DESIGN, AERODYNAMIC ANALYSIS AND MANUFACTURE OF A FLYING WING

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Abstract: *This paper has demonstrated the feasibility of manufacturing a flying wing by performing the following steps: making a sketch of the model, establishing the preliminary design and sizing of the model, computer-aided designing using specific software systems, aerodynamic analysis of flight performance, manufacturing and assembling the components, and finally testing the motor and control elements. The wing model has a mass of 750 grams, a maximum speed of about 50 km/h and a range of 17 minutes. The wing model has been designed to accommodate a small video camera that can transmit images in real time. The wing can perform multiple missions: aerial surveillance of certain areas of interest or search and rescue missions in hard-to-reach areas.*

Keywords: *design, flying wing, CFD analysis, finite element analysis, manufacturing*

1. INTRODUCTION

UAV (Unmanned Aerial Vehicle) is an aircraft that can fly without the need for a pilot on board and is autonomously controlled using a remote control [1]. In recent years, UAVs have experienced tremendous development and have gained rapid growth in popularity worldwide. Nowadays, UAVs are widely used in various fields such as [2,3]: military and defence applications, reconnaissance, surveillance and security enhancement, agriculture, fire detection, search and rescue. The sales of the UAVs are expected to grow, especially in the current military situation.

Flying wings can be manufactured from several types of materials (composite, wood, plastic), as each material has both advantages and disadvantages [4]. Typically, flying wings made of polystyrene have a lower mass compared to those made of balsa wood or 3D printed [5]. The foam from which these types of aircraft are made, has a lower density, which implicitly means lower mass. The foam is less strong, but the structural behaviour can be improved by using reinforcing elements, such as inserting carbon rods into its structure [6,7]. Balsa wood is used in the manufacturing of wings, but with the advent of more modern (composite) materials, its use has decreased. Balsa wood has a low weight, rather high strength, and high flexibility [8].

3D printed wings [9] can be manufactured with varying degrees of strength, flexibility and weight depending on the type of material and thickness of the printed parts. The disadvantage of 3D printed wings is that they require a digital model design and the use of a 3D printer, which implies higher costs and more advanced technical knowledge. However, by using a 3D printer, complex shaped parts can be produced as required, whereas polystyrene and balsa wood have less capability in this respect.

Based on various comparisons, it was decided for this paper to make a flying wing out of depron (expanded polystyrene) because it has similar properties to foam.

The use of this material allows the final aeronautical product to have a reduced mass, which will have a positive influence on flight performance, especially aerodynamics and range. At the same time, depron can be easily cut and shaped to obtain the desired aerodynamic profile, can be assembled quickly, and requires the shortest manufacturing time compared to the other materials analysed. Depron is also an easily available material and has a low cost [10]. This material has high insulation properties, this feature being useful when the wing flies at varying temperatures, thermal insulation helps to secure the electronic parts [10].

Depron can also help to create a solid structure. Significant progress has been made in the aerodynamic study of these aircraft, leading to high performance, profiles that provide minimal drag, high controllability, and high stability. Today, the manufacture of flying wings is increasingly based on composite materials because they offer high strength and low mass [11]. With the emergence of 3D printing technologies, considerable advantages have emerged that have allowed precise and relatively fast manufacturing having high quality and strength [12].

Flying wings are equipped with advanced electronic systems that help in conducting missions, such as cameras, sensors, advanced navigation systems. There has been a dramatic evolution in flight autonomy, the first wing models built had low autonomy (a few minutes of flight time), but thanks to the evolution of batteries and optimal aerodynamic profiles, flights lasting several hours have been possible. In conclusion, the evolution of flying wings is characterised by continuous innovations in the materials used, with increasing efficiency, so that they can be used in a wide range of missions in different fields.

2. DESIGN OF THE FLYING WING

The requirements to be met by the flying wing model were to design an aircraft with a short manufacturing time, medium range; to reach a flying height of 120 metres; to create as little drag as possible; to be manufactured at the lowest possible cost. At this stage, the wing design process (Fig.1) was developed using the CATIA V5 software system, considering the conceptual model and the established dimensions. The airfoil (NACA 2412) was imported into the CATIA V5 software from the Airfoil Tools website. Ribs and ailerons have been added as well as winglets. Analyses of other types of flying wings showed that their aerodynamic efficiency would increase if winglet systems were added.

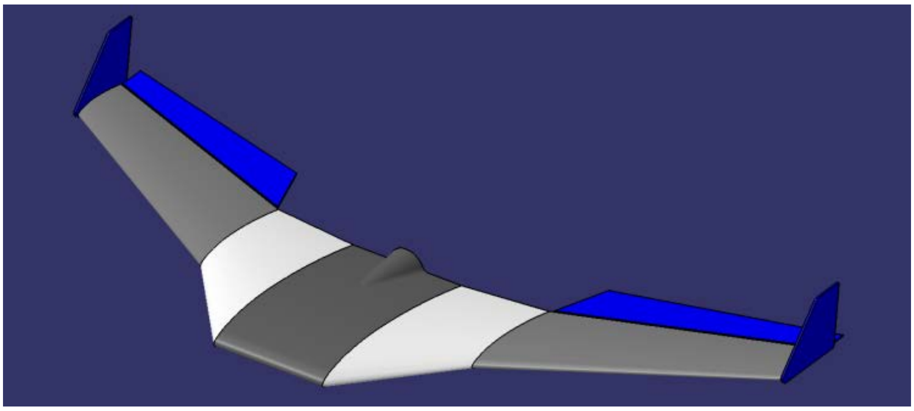


FIG. 1. Digital model of the wing

The flight performance analysis was carried out using the "eCalc.ch" website, which provides a wide range of tools to assess the performance of the radio-controlled aircraft. The most important information calculated are flight time (estimated at maximum 17 minutes), maximum speed of 50 km/h, rate of climb of about 4 m/s and stall speed of 22 km/h. The wing parameters entered into the computer for performance estimation were wing mass 750 grams; number of motors 1; wingspan 1300 mm; wing area 36.54 dm^2; LiPo 2500 mAh battery; speed controller 40 A; SunnySky X2216 motor; GEMFAN 8 x 4 inch propeller.

3. AERODYNAMIC ANALYSIS OF THE FLYING WING

For the analysis, the XFLR5 software system was used to calculate the performance of the flying wing. The NACA 2412 airfoil (Fig.2) was imported from the Airfoil Tools website into the XFLR5 software system in order to analyse the wing.

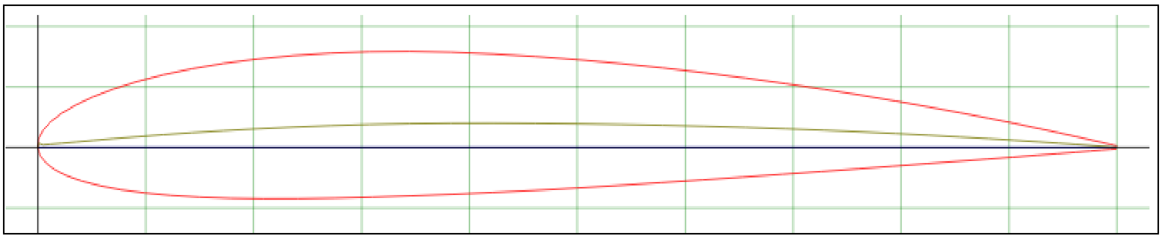


FIG. 2. NACA 2412 airfoil

The wing modelling steps: the flying wing was modelled in the XFLR5 software system (Fig. 3), with real configurations, 1300 mm wingspan; 750 g weight was set; winglet surfaces were modelled in each plane, the profile used was NACA 2412. Aerodynamic analysis was carried out for a speed of 10 m/s, and angles of attack varied from -4° to 7°.

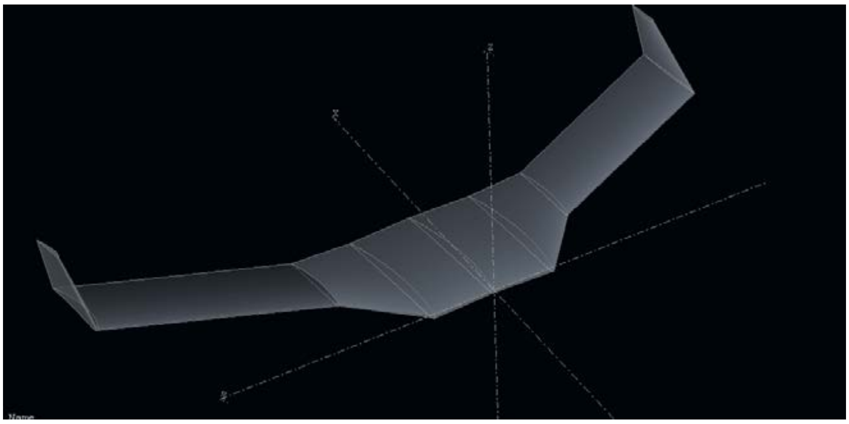
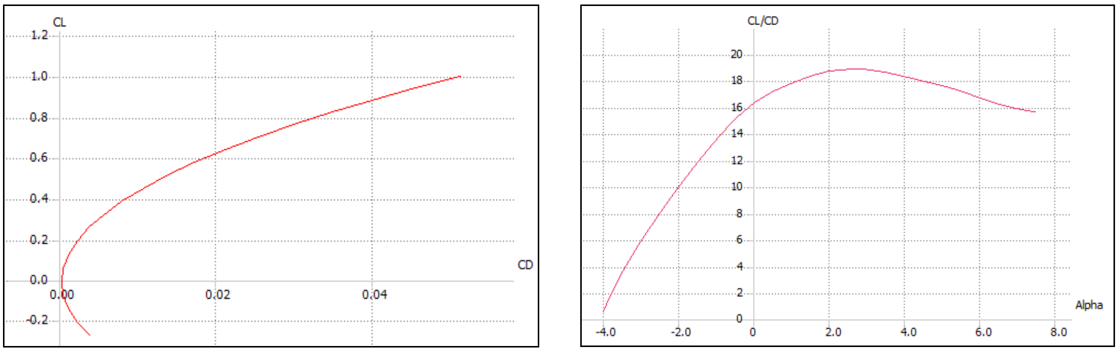


FIG. 3. Digital wing model designed in XFLR5 software system

The polar curve (Fig.4a) shows the relationship between the lift coefficient and the drag coefficient. This graph is used to analyse the aerodynamic performance of the wing.

The wing fineness as a function of the angle of attack (Fig.4b) refers to the ratio between the lift coefficient (CL_{max}=1) and the drag coefficient (CD_{max}=0.05) of the wing at a given angle of attack. The fineness (lift-to-drag ratio) is an aerodynamic characteristic that influences the performance of any aircraft.



(a) (b)

FIG. 4. Aerodynamic performance of the wing (a) Distribution of lift coefficient as a function of drag coefficient (b) Wing fineness as a function of the angle of attack.

The distribution of the pressure coefficient on the wing as a function of the angle of attack indicates the simulation of the pressure of the airfoils acting on the wing. This pressure influences the lift and the drag and varies along the wing. At low angles of attack the pressure coefficient distribution is characterised by higher values on the upper surface and lower values on the lower surface (Fig.5a). As the angle of attack changes (Fig.5b), the pressure coefficient distribution changes, as can be seen in Fig.5, when the angle of attack increases the pressure coefficient tends to increase as well, but this happens up to a certain limit, called the airfoil separation point or stall speed.

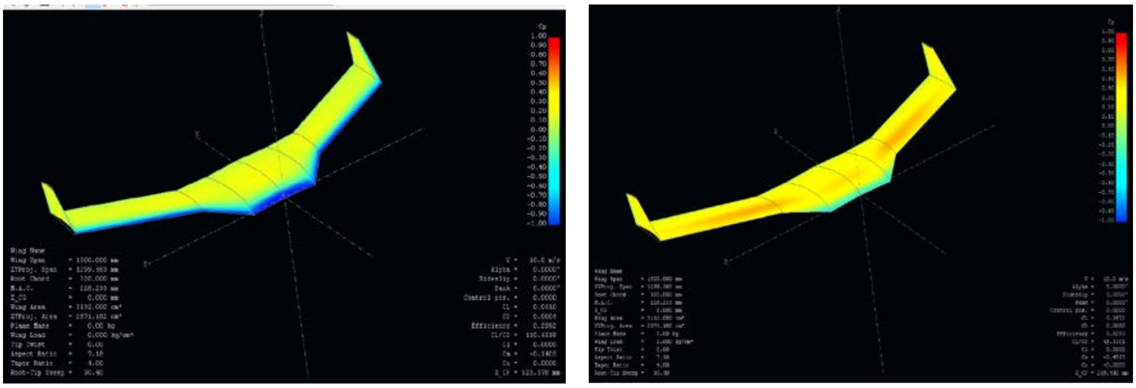

(a) (b)

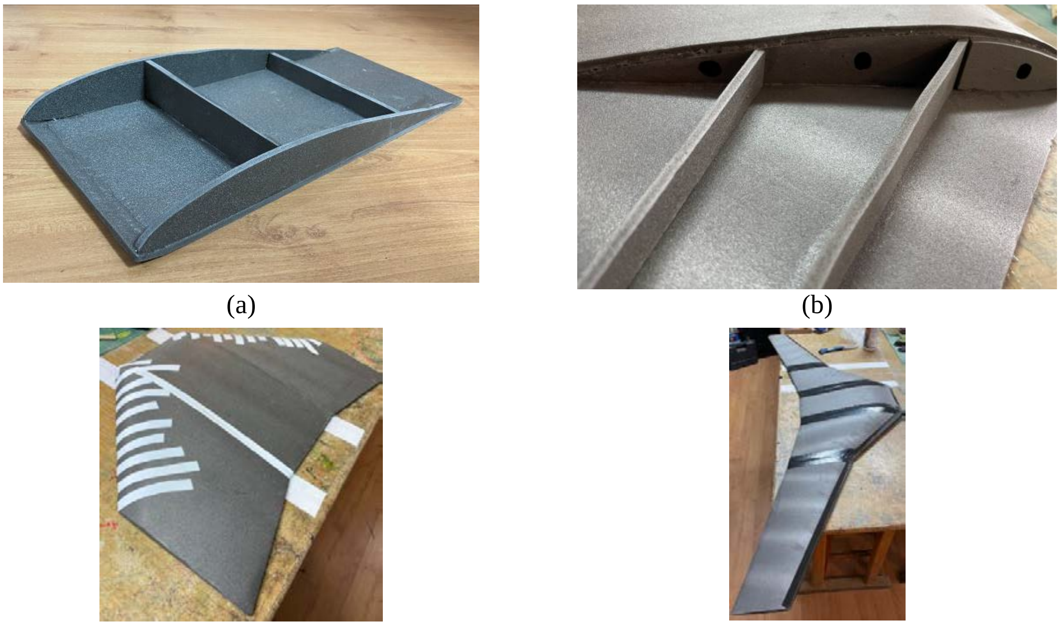
FIG. 5. Aerodynamic analysis of the wing (a) Pressure coefficient distribution at 0° angle of attack (b) Pressure coefficient distribution at 5° angle of attack

4. MANUFACTURING AND ASSEMBLY OF THE WING COMPONENTS

The primary need of UAV designers and operators is to manufacture an aeronautical product with low mass and high strength. With this in mind, depron was chosen as the main material for the wing manufacturing. The assembly of the wing parts was a complex process involving several steps and bonding methods (Fig.6a). An adhesive which is compatible with the depron is required, as most adhesives will melt these boards.

The role of the spars (Fig.6b) is to take up the loads and transfer them evenly so that no significant deformation occurs in flight. A rib was placed at the junction (Fig.6c) between the two wing planes to increase the strength of the area. The next step was to add the control surfaces, winglets, electronics, and motor mount.

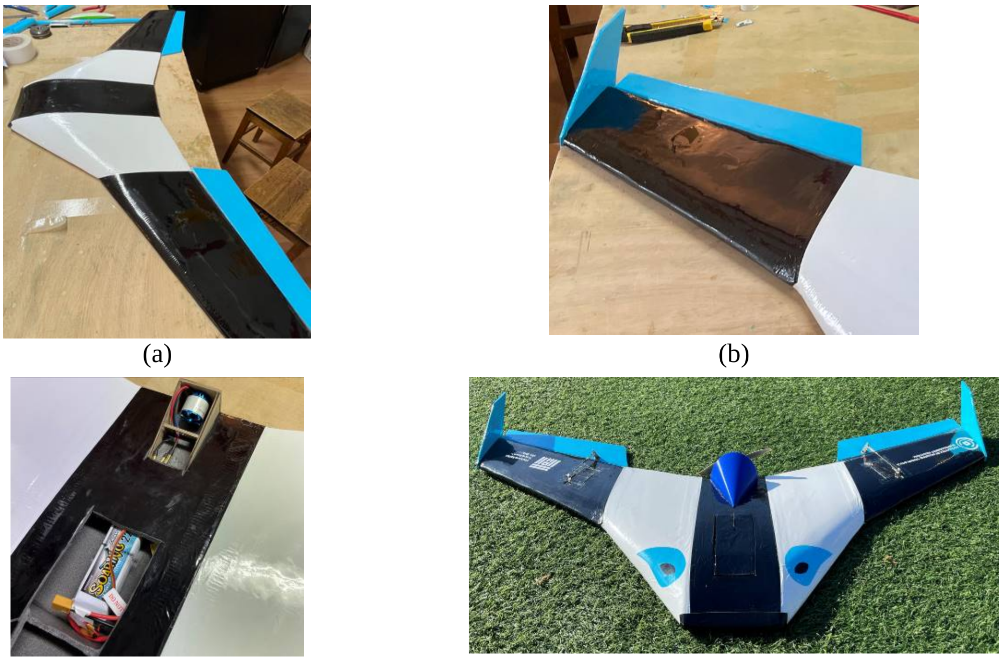
Fig.6d shows how the adhesive tape with fibreglass inserts was applied to the leading edge and all areas where jointing was carried out.



(a) (b) (c) (d)

FIG. 6. Main steps of wing assembly (a) internal structure (b) positioning the spars (c) assembly of the central structure (d) application of adhesive tape to the outer surface

Next, as may be seen, the blue thermal adhesive tape was applied to the control surfaces and attached to the wing structure by means of a transparent adhesive strip (Fig.7a). The winglet surfaces were then added on the right and left planes (Fig.7b). The winglet is intended to improve the aerodynamic efficiency of the wing by reducing the drag induced at the wingtip.



(a) (b) (c) (d)

FIG. 7. Final assembly of the wing (a) Adding the control surfaces (b) Fitting the winglets (c) Positioning the LiPo battery and brushless motor (d) Wing ready for flight.

In the next stage of manufacturing, the motor mount was fitted to the wing, using the bonding process with the same adhesive that was used to bond the depron (Fig.7c). As shown in Fig.7d, the motor cone (3D printed) was attached to the wing by bonding, which covers the motor, provides protection, and helps reduce drag. The completed wing ready for flight can be seen in Fig.7d. The manufacturing process took aproximately 35 hours and required a relatively simple set of tools and a single type of adhesive.

5. CONCLUSIONS

This study demonstrated the feasibility of manufacturing a flying wing starting from the preliminary design stage and ending with ground testing of the model. An important aspect to consider is the quality of the manufacturing of the wing, the low cost at which it was made, and the relatively short time in which the wing was manufactured. The final weight of the wing, equipped for flight, was about 750 grams, which is an advantage compared to the 1300 mm wingspan. The maximum speed the wing can reach is about 50 km/h. The estimated flight time is 17 minutes, but this may be influenced by the capacity of the battery and its quality. The speed at which the critical stall speed is reached is about 22 km/h and the maximum height to which the wing can lift is up to 500 metres. The flying wing can be used for reconnaissance, surveillance, search and rescue missions with the use of a camera.

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