Multifunctional 3D Printed Unmanned Aireal Vehicle

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***Abstract*—This paper is focused on explaining the design process and functionality of multifunctional, long range, unmanned aerial vehicle, with the intention to be printed, repaired or modified with use of any common 3D printer. This paper also focuses on a few possible future uses and improvements for said unmanned aerial vehicle.**

Keywords—unmanned aerial vehicle, 3D printing, drone, multifunctional

I. Introduction

Ever since the dawn of mankind, we always looked up to the sky and were amazed by birds with their ability to fly. Nowadays we have means to produce our own flying machines. We even started to make them remotely controlled, and with that the Unmanned Aireal Vehicles (afterwards referred to as UAV) were born. With the popularity of UAVs rising in the last few years, especially quadcopters, they are being implemented into many different fields of work [1]. So, when I was looking for an idea on the topic of my work, these facts convinced me to choose making of the UAV, as it provided some freedom of design and also many different possible uses. This paper mainly focused on explaining my design process of making my UAV, with some possible uses and later improvements.

As I had little prior experience with making or flying a UAV, I started this project with a lot of research around the topic. Another reason why I chose this project is that I have a lot of experience with 3D printing, that is why I decided to use a 3D printer as a main form of construction for the UAV. I also had quite a lot of experience with 3D modeling and designing in SolidWorks [2], from when I gained my CSWA (Certified SolidWorks Associate) certification, so using SolidWorks as my primary modeling tool for this was probably the best choice for me.

Because there are many different ways to make a UAV, with equally as many different uses for it, so I decided on a few main goals for my UAV, which are:

- Simple manufacture, in my project, I strongly relied on 3D printing
- Long range flight, because I wanted this UAV to cover as much area per flight as possible
- Multifunctionality and future modifiability, as I wanted this UAV to be versatile and also so I could later develop modifications (see more in section V. and VI.).

With the start of this project, I also got an opportunity to attend internship in a local company OEZ Letohrad, which helped development of this UAV with consultations, advice and partial founding of this project.

II. Constuction

As long-range flight was one of my main goals, I settled on design with fixed wings and one push motor with a 10-inch, two leaf, foldable propeller. I designed this UAV into smaller segments, so they can fit on to most of the common 3D printers and can be easily modified or replaced if needed. The design of the UAV is my own work, and it is a result of my different early sketches and 3D models. The only thing I took some inspiration in from different models was the way to attach the back wing to the body, using two thin tubes. Which I found quite common in the UAV community, at least for UAVs with motor in the back. The 3D printer used for this project was my modified Ender 3 V2. Because weight is one of the major factors in long-range flights. I decided to use Light Weight PLA (or LW-PLA) as a main type of filament, specifically Black eSun LW-PLA [3], as it was the easiest one for me to obtain. I chose LW-PLA because it offered good weight properties, as it can be up to 21% lighter than normal PLA, even if it is at cost of some strength [4], but that does not really affect me, as I have installed PVC tubes as reinforcement in the wings. Lighter body meant that I had more freedom choosing electronics and also for the future modifications.

The UAV consists of 3 main parts (Fig. 1):

A. Fuselage has shape of a tube, as it offers good aerodynamics with decent amount of space, and it is also easy to print.
B. Front wings are separated into 4 segments, with one long aileron on each side. I used Clark-Y Airfoil, because of its good performance at low speeds with ailerons down, and low drag with ailerons in normal position [10].
C. Back wing has teardrop airfoil, so the airflow is approximately the same on top and bottom sides of the wing, for the best elevator performance. There are two separate elevators on the back wing with one vertical stabilizer on each side.

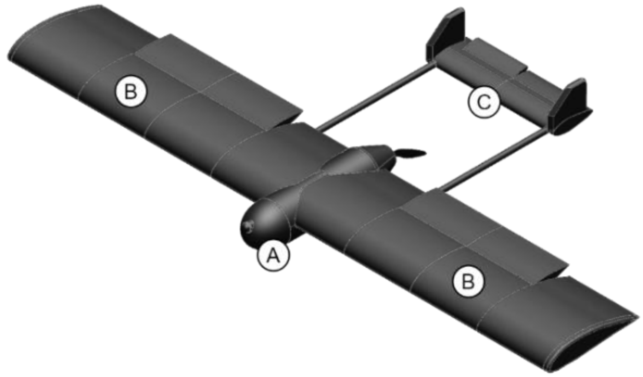

Fig. 1 – Picture of the UAV with highlighted parts

The change of direction is achieved by a combination of aileron and elevator input, as I decided to not use rudder for less complicated construction, even at cost of some agility, which should not be crucial for most of my UAV flights, I might add rudder in later iteration if there will be need for better agility.

Take-off with this UAV is achieved by a help of custom cart which is used as wheels, until the UAV leaves the ground, leaving the cart on ground. As of now, this UAV needs fairly long space for reaching its take off speed (see section IV.).

The actual process of assembling the UAV was more or less simple, as I have spent long time designing the parts to easily fit together. But even after all the preparation, I still had to modify some of the parts by hand, as I have made some changes of electronics between printing some of the parts and putting the UAV together, however after the final assembly I have updated all the part files, so they are ready to use.

III. Electronics

Electronics in this UAV have 6 main components (Fig. 2):

1. Two 2200 milliampere hour, six cell batteries connected in parallel for a total of 4400 milliampere hours. The batteries are mounted in the fuselage under the wings, because they are the heaviest component, and I do not want them to offset the center of mass too much. There is the possibility for future use of bigger batteries, up to 17000 milliampere hours of total battery.
2. EM3110[9] Motor mounted in the back of the fuselage
3. Matek F405-Wing-V2 [5] flight controller mounted in the nose section of UAV. This controller, with an integrated gyroscope, accelerometer and barometer, is used for communication between all the different modules, stabilization and maintaining flight. I am also using this controller to convert 22 volts from batteries to 5 volts used in the rest of the UAV. With this controller there is a possibility for later partial automation of the UAV.
4. Six MG90D servos that are used for movement of flaps. There are two servos for each of the ailerons, so they are moved evenly because of their length. There is also one servo for each of the elevators, so they can be controlled separately.
5. 2.4 gigahertz receiver with double antenna, for better connection, mounted in the back of the UAV. For control of the UAV, I am using ExpressLRS [6] which is an open-source radio control link.
6. An additional feature of my UAV is the Universal Mounting Spot (UMS) on the bottom of the middle section of the fuselage. This is a custom-made mounting spot which can be used to mount and connect different instruments such as:
   - Infrared camera
   - Thermal camera
   - High quality camera
   - Lidar module
   - Ground penetrating radar
   - Possible other instruments

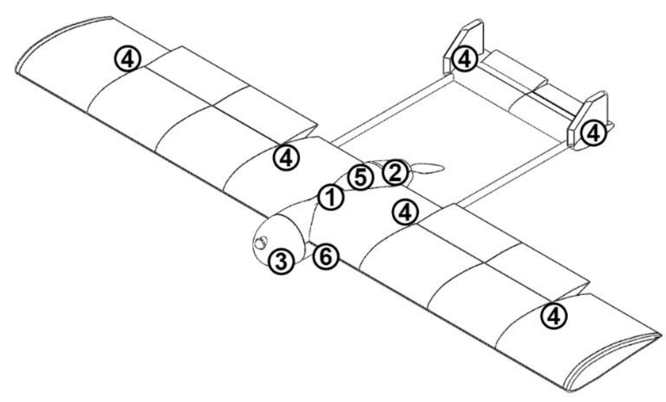

Fig. 2 – Picture of UAV with highlighted components

In the Fig. 3 we can see the simplified wiring diagram of my UAV, we can also see connections for future components (see dashed line borders)

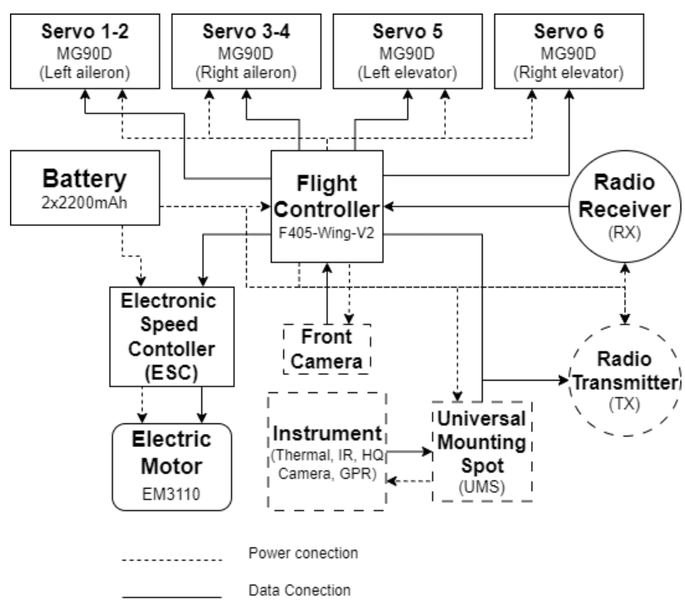

Fig. 3 – Simplified wiring diagram

IV. PARAMETERS

Here we can see in Tab. 1. with some basic parameters, which we can use to calculate some theoretical properties flight properties of the UAV:

Weight of the body	3412.5 g
Weight of the components	840.5 g
Total weight	4253 g
Wingspan	1625 mm
Wing area	47200 mm²
Length of the body	844 mm
Diameter of fuselage	100 mm
Operational motor power (50%)	276.7 W
Maximal motor power (100%)	1248.6 W
Optimal take-off weight	5000 g

Tab. 1 – Table of basic parameters

To determine the speed needed for take-off with optimal take-off weight, we can use the lift formula:

$$L = \frac{1}{2}\rho v^2 S C_L \quad (1)$$

Where L stands for lift, ρ stands for density of air, v is for the velocity of the UAV, S is for surface area of the wings and C_L stands for lift coefficient which for Clark-Y is approximately C_L = 1.3 for angle of attack of 15 degrees [10]. The result is that we need at least v = 43.2 km/h to achieve flight, but this value does not consider in the position of ailerons on the wings, because with them facing downwards, the speed needed is likely to decrease, as the lift coefficient should be higher [10].

V. POSSIBLE USE

Because this UAV can be modified and it is meant to be multifunctional, I cannot really specify all the possible uses for it, but I can at least specify a few of them, which were on my mind in the process of making this UAV.

When an avalanche happens, and there is possibility of people being buried under snow, their survival chances depend on how quickly they can be dug up [7]. And for those situations I think using a UAV could potentially help save those victims using ground penetrating radar (GPR), which could be used to locate people under snow [8], as UAV can cover large and hard to reach areas in short amount of time, even at the cost of some accuracy of the GPR due to data noise caused by the UAV being off ground. This application would need more testing in the field and more development, to surely determine if it is feasible, so I am planning to continue working on this option to see its future development. Also, another use could be during search and rescue using thermal camera, because deploying UAV is fast and easy, and it would potentially save the time needed to call a helicopter equipped with thermal camera, and also the UAV could be easily stored in any emergency service vehicle or building.

Another possible use for my UAV could be terrain scanning, which could be used in many different fields of work [1], like construction, farming, or nature protection or with a mounted thermal camera, the UAV could be used for wildlife monitoring.

I also want this UAV to be relatively easy to 3D print and assemble, so it could be in the printed, modified or repaired anywhere, as the only thing needed for its manufacture is some common 3D printer and few other previously specified parts, and could be used widely across different work fields.

VI. FUTURE IMPROVEMENTS

There is a limit of what I can do on my own, so there are a few things I would like to add or focus on in future iterations of this UAV, such as:

a. Easily accessible battery assembly, so both batteries can be taken out at once from outside and replaced. This would improve the effectiveness of my UAV, because it would not need any charging between flights.
b. Simplified construction, which would lead to some weight loss, thus better flight efficiency, saving material and easier 3D printability.
c. Making my own PCBs with modules, so I could possibly make the UAV easier to assemble and maybe little lighter.
d. Contra-rotating propellers, which could improve efficiency and stability of UAV by canceling the centrifugal force of the airflow caused by single propeller and therefore focusing more direct airstream on the back wing. The UAV with this feature would need some kind of gearbox, which would increase its complexity, but could lead to better flight performance.
e. Develop simple and safe way to launch the UAV from ground. Maybe like a ramp, catapult or maybe develop a way to launch the UAV from moving car to help achieve take-off speed in much shorter distance.
f. Make my drone partially autonomous, so it can do basic actions, like flying to a point, over some area or following some object or path on its own.

VII. TEST FLIGHT

In Tab. 2. below we can see theoretical flight data, for the UAV, in current configuration, with perfect conditions:

Flight duration	24 min
Distance flown	20160 m
Weight of the UAV	5000 g
Speed	50 km/h

Tab. 2 – Flight parameters

These values should be used as a benchmark for future modifications and will be tested as soon as possible to see if they are right.

VIII. CONCLUSION

In this paper, I have focused on an explanation of my journey with designing and building my own 3D printed UAV. I have also explained some possible uses for it. Even though I have finished this UAV, there are always things to improve, and I plan to continue developing said UAV, with more modifications and improvements in the future.

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