and the device will analyze it. The main part of the control system is the Pixhawk - on-board computer with the autopilot function. It belongs to the group of the best flight controllers on the market, based on open software and with the ability to update. It is an universal tool for flight control and stabilization for aircrafts. Pixhawk is responsible for autonomous flight and controls all of the systems in the UAV. What is more, it allows to modify missions on an ongoing basis and provides safety during the flight.

There is also the ability to program the flight. For this purpose, the "Mission Planner" application was used. By using Google Maps / Bing / Open street maps / 12 Custom WMS we have the possibility to set waypoints of the flight.

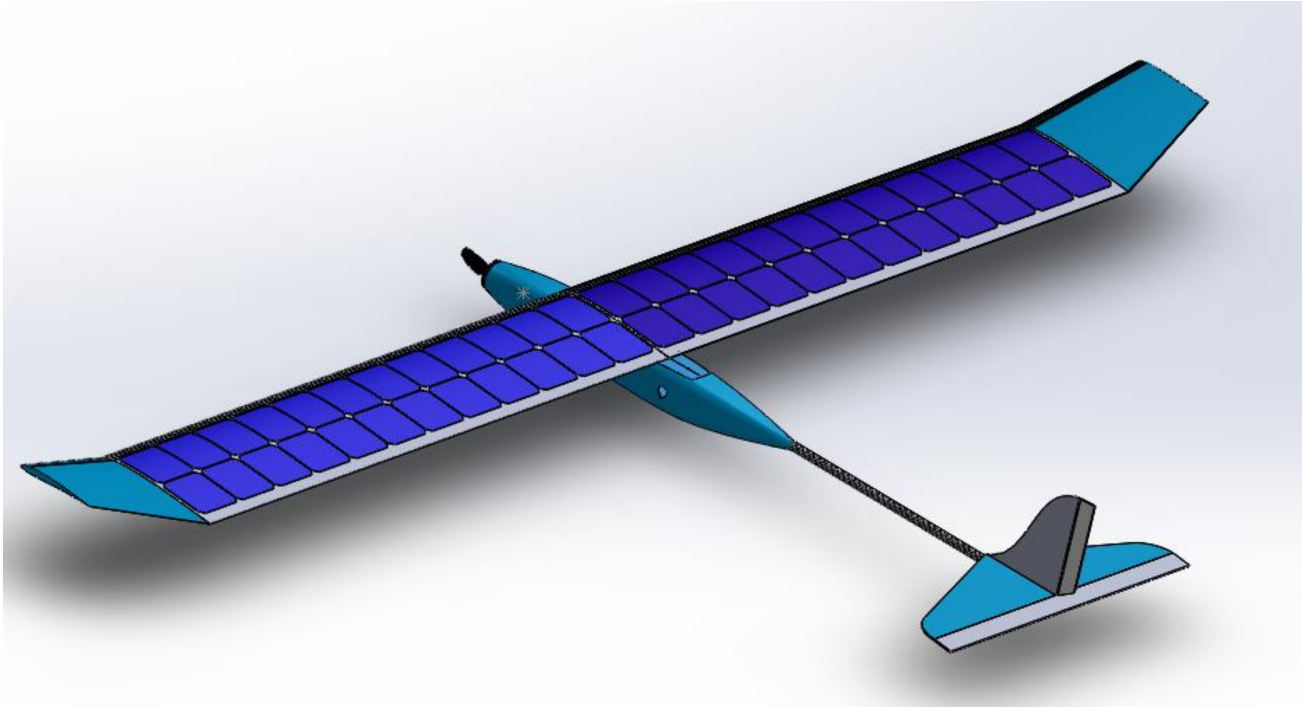

Figure 2. Visual design of the aircraft

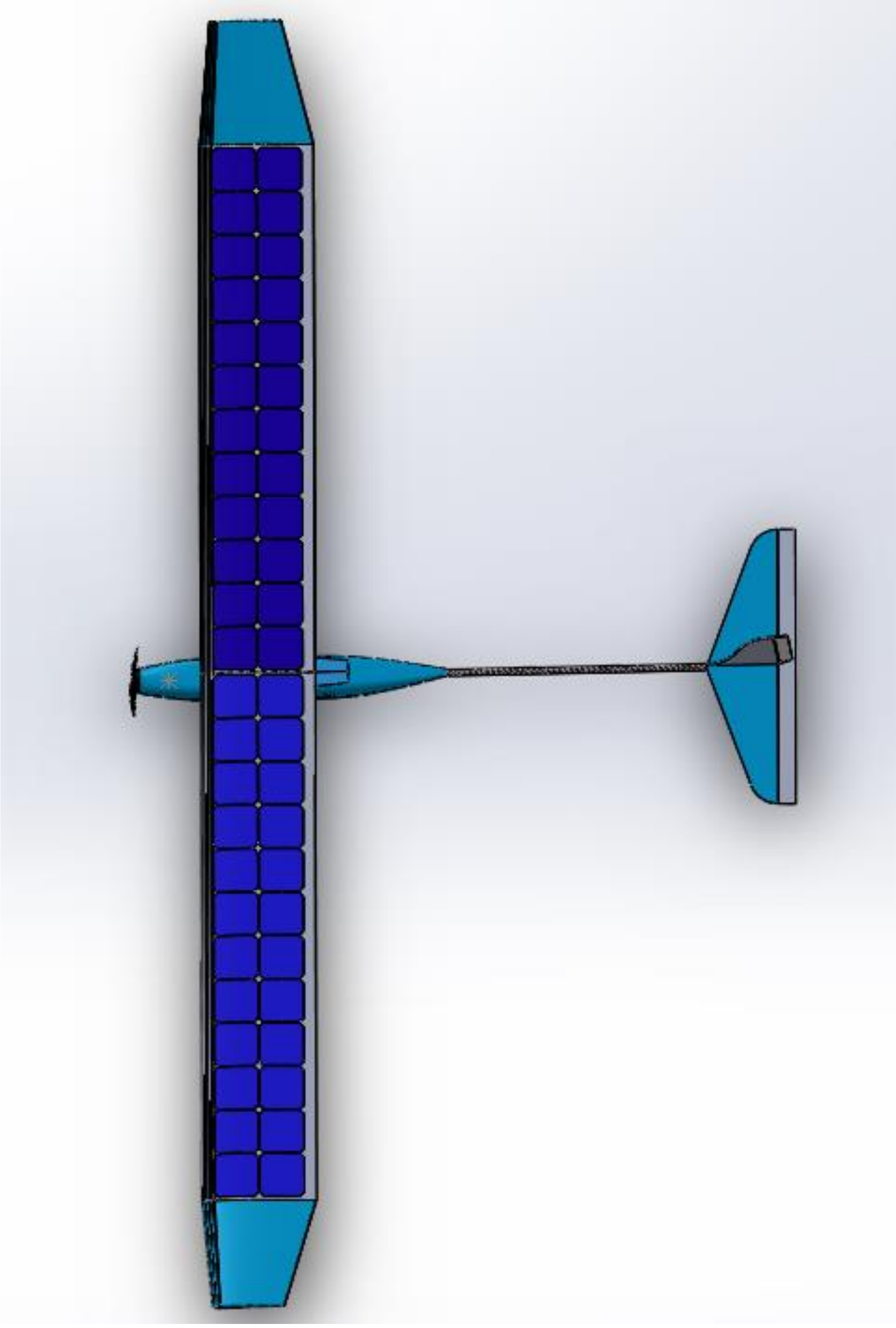

Figure 3. Top view of the aircraft

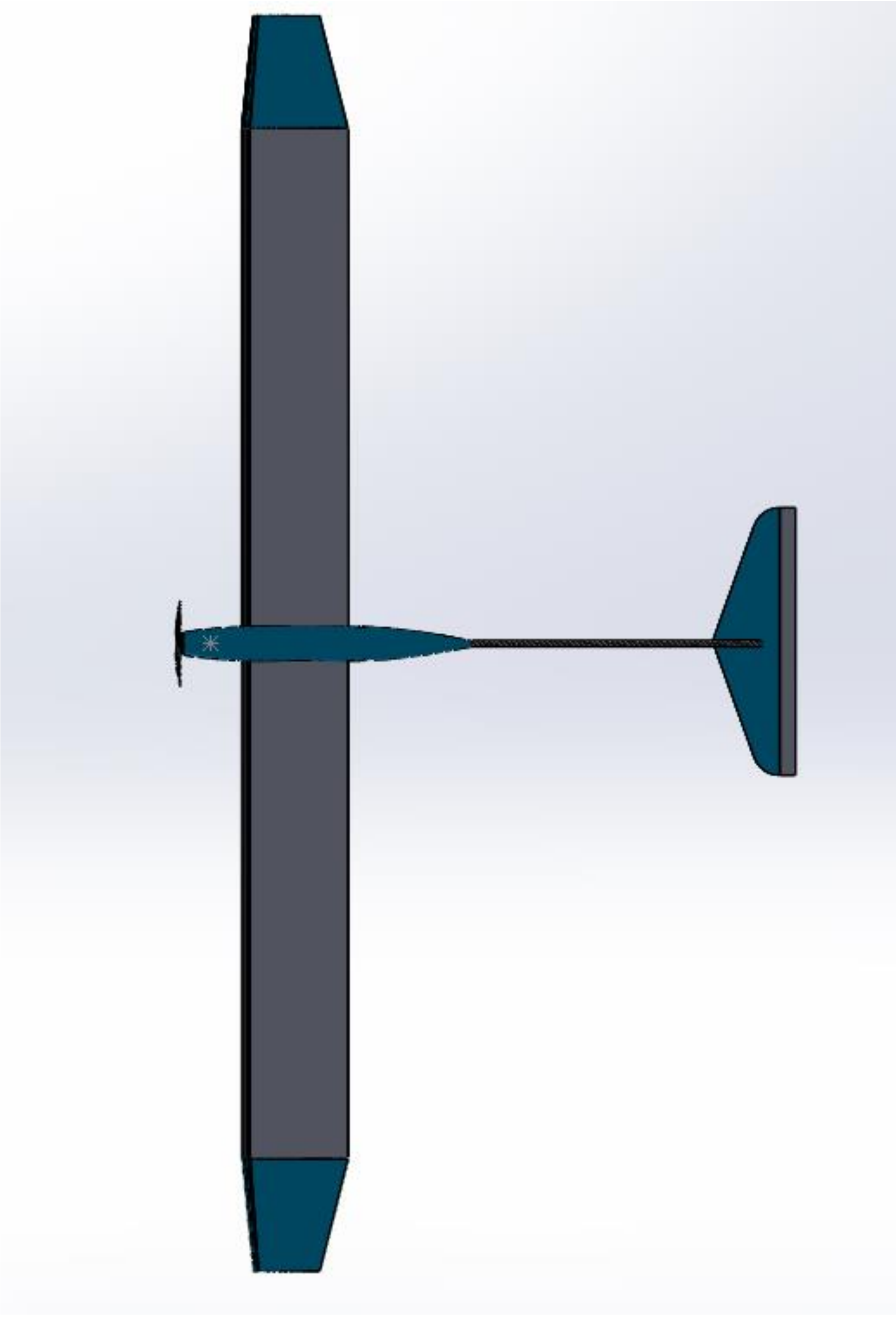

Figure 4. Bottom view of the aircraft

2.3.Aerodynamic, Stability and Control Features

The profile of the wing that was chosen: $AG-35il$

Length of chord: $L = 0{,}32[m]$

Cruising speed: $v = 12\left[\frac{m}{s}\right]$

Reynolds number: $\Re = 250000$

Standard list coefficients for this profile ($\Re = 250000$ and $L = 0{,}32[m]$), which was found in database and scaled for our chord's length are following:

Lift coefficients for $\boldsymbol{AOA = 0°}$	0,1459
Drag coefficients for $\boldsymbol{AOA = 0°}$	0,00475
Max $\boldsymbol{\frac{Cl}{Cd}}(\boldsymbol{AOA = 5°})$	46,6

The wings of our aircraft have been fixed at an angle of 2 degrees towards the fuselage. Coefficients of this angle are following:

Lift coefficients for $\boldsymbol{AOA = 2°}$	0,2099
Drag coefficients for $\boldsymbol{AOA = 2°}$	0,00511
Max $\boldsymbol{\frac{Cl}{Cd} for AOA = 2°}$	41,04

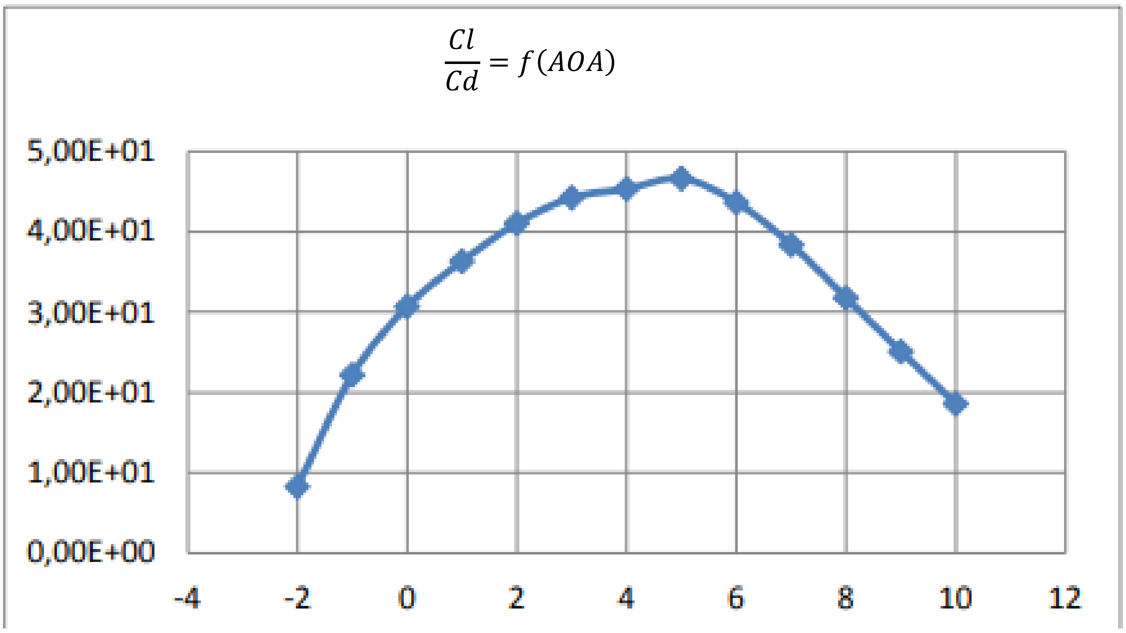

Figure 5. Lift to drag ratio in the function of the angle of attack

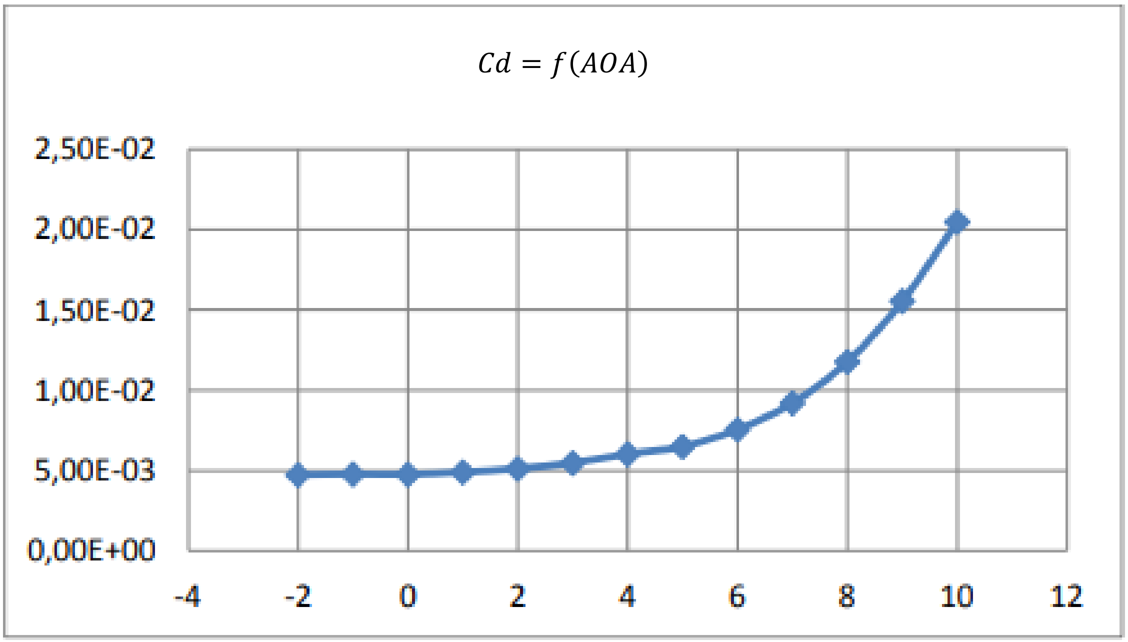

Figure 6. Drag coefficient in the function of the angle of attack

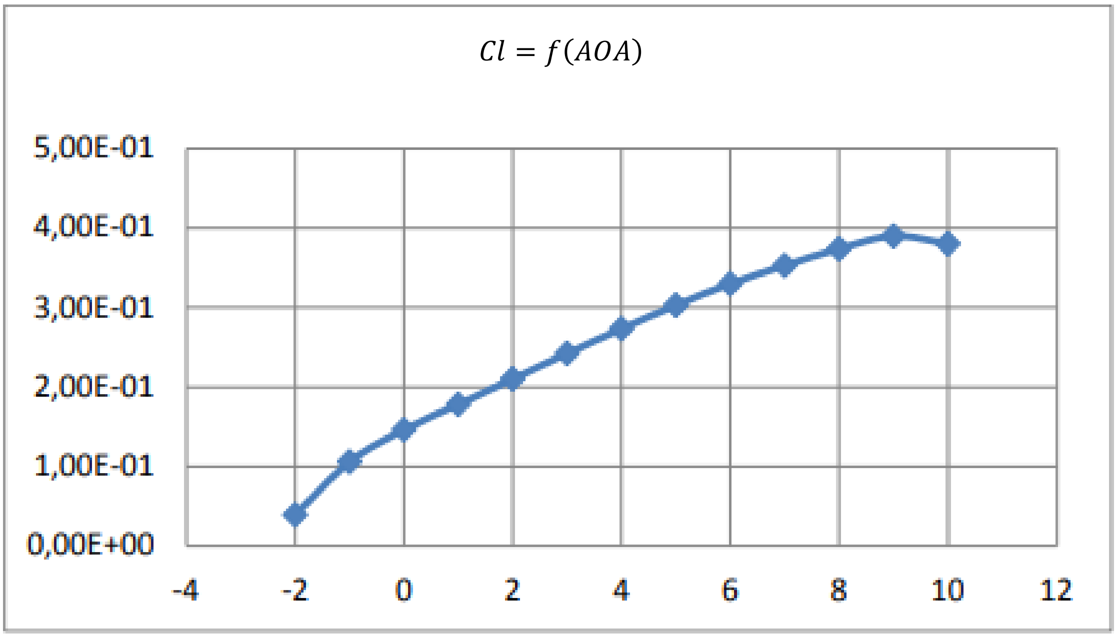

Figure 7. Lift coefficient in the function of the angle of attack

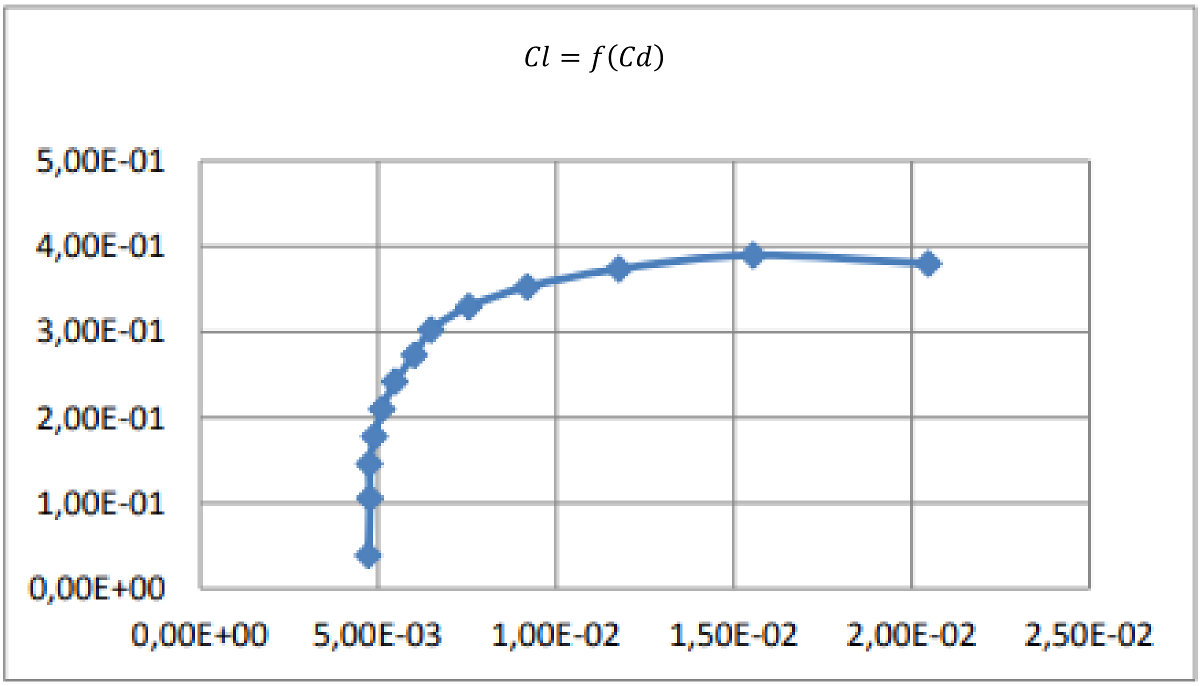

Figure 8. Lift coefficient in the function of drag coefficient

The take-off of the aircraft will be carried out manually and the flight will end as landing on belly. Start, flight and landing will be held with support of Pixhawk at the same time. The flaps located at the ends of wings additionally influence the stability of the flight and dampen vibrations.

2.4. Task Mechanism Systems

Task mechanism systems range two servomechanisms. The drops are automatically activated by system when the aircraft is located at the algorithm calculated place. The mechanism contain two loading chambers, which are the proper size to accommodate silicon balls. Moreover, the aircraft implies the smaller chamber, where the tappets of two independent flaps work.

The modes in used servos (TowerPro SG92R) are made of carbon fiber. The use of carbon fiber makes the servo lighter than servos whose modes are made of steel. The maximum torque that can be achieved is 0.24 Nm (2.5 kg). The weight of the servo is 9 g, while the weight with cables is 12 g. The dimensions of single servo are 23 x 12.2 x 27 mm. The temperature range, which they can operate in, is from 0 to 55 °C. The operating voltage for the servo is 4.8V. Speed is 0.1 s/60°.

The case of the dropping mechanism, shown in the visualization below (Figure 9.), was made of fiberglass combined with epoxy resin. This ensures high durability. What is more, in order to separate the chambers and stiffen the case, two plywood partions are glues inside. In order to fix them, the two-component epoxy adhesive “Poxipol” was used. This way it is possible to achieve the highest strength at room temperature and work well for modelling applications.

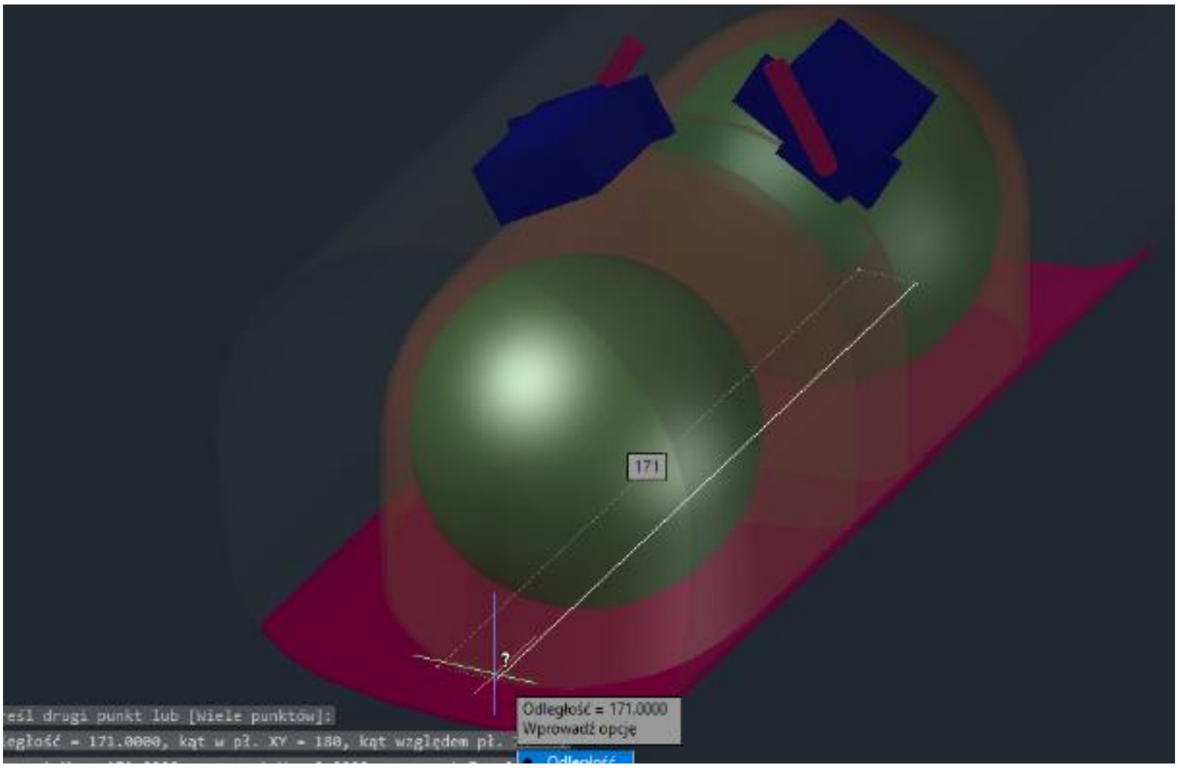

Figure 9. Visualization of the task mechanism system

2.5. Electrical Electronic Control and Power Systems

The aircraft uses an alternative source of energy – energy from solar irradiance. The solar cells located at the wings are monocrystalline SunPower Maxeon Gen III IBC (Interdigitated Back Contact) cells. They are designed to achieve maximum efficiency. It results in the maximum power of these cells in STC conditions is 3.77W, with an efficiency up to 24.4%.

Due to the brushless motor, which was used in power system of our aircraft, it is planned to use a battery with a voltage not less than 14.8V (4S). Because of selected engine – AXI 2830/12 GOLD LINE V2 LONG, it is recommended to use a battery with rated voltage of 18.5V (5S). The selection of the battery capacity depends on the expected flight time and the permitted total weight of the UAV. The worst case was presumed. The flight time with the full power of 750W electric motor was assumed for the calculations of 10 minutes. With a maximum continuous electric current consumption of 30A by the aircraft propulsion, it gives the required minimum battery capacity of 5000 mAh. Empirical calculations were performed using the product of flight time and the maximum current consumption by the electric motor. The extreme situation of battery loading by main drive of the designed airplane has been assumed. It allows to ignore the influence of energy consumption by other components. Assuming weight optimization, it is necessary to take into account the actual parameters of energy consumption by all energy-consuming components located in the aircraft. During the selection of capacity, it was kept in mind the rated capacity of the battery was 90%. The minimum acceptable class of batteries for needs of airplanes totals 10.8 C. Due to maximum power consumption of the electric motor and the safety factor aspect, we conclude that appropriate energy bank for our aircraft will be 5S 5000mAh 45C battery. Nevertheless, we allow the use of smaller Li-Po battery due to the required flight time. The influence of the additional power supply from the photovoltaic installation was not included in calculations. The worst operating conditions of the solar panels were assumed – no electricity generation.

2.6. Target Detection and Recognition System

The detection of the dropping location takes place during the first circuit. The system uses Open CV algorithms (OpenCV module) to locate absolute location of the dropping place. Raw vision from the camera is being converted into HSV colours, and then transmitted through red filter. In the final vision, contours are searched and the ellipses are being fitted to them. The centre of the ellipse goes through the next analysis as the centre of the dropping place in regard of camera. On the basis of telemetric data supplied by board computer – Pixhawk (Mavlink module), system calculates prospective dropping location. Employing algorithm such as georeference (Georeference module), the location of the point regarding camera, aircraft and environment is computed. These operations are essential to determine the appropriate time of starting the drop (Estimation module). Microcomputer Raspberry Pi 4B was used in the task realisation.

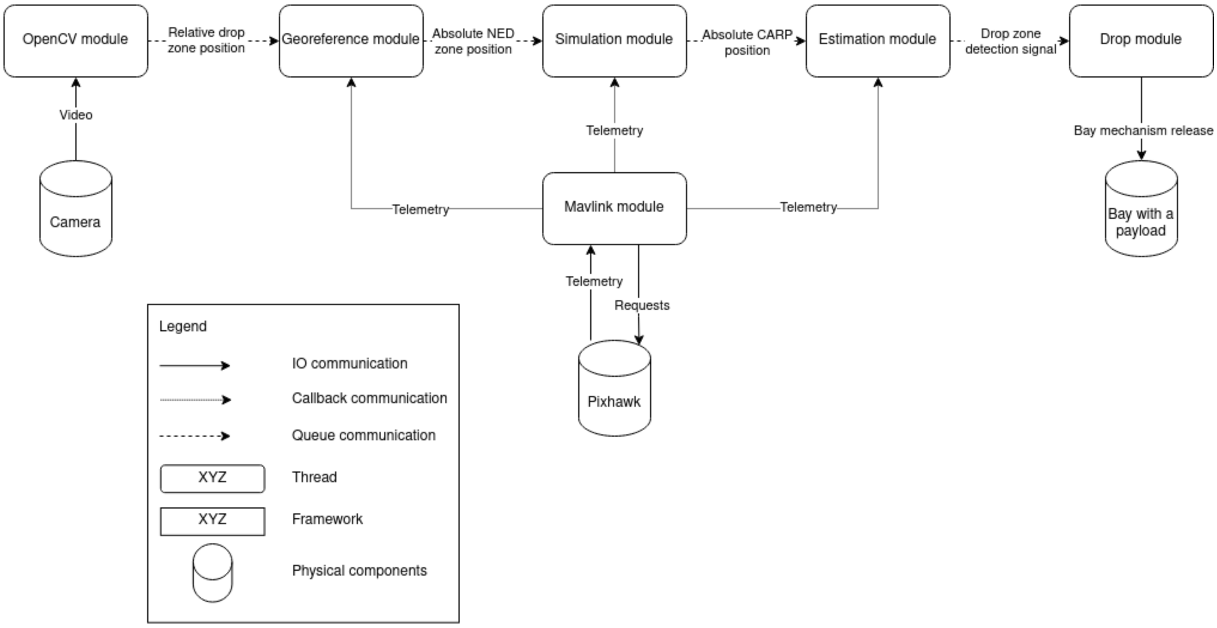

Figure 10. Target detection and recognition system

2.7.Flight performance parameters

The UAV cruising speed totals between 30 and 50 km/h. That will be the speed during the missions. The estimated flight altitude during the task is around 10 meters. LiPol battery with a capacity of 5000 mAh allows for 20 - 30 minutes of flight. The start will be made from the hand, belly landing, the flight will be held manually using the RC equipment FrSky Taranis.

2.8. UAV Cost Distribution

No	Component Name	Unit price ((TL))	Quantity	Total price (TL)
1.	Battery 5S 5000mAh 45C	660	1	660
2.	Solar cell SunPower Maxeon Gen III IBC	26	48	1248
3.	Engine AXI 2830/12 GOLD LINE V2 LONG	980	1	980
4.	Carbon fiber	1152	1	1152
5.	Glass fabric	4312	1	4312
6.	Extruded polystyrene	173	1	173
7.	Pixhawk 2.1 Cube Black	4120	1	4120
8.	Wiring	1801	1	1801
9.	Raspberry Pi 4	615	1	615
10.	Raspberry Pi Camera HD v2	135	1	135
11.	Transmitter R7008SB	1274	1	1274
12.	Controller Futaba T14SG	5835	1	5835
	Total			**22305**

2.8. Originality

Composite materials have become more popular recently. During the stage of design, we decided to use composites as the alternative materials for traditional ones. The use of composites let us create the aircraft with a lower final weight, while increasing its mechanical strength.

Elements powering the aircraft are sets of photovoltaic cells. Obtaining energy from the Sun is a very interesting and unique solution when it comes to planes. Our team decided to make this modification due to its environmental friendliness. What is more, the way the solar panels are attached to the wings also deserves to be mentioned. Placing photovoltaic modules not only on flat surfaces, but also on those with curvature is possible because of the development of the technology. Thin layer of epoxy resin increases the strength and resistance for mechanical damage of the photovoltaic modules. The preservative layer of glass fabric soaked with epoxy resin is marked by low surface roughness. This way it is possible to maintain the aerodynamic properties of the UAV.

AGH SOLAR PLANE 2.0, FIXED WINGS, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY IN CRACOW													
PROJECT TIMELINE													
WORK PACKAGES AND ACTIVITIES		Start Date	End Date	Duration (Day)	January	February	March	April	May	June	July	August	September
1.	**Design and construction**	**11.01.2021**	**22.03.2021**	**70**									
1.1	Execution of the project in the SolidWorks program			20									
1.2	Creating the hull from carbon fiber			20									
1.3	Design of the wing profile			10									
1.4	Manufacturing of fibreglass and epoxy resin wings			45									
2.	**Creating a power system**	**11.01.2021**	**31.03.2021**	**79**									
2.1	Execution of the electrician project			20									
2.2	Installation of servo systems			3									
2.3	Execution of the energy storage system			40									
2.4	Lamination and connection of solar panels			30									
2.5	Connection of both systems			10									
3.	**Creation of electronic components**	**11.01.2021**	**31.05.2021**	**140**									
3.1	Designing our own tracking system			120									
3.2	Performing data transmission			70									
3.3	Programming of security systems			60									
4.	**Airplane tests**	**12.04.2021**	**19.07.2021**	**98**									
4.1	Checking the correctness of all elements			45									
4.2	Testing of the autonomy module			90									
4.3	Possible corrections			40									