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CONCEPTUAL DESIGN OF A 3D PRINTED FLYING WING eVTOL DRONE USED FOR EMERGENCY DELIVERIES

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Abstract: *This research focused on the conceptual design of a novel hybrid configuration of a drone. Therefore, a flying wing eVTOL (electric vertical takeoff and landing) is an innovative design that combines the efficiency of a flying wing with the vertical capabilities of an eVTOL. The proposed drone is equipped with a cargo box for emergency medical deliveries. A novel drone development methodology consisting of eight main steps was proposed. The 3D model of the drone was obtained using computer-aided design (CAD) software. A preliminary aerodynamic study for cruise flight was performed using computational fluid dynamics (CFD). The results have shown a flying wing lift force of 89.2 N. A 1:2 scale rapid prototype for testing, which contains a thin shell, a rectangular shape spar, and ribs placed at +/-45 degrees, was proposed and fabricated by 3D printing using the fused deposition modeling (FDM) method.*
Keywords: *conceptual design, medical delivery drone, eVTOL, CFD, 3D printing, FDM.*

1. INTRODUCTION

Unmanned aerial vehicles (UAV) or drones have different flight missions with applications in many domains such as cargo delivery [1], communications [2], rescue and emergency [3], meteorology, aerial image acquisition and processing, agriculture [4], urban mobility and so on.

Nowadays, emergency deliveries carried out by drones are gaining more and more interest in the medical field. Some researchers have investigated different configurations of VTOL drones focused on specific flight missions. Thus, a tilt-wing ambulance delivery drone, which can carry and deliver a payload box containing a first aid kit consisting of an automated external defibrillator, a set of medical instruments, drugs, and blood, was proposed in [3]. Drones can also be used in drone networks that could provide communication between isolated areas or in areas with technical damage, using topological maps in the form of a collection of regular polygons [2,5].

The configuration of the drone plays an important role in the possibility of fulfilling a specific flight mission. Thus, many types of drone configurations have been investigated [6-8]. The most known drone configurations are fixed-wing, rotary-wing which includes multi-rotor design, and hybrid VTOL systems that combine features of both. Fixed-wing drones are efficient for long range flights, while rotary-wing drones are agile, capable of hovering, and suited for complex environments.

Hybrid VTOL drones offer the best performances, enabling vertical takeoff and landing like rotary-wing drones and efficient, fixed-wing flight for extended missions. Tilt-wing with rotors, tiltrotor, and flying wing with rotors are some relative new solutions that allow hybrid VTOL [3]. Transition from the VTOL to the cruise is a complicated step of the drone flight. As a result, some VTOL drones, such as tiltrotor and tilt-wing needs complicated mechanism to change the orientation of the rotors [6]. A simplified solution consists in placing the VTOL motors on mounting arms. These kinds of VTOL drones are quad-plane [6] and tandem wings [7].

A few research was focused on flying wing VTOL drones with rotors placed on arms, which combine the operational flexibility and confined-area capabilities of multirotor drones with the extended range of fixed-wing aircraft.

Given the new design of drones, new manufacturing technologies, such as additive manufacturing that offer quick manufacturing solutions for drone structure, should be involved. Thus, in the study [8], it was proposed and analyzed a 3D printed drone wing having different infill configurations. They concluded that a tri-hexagon pattern was the most durable infill for their wing drone.

There are some studies conducted on the VTOL drones design, also on additive manufacturing of drone components, but a lack of knowledge around the development methodology of the flying wing eVTOL drones was found. While 3D printing offers design freedom, its application to a flying wing eVTOL design for emergency deliveries is underexplored.

The main goal of this research was the conceptual design and rapid prototyping of a novel hybrid drone with a flight mission focused on delivery to medical laboratories, missions in quarantine areas or activities in isolated areas.

2. METHODS AND MATERIALS

2.1 Conceptual design of the eVTOL flying-wing drone

A new methodology regarding the design and development of a drone is proposed in Figure1.

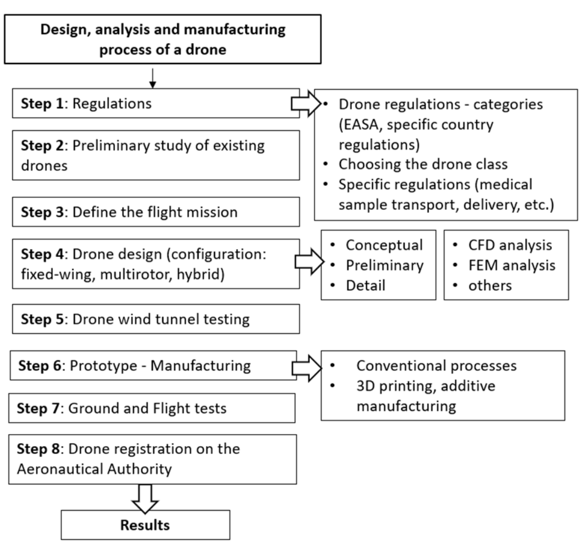

Fig. 1. Development methodology of the eVTOL drone.

The drone development process involves several key stages: drone regulations study, preliminary study of the current drones, defining the requirements and the flight mission, drone design, drone wind tunnel testing, drone prototyping and manufacturing, ground and flight tests, and certification and registration of the drone at aeronautical authority. Some key stages on the drone design process involves establish the drone configuration, designing the airframe, analyzing and validation of the design, integrating the electrical systems, and testing.

Preliminary study of current drones plays an important role in understanding the main features that the design of a new drone model will focus on. The following drones are found, selected, and analyzed from the literature [9-14]: Professional UAV CK 23 VE [9], Vrabac Mini UAV [10], Superbird [11], Eleron-3SW [12], Bramor C4EYE [13], and Swoop aero kite [14].

Comparative studies of current drones were conducted, focusing on wingspan, maximum take-off weight (MTOW), payload and cruise speed, as shown in Figures 2, 3 and 4.

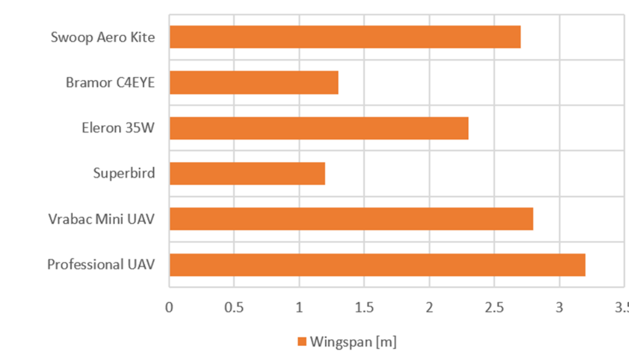

Fig. 2. Comparative study of wingspan of the current drones.

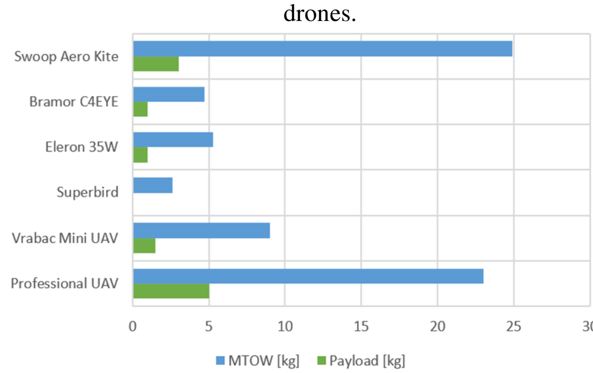

Fig. 3. Comparative study of MTOW and payload of the current drones.

Based on the analysis of the current state of the art, a hybrid flying wing drone configuration with VTOL engines placed on mounting arms was chosen for development.

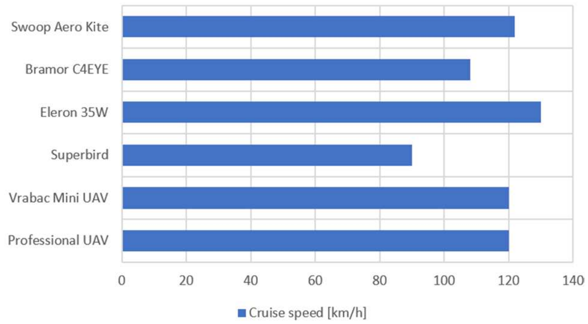

Fig. 4. Comparative study of cruise speed of the current drones.

The 3D printed hybrid drone has the following advantages in terms of performance:

- A flying wing eVTOL combines the efficiency of a flying wing with the vertical capabilities of an eVTOL.
- Integration of 3D additive manufacturing technology in order to streamline production, obtain parts with aerodynamically optimized shapes, as well as achieve a reduced manufacturing cost.

The mission profile of the proposed hybrid drone consisting of sixteen flight segments is presented in Figure 5. The mission of the drone was mainly focused on deliveries of things to medical laboratories. A series of probable situations could be identified:

- Transport of medical specimens between the collection center and the laboratory;
- Urgent transport of blood samples from an accident place to the hospital where the victim is to be transported in order to quickly obtain medical information;
- Transport of a medical sample collection kit in areas without specialized collection centers to support people in difficulty or unable to move.
- Fast and efficient transport of medicines and rapid tests in areas under a state of emergency due to the pandemic, for example due to Covid.

The aerodynamic shape of the wing was designed using Joukowsky airfoils series 0021 at the wing root, and series 009 at the wing tip. The 3D model of the wing is shown in Figure 6. Winglets are placed at the wing tip.

The internal structure of the wing consists in outer thin shell, rectangular carbon fiber spar, and ribs placed on it at +/-45 degrees. The thickness of the wing shell and ribs was 0.8 mm.

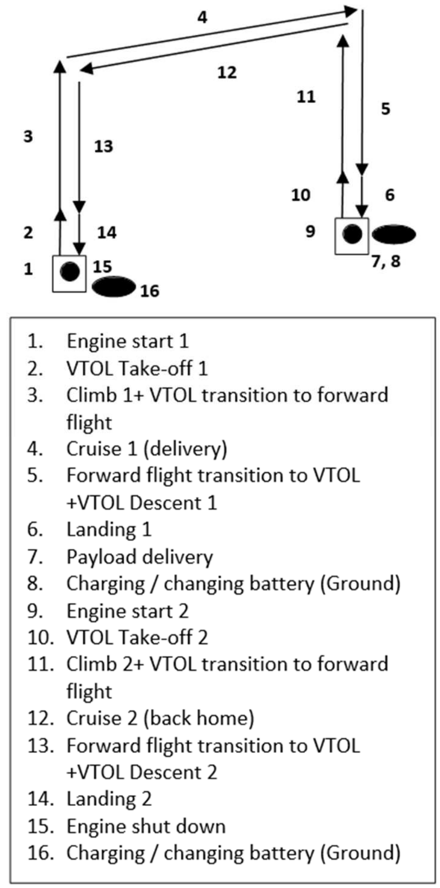

Fig. 5. Mission profile of the eVTOL drone.

Preliminary design requirements for the hybrid drone were presented in Table 1.

Table 1.

Hybrid drone design requirements

Preliminary characteristics	**Value**
Wingspan	1.8 m
Wing length	0.6 m
Cruising speed	30 m/s
MTOW	8 kg
Maximum payload	2 kg

Two intermediate engines mounting brackets are placed on the wing. A CFRP (carbon fiber reinforced polymer) tube runs through each bracket and the VTOL engines mounts are mounted on this. The power plant of the drone consists in four electric motors for VTOL phase and one electric motor used for cruise phase. The drone landing gear includes skids attached to the drone's body.

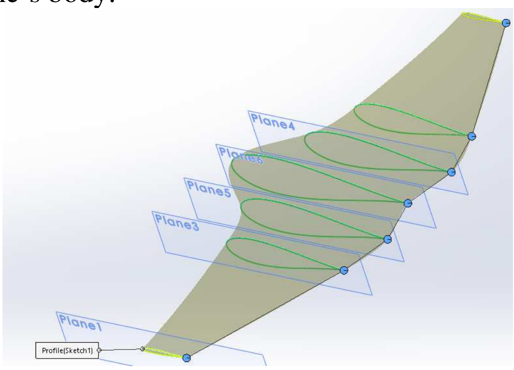

Fig. 6. Design of the drone wing.

The 3D model of the drone was designed using SolidWorks software. The aerodynamic shape of the drone was analyzed using Ansys CFX software. The primary objective was to investigate how air pressure and velocity are distributed around the flying wing drone, and calculate the resulting lift and drag forces.

2.2 Materials and manufacturing method

A 1:2 scale prototype of the drone wing was fabricated using the additive material extrusion process using Fused Deposition Modeling (FDM) technology.

The drone wing structure was divided into four parts to facilitate the 3D printing. The 3D models of the components were saved as STL files (Figure 7) and then imported into the Prusa slicer program. All parts were 3D printed on a Prusa i3-MK2 3D printer using PLA filament as the base material. Material consumption and print time estimation were performed using Prusa slicer 2.9. The main 3D printing parameters were set to a layer thickness of 0.15 mm, a wall thickness of 0.8 mm, and an infill of 100%. Then, the G-code files were generated.

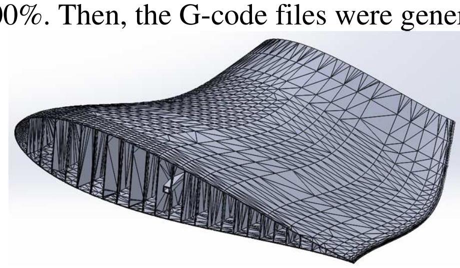

Fig. 7. STL image of a wing component

The assembly process was carried out using a rectangular carbon fiber bar that supports the wing structure. The wing parts were glued together using a structural adhesive.

3. RESULTS AND DISCUSSIONS

3.1 Results of the 3D design of the flying-wing eVTOL drone

The 3D assembly of the flying wing eVTOL drone is shown in Figure 8. A cargo payload box was designed for blood samples as is shown in Figure 9. The cargo box is mounted directly onto the drone's landing gear.

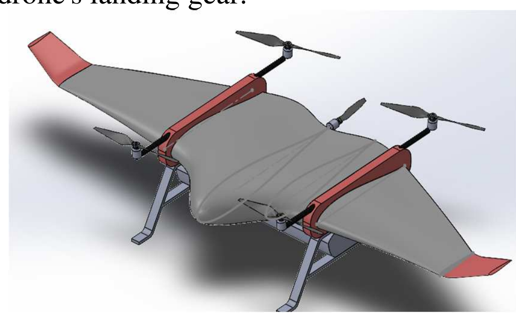

Fig. 8. Conceptual design of the eVTOL drone.

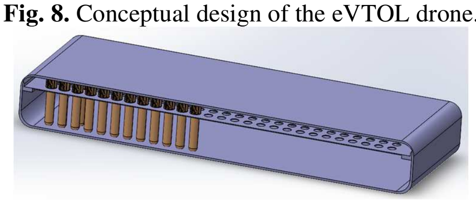

Fig. 9. Conceptual design of the cargo payload box for medical delivery.

3.2 Aerodynamic analysis of the flying wing

The CFD analysis of the flying wing was performed for the cruise flight at an angle of incidence of 4 degrees.

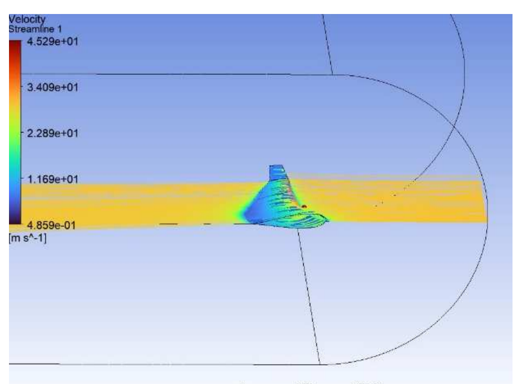

Fig. 10. Flow trajectories and velocity distribution.

The preliminary CFD analysis results show the velocity (Figure 10) and pressure (Figure 11) distributions. It was determined a lift force of 89.2 N and a drag force of 6.56 N. Thus, the drone's wing is shaped and sized correctly to generate enough lift for the required MTOW.

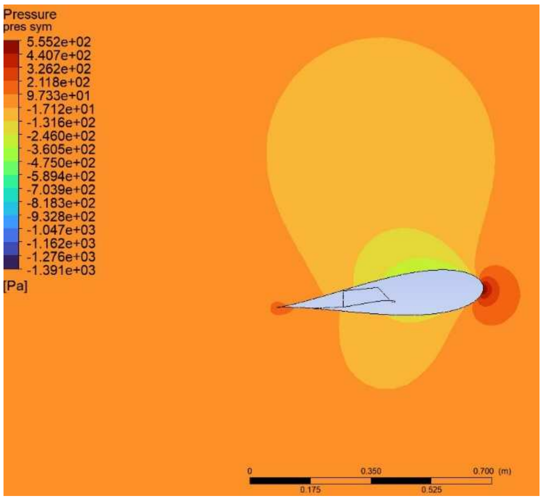

Fig. 11. Pressure distribution on the wing section

3.3 3D printing process of the drone prototype

The simulation process of the 3D printing of wing components and engine mounting brackets are shown in Figure 12 and 13.

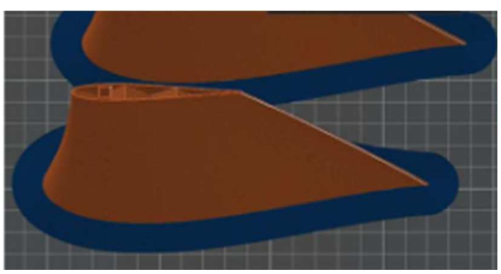

Fig. 12. 3D printing process of the wing components

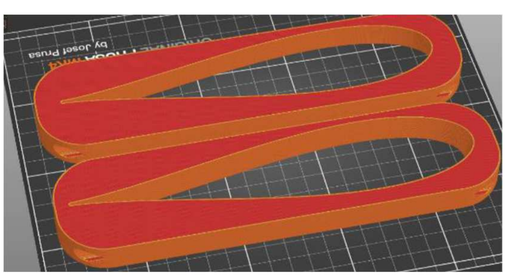

Fig. 13. 3D printing process of the engine mounting brackets

The total printing time and material consumption for the drone wing were calculated, as is shown in Table 2.

Table 2.

Results regarding the wing 3D printing

Component	**Printing time**	**Material consumption**
Central parts of the wing (2 pieces)	26h 48 min	570.62 gram
Tip parts of the wing (2 pieces)	9h 5min	142.19 gram
Winglet component (2 pieces)	1h	20 gram
Engine mounting bracket (2 pieces)	13h 40min	111.47 gram
Total	50h 33min	844.28 gram

The final prototype of the wing, during the assembly process, is shown in Figure 14.

Fig. 14. Final step of the wing assembling

4. CONCLUSION

The flying wing eVTOL drone proposed in this paper has the main mission to transport on short distance of cargo payload dedicated to medical laboratories. The following conclusions can be drawn:

- A new development methodology of the eVTOL drones was proposed.
- A novel hybrid drone was proposed.
- A lightweight internal structure of the wing based on a thin outer shell, rectangular spar, and ribs placed on it at +/-45 degrees was proposed, which reduced the manufacturing time and cost.

Future research directions will be focused on detail design and testing of the hybrid drone.

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Design conceptual al unei drone eVTOL de tip aripa zburătoare, realizată prin printare 3d, utilizata pentru livrări de urgență

Această cercetare s-a concentrat pe designul conceptual al unei configurații hibride inovatoare a unei drone. Prin urmare, o aripă zburătoare eVTOL (decolare și aterizare verticală electrică) este un design inovator care combină eficiența unei aripi zburătoare cu capacitățile de decolare și aterizare verticală ale unei eVTOL. Drona propusă este echipată cu o cutie de marfă pentru livrări medicale de urgență. A fost propusă o metodologie inovatoare de dezvoltare a dronelor, constând în opt etape principale. Modelul 3D al dronei a fost obținut folosind software de proiectare asistată de calculator (CAD). Un studiu aerodinamic preliminar pentru zborul de croazieră a fost efectuat folosind dinamica computațională a fluidelor (CFD). Rezultatele au arătat o forță de portanță a aripii de 89,2 N. Un prototip rapid la scara 1:2 pentru testare, care conține un invelis subțire, un longeron de formă dreptunghiulară și nervuri plasate la +/-45 de grade, a fost propus și fabricat prin imprimare 3D folosind procedul de depunere de material topit prin extrudare termoplastică (FDM).

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