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DESIGN, ADDITIVE MANUFACTURING AND TESTING OF A QUADCOPTER DRONE

Diana-Mihaela ȚURA
Transilvania University of Brașov, Romania
diana.tura@student.unitbv.ro

Sebastian-Marian ZAHARIA
Transilvania University of Brașov, Romania
zaharia_sebastian@unitbv.ro

ABSTRACT

In a world where technology and aviation are developing at a rapid pace, and where innovations and designs in this field are growing exponentially, drone-like aircraft has become an extremely popular topic in both the civilian and military fields in recent years. In this study, a complete development cycle of a quadcopter drone has been carried out, starting from preliminary design to flight validation of the model manufactured by additive processes. Thus, the preliminary design of the drone was performed, followed by aerodynamic and finite element analyses of the drone structure, and then the additive manufacturing of the drone components. The final steps of this study are the assembly of the drone components and the flight testing of the quadcopter drone model.

KEYWORDS: design, additive manufacturing, drone, finite element analysis, testing

1. Introduction

In the last decade, unmanned aerial vehicles (UAVs) have gained popularity in the scientific and technical community because of the advantages they offer, including: diverse applicability, high manoeuvrability, quality, reliability and low cost. UAVs are used in a wide range of applications: military, scientific research, weather forecast, civil engineering, wildlife monitoring, aerial mapping, search and rescue operations and hazard area inspection (Xuan-Mung & Hong, 2019).

3D printing or FFF (Fused Filament Fabrication) is an additive manufacturing (AM) process for building a wide range of complex parts and geometries starting from a three-dimensional model, by depositing successive layers of extruded material, to the final shape of the desired part (Kaur, Singari & Kumar, 2022). Additive manufacturing involves various methods, materials and equipment, with a rapid evolution over the years and an ability to transform production and logistics processes, with widespread applications in different industries such as aerospace, automotive, construction, medical and biomechanical (Zaharia, Enescu & Pop, 2020).

The FFF process is used for the manufacture of small-scale drones due to the advantages (elimination of dies, short manufacturing time, wide range of materials, low cost of 3D printing systems and

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filaments) that additive processes have. There are currently several main directions in additive manufacturing of drones: preliminary calculations on how to optimise performance, finite element analysis on the main structure and validation of manufactured 3D printed parts (Brischetto & Torre, 2021); reduced weight of a strength frame of a quadcopter drone through topological optimisation using the finite element method, and finally the optimised frame was manufactured using the FFF process using Acrylonitrile Butadiene Styrene filament (Nvss, Esakki, Yang, Udayagiri, & Vepa, 2022); design of a small-sized unmanned aerial vehicle and going through all preliminary design stages, followed by finite element analysis, resulting in a new design fabricated by the FFF process from polylactic acid (MohamedZain, Chua,Yap, Uthayasurian, & Jiehan, 2022).

Starting from the analysis of the current state of drone manufacturing using the FFF process, the purpose of this paper is to describe the process of developing a quadcopter drone by presenting the main steps, respectively design, analyze, physically manufacture and test a quadcopter drone model using additive manufacturing technologies

2. Drone Structure Design

In order to manufacture the three-dimensional model of the drone, we started from the equipment previously purchased (engines, electronic speed controller, battery, Arduino board, RC controller, rotors, camera, propeller). The three-dimensional model was created in the SolidWorks 2020 software system, and its template dimensions were: 134 mm length and 103 mm width. For the aerodynamic shape of the front surface, two cutouts of 3 mm width were made. The thickness of the skin was 1 mm over the entire strength structure of the drone. Figure no. 1 depicts the shape of the upper housing of the drone.

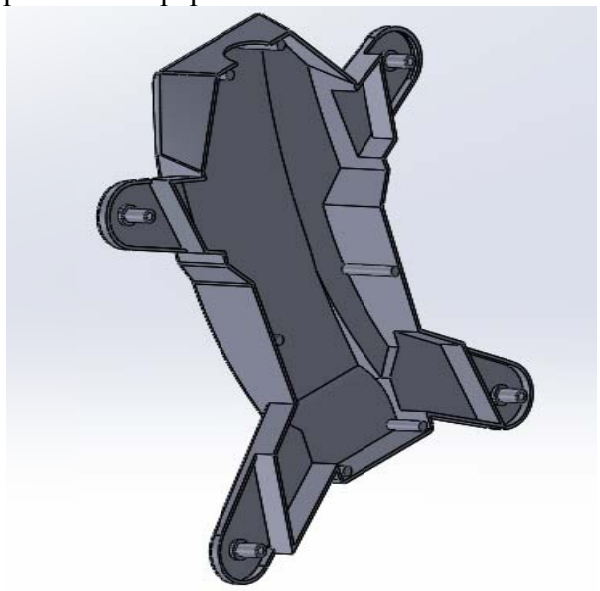


Figure no. 1: *Upper housing of the drone*
(Source: Authors)

The lower housing is 13.5 mm high and 134 mm long. The places where the cameras will be placed will be created on the lower part of the housing. Moreover, holes have been drilled on this side to make the housing lighter and provide good ventilation for the base plates (Figure no. 2).

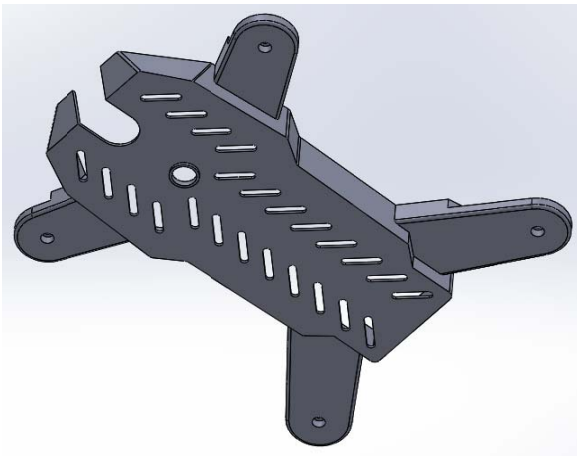


Figure no. 2: *Lower housing of the drone*
(Source: Authors)

Figure no. 3 details the arms of the drone which have a diameter of 35 mm, the thickness of the walls is 1 mm and inside the assembly there are 4 engine fasteners with a diameter of 2.5 mm.

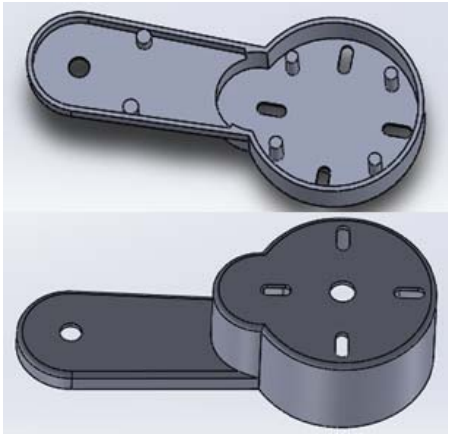


Figure no. 3: *The arm of the drone*
(Source: Authors)

Next, the following components of the drone were modelled: rotor, blade, rotor hub, and finally the final version of the three-dimensional model of the quadcopter drone was obtained (Figure no. 4).

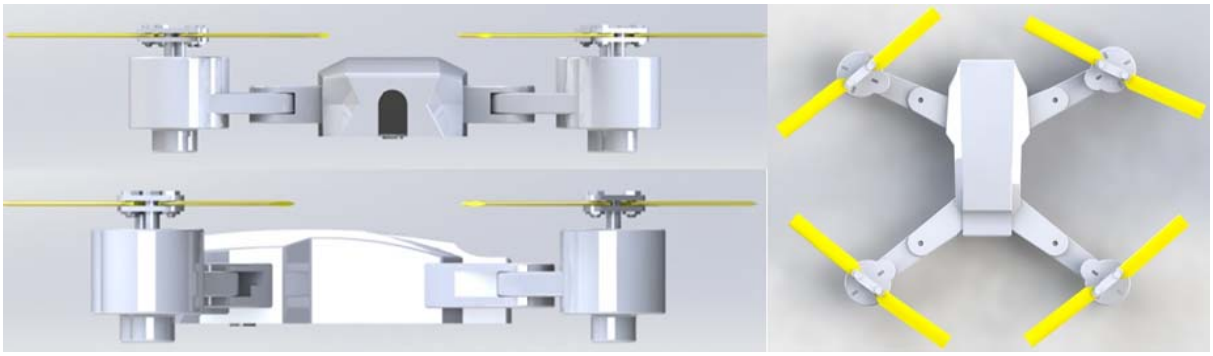


Figure no. 4: *Three-dimensional model of the drone*
(Source: Authors)

3. Aerodynamic Analysis of the Drone

The aerodynamic analysis was carried out using the SolidWorks 2020 software system. This analysis was performed on all four rotors and then on one of the rotors only. The rotating domain is represented by a 155 mm diameter cylinder with a rotational speed of 1500 rpm. Sea level atmospheric pressure with a value of 101325 Pa and a temperature of 293.2 K was used for the analysis. From the aerodynamic analysis (Figure no. 5) it can be observed that there is no interference between the four rotors of the drone, and the speed varies in the range 0.119 m/sec. to 1.186 m/sec.

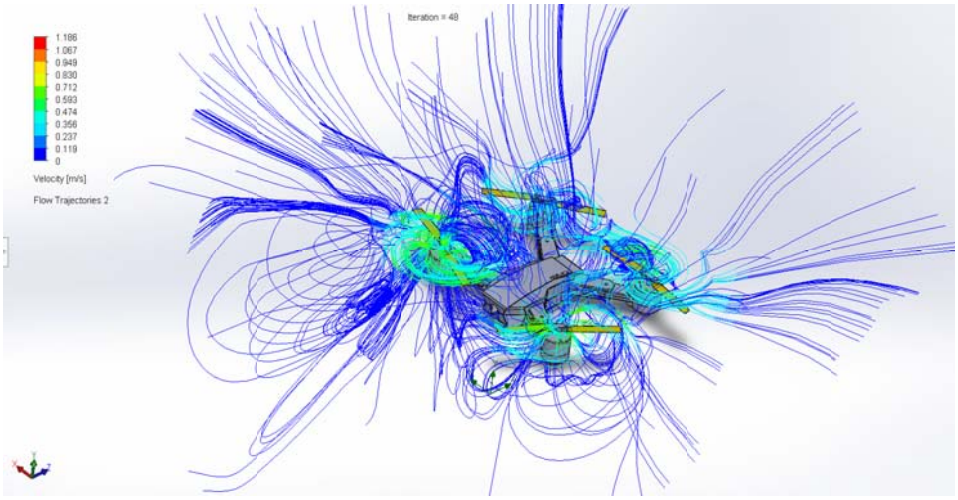


Figure no. 5: *Flow velocity variation around the drone*
(Source: Authors)

The next aerodynamic analysis carried out was on a single rotor of the drone. For this analysis, the rotating domain remains the same, represented by a 155 mm diameter cylinder, and the same speed of 1500 rpm. The pressure distribution on the blade is higher in the leading edge area and reaches a value of 104625 Pa, the average value is present in the middle area of the blade and decreases towards the trailing edge (Figure no. 6).

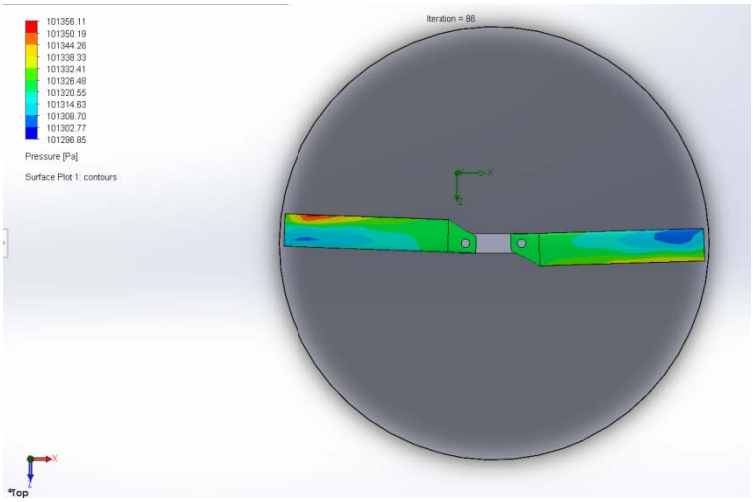


Figure no. 6: *Pressure variation on drone rotor blades*
(Source: Authors)

4. Finite Element Analysis of the Drone

ANSYS 16.0 software was used to carry out the finite element analysis of the strength structure of the drone. The first step consists in importing the drone geometry in ANSYS 16.0 software in static structural module.

The next step was to add the characteristics of the polylactic acid material required for the finite element analysis. The mesh of the model was done with a mesh element size of 2 mm. Next the boundary conditions (fixed support) and the stress loads on the drone model were applied. The loadings applied to the drone were: the engine thrust and drone weight. The thrust force acts from bottom to top on the frame arms.

This is calculated by multiplying the average engine thrust force (32.2 N) by a safety factor (CS = 1.5) and dividing the result by 4, so that it can be applied to each arm of the frame (F = 12.5 N). The weight force acts on the arms of the drone. The weight is calculated by multiplying the weight of the drone (300 g) by the gravitational acceleration (9.81 m/s) and the safety coefficient (CS = 1.5) and then dividing it by 4 so that it can be applied to each arm of the structure (F = 0.73 N). The maximum total displacements occurring on the drone strength structure reach a value of 0.23 mm and are recorded in the engine area (Figure no. 7). The equivalent stresses (Figure no. 8) have small values and also occur in the embedding area, reaching a maximum value of 16.841 MPa. These values do not exceed the maximum strength of the polylactic acid material (54.1 MPa) defined in the finite element analysis.

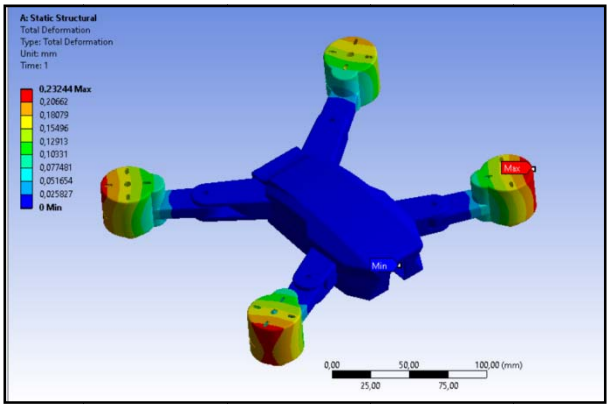


Figure no. 7: *Distribution of total displacements*
(Source: Authors)

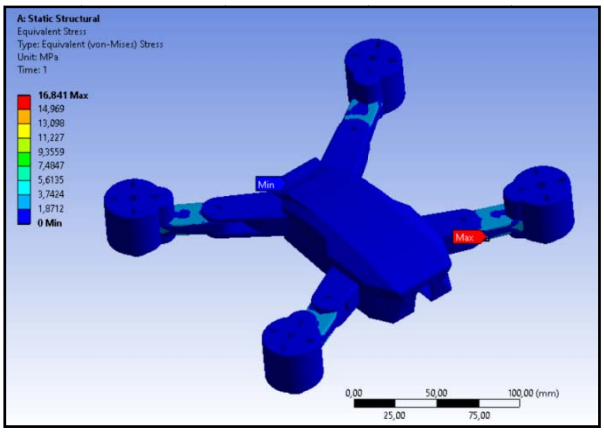


Figure no. 8: *Distribution of equivalent stresses*
(Source: Authors)

5. Additive Manufacturing of Drone Housings

The Ultimaker S5 system was used for the additive manufacturing of the drone housings, using polylactic acid (PLA) as the filament. A series of manufacturing parameters were specified which were used to 3D print the drone housings: layer height 0.1 mm, infill density 100%, 3D printing temperature 200° C, 3D print speed 50 mm/sec, building plate temperature 60° C. Given the small size of the drone housings, it was chosen to 3D print them together (Figure no. 9), and the 3D printing time of the housings was 29 hours 33 min and the mass of the filament used was 88 g. Printing preparation of the drone housings was carried out in the Ultimaker Cura 4.13 software system.

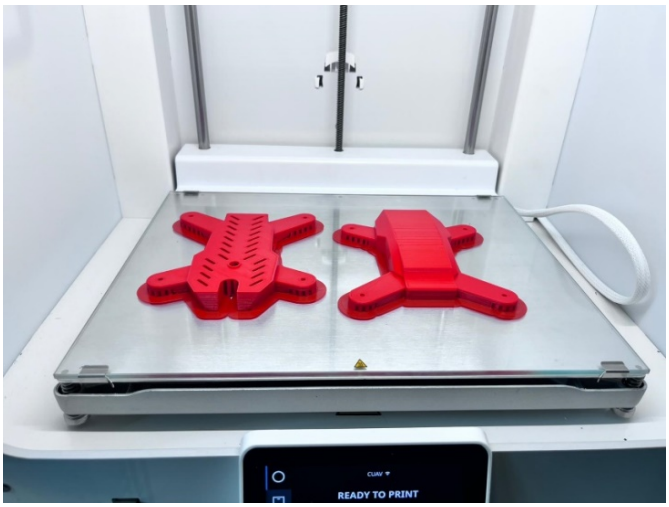


Figure no. 9: *3D printed drone housings*
(Source: Authors)

The arms of the drone were 3D printed (Figure no. 10) using the same manufacturing parameters as for the housings. The 3D printing time of the drone arms was 25 h 9 min and the filament weight used was 72 g.



Figure no. 10: *3D printed drone arms*
(Source: Authors)

6. Assembling and Testing the Drone

The first step was the removal of the support from the inside of the housings, which was carried out with pliers (Figure no. 11). After removing the support, the surfaces that needed sanding were sanded.



Figure no. 11: *Drone housings before removing the support*
(Source: Authors)

Once the parts have been cleaned, the actual assembly of the drone components begins. The first components positioned on the lower housing are the cameras (Figure no. 12) together with the base plate. The cameras were attached using cyanoacrylate adhesive. Once the glue was applied, the upper housing was also temporarily positioned so that we could see how the cameras fit, and the glue could dry. Two small presses were used to hold the front part fixed until the adhesive dried.



Figure no. 12: *Attaching the cameras to the lower housing*
(Source: Authors)

The next step is to fix the lower parts of the driving arms (Figure no. 13), and for better bonding after the application of the glue, two pliers were used to hold the area still until the glue dries. Once the lower parts of the arms were positioned, the engines were placed, and they were fixed in the supports inside, as it is very important that they do not move during operation.

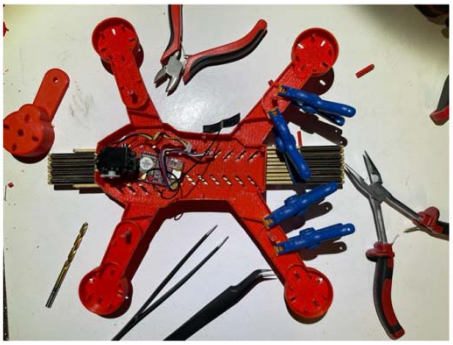


Figure no. 13: *Fixing the lower parts of the driving arms*
(Source: Authors)

Once the engines have been attached, the upper parts of the driving arms will also be attached and glued. The battery was then attached, and the charging area was created. The battery was positioned at the back of the housing, and the charging port was chosen to be positioned on one of the edges (Figure no. 14). After attaching them, a test was performed to see if everything was functional so far.

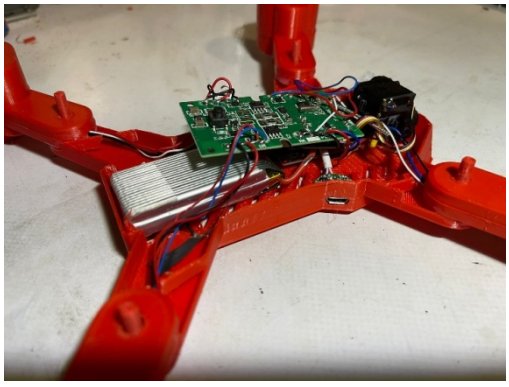


Figure no. 14: *Attaching the battery and the charging port*
(Source: Authors)

The drone is almost in its final form (Figure no. 15), but a few more tasks need to be completed before the first flight. Three cutouts were made on the upper housing to allow access to the start button, then the upper housing was attached to the lower housing, and the last step is to position the rotors.

Before the actual testing of the model, a test of the radio controls (Figure no. 15) and the engines will be carried out. First the radio control will be switched on and connected to the drone, after connecting the radio control to the drone the ground functioning of the engines will be tested. This test is necessary in order to be able to observe if there are any problems with the connection between the radio control and the drone and to observe if there are any problems with the operation of the engines. The final shape of the 3D printed drone has been depicted in Figure no. 16.



Figure no. 15: *Testing of the radio controls drone*
(Source: Authors)



Figure no. 16: *3D printed drone – ready for flight*
(Source: Authors)

Once the ground tests have been performed, the flight tests are carried out. The drone was gradually raised to various altitudes to see how it behaves in the air, after which flight tests were carried out to observe its behaviour and manoeuvrability. The flight tests were performed on various days in windy and still air conditions and the conclusion was that the 3D printed drone is manoeuvrable and stable (Figure no. 17).



Figure no. 17: *3D printed drone flight*
(Source: Authors)

7. Conclusions

3D printing has become increasingly used in the manufacture of drone and unmanned aircraft models, mainly because it has many advantages over traditional processes. In the case of 3D printed drone parts there were several advantages that need to be mentioned: low material costs (PLA filament is the cheapest on the market); no moulds required to make the housings and arms (only the 3D model is needed); short manufacturing time (54 hours and 42 minutes).

This study demonstrated the feasibility of manufacturing drone parts using 3D printing, going through a complete development cycle, starting from design, aerodynamic analysis, finite element analysis, manufacturing, assembly and up to flight validation of the quadcopter drone. From the analytical calculations, the operating life of the drone with a 100% charged battery is about 19 minutes, and the drone can be used for search and rescue missions, video inspections as it is equipped with a 4K video camera. In conclusion, future directions of research should explored the manufacturing by FFF process of the drone from composite materials or high-performance engineering polymers.

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