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Design of a Portable Drone for Educational Purposes

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Design of a Portable Drone for Educational Purposes

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***Abstract*—This paper discusses the design of a portable drone to be used by students for practical investigations of drone operating principles. The drone design is based on a Y6 frame module concept and takes into account the affordability and combinability of components which are widely available via the hobbyist drone manufacturing market. It is a foldable device and is protected against water ingress according standard DIN EN 60529 (IP01). The drone generates high thrust for a Maximum Take-off Mass (MTOM) of 5 kg and the propeller design has been investigated and analysed in detail to determine the optimum location required to provide maximum thrust.**

Keywords—Unmanned air vehicles; portable drone; propeller design; ANSYS

I. INTRODUCTION

In modern times the airspace above our heads is no longer the sole preserve of manned aviation and it is increasingly common to see Unmanned Air Vehicles (UAVs), usually referred to as drones or multicopters, in airborne operation. UAVs attract much interest from research and business in order to implement it in various areas of commercial, research and hobbyist activity. The unique selling point of UAVs is that these devices are unmanned. They can operate, for example, in disaster zones without harming any humans and can be deployed much more quickly than a manned helicopter. Furthermore, a UAV is much smaller than a manned aircraft and can be used in constrained areas like buildings or a forest. [1]-[4].

Drones have the potential to become more technologically advanced in the future due to the dramatic increase in the development of microelectronics and manufacturing technology. The increase in the computational resources of the processor, diverse sensors, GPS transmitting and communication connectivity to nearly every device supports UAV operations in many application areas. UAVs have also become more affordable for the general public due to the decrease in the cost of their parts. In addition, drone weight can be decreased using new composite materials like carbon fibre and the airframe components more readily produced using 3D printer technology [5]-[8].

In order to cover the majority of possible operational applications, a UAV should be portable, multifunctional for mounting equipment and carry an acceptable amount of payload. The flight endurance, stability, and manoeuvrability are also important factors and it is desirable that drones should be waterproof to keep the sensitive electric and electronic components safe. Each design of a drone may have its own advantages but, to be useful for a wide variety of applications, it must at least be capable of carrying a large payload which requires more motors and consequently higher cost [9].

Currently across the European Union each National Aviation Authority has the responsibility for the regulation of Drone operations within its airspace for MTOMs not exceeding 150 kg. In the UK, the CAA offers guidance on both private and commercial UAS operations [10] and categorise Small Unmanned Aircraft (SUA) as those with an MTOM below 20 kg. Whereas in Germany, for example, this mass threshold is set at 25 kg. Since the Riga declaration of 2015, on Remotely Piloted Aircraft [11], the European Aviation Safety Agency (EASA) have been tasked with the development of harmonised regulations across the Union. This work has resulted in the publishing of a proposal for the introduction of a Europe wide regulatory framework for the operation of drones and is applicable to all SUA having a MTOM of 250g or more [12]. Drone operations at Wrexham Glyndwr University are conducted with SUA having a MTOM not exceeding 7 kg and are also considered a commercial undertaking [13].

This paper describes the design of a portable drone combining 3 basic types of technologies: electrical, software and mechanical engineering. The design is based on the Y6 concept of a foldable drone applicable for many operational fields. It has been developed to be an educational aid and is intended to provide a modular design and good affordability. The drone can be effectively used for the study of UAV operational principles. The proposed Y6 airframe provides the ideal platform for students to either develop bespoke electronic flight controller modules, for example based on Arduino microprocessor technology, or configure open source firmware and controller designs, such as Ardupilot and Pixhawk, to include telemetric links and ground station capabilities. Thus allowing in-flight handling and performance data to be logged. The modular design also makes the drone multifunctional, and not restricted to a single operation. The airflow of the stacked propellers is analysed in details to investigate the impact of the separation distance between them. The proposed design also takes into account the future development of legislation from the EASA (European Aviation Safety Agency). The drone has a MTOM not exceeding 5 kg and is therefore categorised as a Small Unmanned Aircraft (SUA). This provides an advantage, as SUA do not require formal certificates of Airworthiness to be issued by the NAA, and this aspect therefore greatly eases the educational process with regard to the design and development of drone related technologies.

II. EASA Future Regulations

The EASA is the agency in Europe responsible for the regulation in the area of aviation. Their mission in Europe is to set law for public safety and environment protection. In addition, they certificate members or products and promote for setting their standard for international [14]. They also cooperate with other agencies and actors for developing future limitations. This is an important point which should be considered for every constructed aeroplane, drones included.

The future limitations for drone are at the present day in the proposal stage [12] but most of them will be applied 2018 and 2019 [15]. The drones will be categorised into 3 types.

- open category operations, considering the risks involved, require neither an authorisation by the competent authority nor a declaration by the UAS operator before the operation takes place;
- specific category operations, considering the risks involved, do require an authorisation by the competent authority before the operation takes place and take into account the mitigation measures identified in an operational risk assessment, except for certain standard scenarios for which a declaration by the UAS operator is sufficient;
- certified category operations that, considering the risks involved, require the certification of the UAS and its operator, as well as licensing of the flight crew.

The proposed legislation is likely to make it more difficult for hobbyists to fly their own drones in the future because it will require in many cases an authorisation from the EASA or similar agency. Therefore, these proposed requirements should be carefully considered in any forward looking drone design or proposed operation.

III. Design Approach

The variation in design is dictated by the area of application and the costs of the components. The most common multicopter type is the quadcopter having 4 motors, rotors and ESCs (Electronic Speed Controller). Although there are no restrictions on the design of the drone, in theory, it can fly on a single or multiple motors. In fact, there is no restriction in terms of flight controller and software to support any number of motors, however, the more rotors used in the drone design the more cost of the device.

The increasing number of arms, propellers, ESCs and motor require the increase of the battery capacity. This is all payload and the side effect is decreasing flight time with increasing weight. The most important factor in designing the device is to keep it as light as possible. Therefore, all material and every component used in the UAV should be as light-weight as possible with respect to the affordability.

The proposed drone design is based on a Y6 concept which consists of 6 rotors. The advantage of a Y6 copter is that it operates like a normal hexacopter but due to the mounting of the rotors the drone size is reduced [16]. This means that the weight is also reduced because of the reduced number of arms. Additionally a novel arm hinging and locking mechanism was developed for this drone enabling it to be quickly deployed and stowed. The Y6 design also offers better wind resistance than a traditional hexacopter. Furthermore, a Y6 copter runs normally with a lower motor speed than other UAVs because of the stacked motors. This reduces the heat-losses and improves the motor runtime [16]. However, the thrust efficiency of a Y6 design can be reduced by 5% due to the stacked propeller arrangements. [17]. The turbulent air flows through both rotors cause this loss.

The basic components required are the same for most of UAVs. They need a flight controller, software, RC transmitter/ receiver, motors, propellers, ESCs, frame, battery, and connectors. The basic sensors are normally installed on the flight controller. Further sensors transmitter and devices such as a camera, GPS, FPV antenna (First-Person-View), gimbal etc. can be added if the flight controller and the payload of the drone support it [18]. The proposed design of the drone is shown in Fig 1.

The limits were chosen with respect to the current German government LBA (Luftfahrt Bundesamt) restriction for private

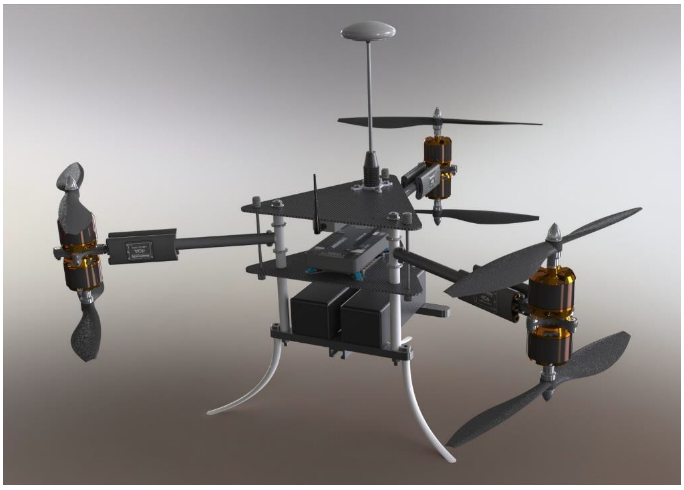


Fig. 1. The proposed design of the Y6 drone.

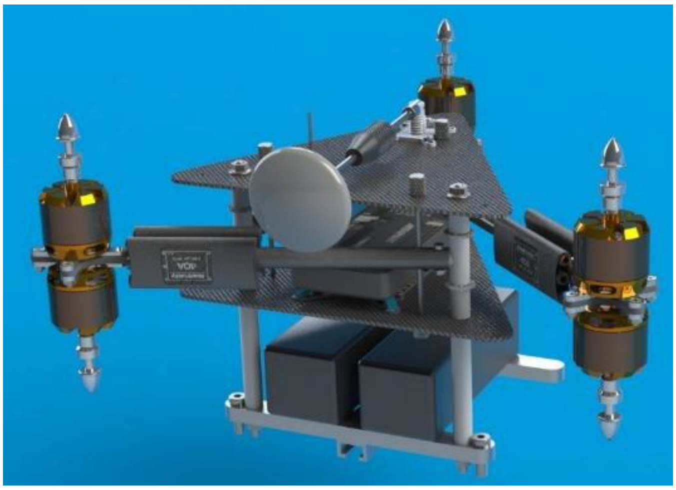


Fig. 2. Drone in folded position.

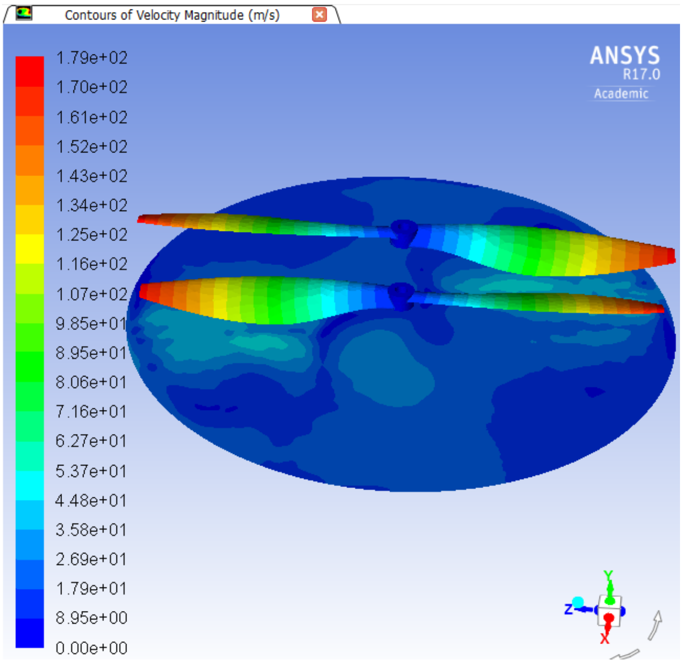


Fig. 3. The measure plan and propellers in ANSYS simulation.

flyers. It is allowed to fly, without a permission, if the drone has a maximum total weight of 5 kg. Nevertheless, an insurance is always required for both private and commercial use. The fly time should be enough for educational exercises and is estimated for 15 minutes. This can be extended with adding battery packs or by reducing the payload.

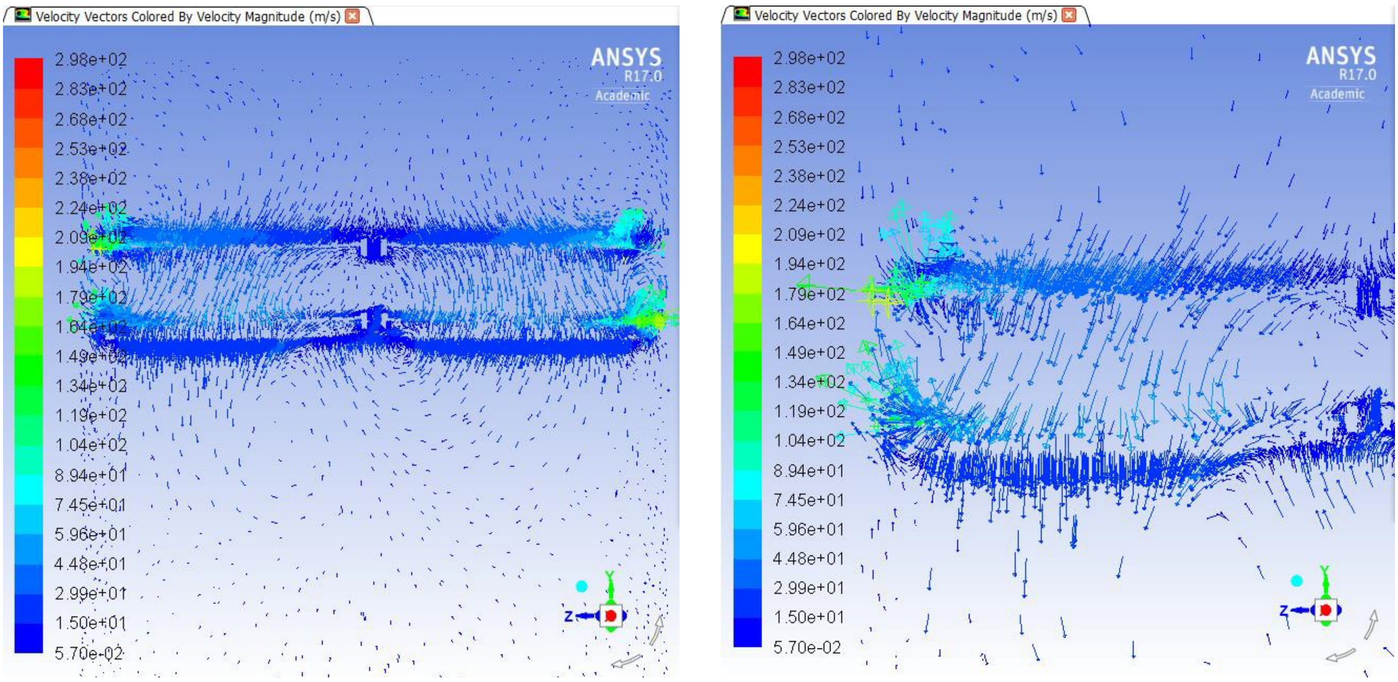
The drone is designed to be folded for storage and transportation purposes. It is transformed into a portable size by removing the legs and propellers and folding the arms and antennas. Fig. 2 represents the drone in a folded condition.

IV. PROPELLER

The propeller of a drone is crucial part of the device which affects the drone's lifting thrust, flight speed, and manoeuvring and flight stability. There are several options for choosing the propellers. For example, a long blade propeller (10-inch diameter or higher) with 2 blades are used for heavy weight drones whereas the smaller blades or those with more than 2 blades are normally used for high speed (racing) drones and are not as efficient as the 2 blades. In order to generate the same thrust a smaller propeller must rotate at a faster speed. The increase in the rotational speed requires higher current for the motors and thus shorter flight durations. In addition, a bigger propeller has the disadvantage of a higher rotational mass and its associated inertia which results in a slower response when manoeuvring during the flight.

The propellers considered in the analysis are shaft driven and directly coupled to each motor drive shaft. The top propeller rotates in an anti-clockwise direction whilst, in order to nullify adverse torque effects, the lower propeller rotates in a clockwise direction. Both propellers are considered to rotate at the same speed. A typical operational cycle involves a take-off at the maximum 100% rpm, hovering at 50% rpm and manoeuvring at rotational speeds between 50 and 100% rpm. For the purpose of the ANSYS CFD simulation a 3D model of the propeller was generated using Solidworks CAD software. The propeller has a 10 inch diameter with a 4.5 inch pitch and is designed to match the form of the Gemfan 1045 plastic multi-copter propeller specification.

The coaxial running blades was simulated in ANSYS to determine the optimal distance between the blades for the maximum thrust generation. Each distance is simulated with two rotational speeds corresponding to 50% and 100% of the motor performance (6,734 rpm and 13,468 rpm). The 3D propeller model was imported into ANSYS, a mesh was



a) b)

Fig. 4. (a) the velocity and air flow (distance between blades is 25 mm; rotational speed is 13,467 rpm); (b) detailed illustration.

generated and the simulation conditions were defined. The air velocity data generated was then used to calculate the propeller thrust performance for various distances between the propellers. The following formula was used for the thrust calculations:

$$Thrust = \frac{\pi}{4} \times D^2 \times \rho \times \Delta v \times v$$

where *Thrust* [N]; *D* is propeller diameter [m]; ρ is density of air [kg/m^3]; Δv is average upper propeller air velocity [m/s]; v is average lower propeller air velocity [m/s].

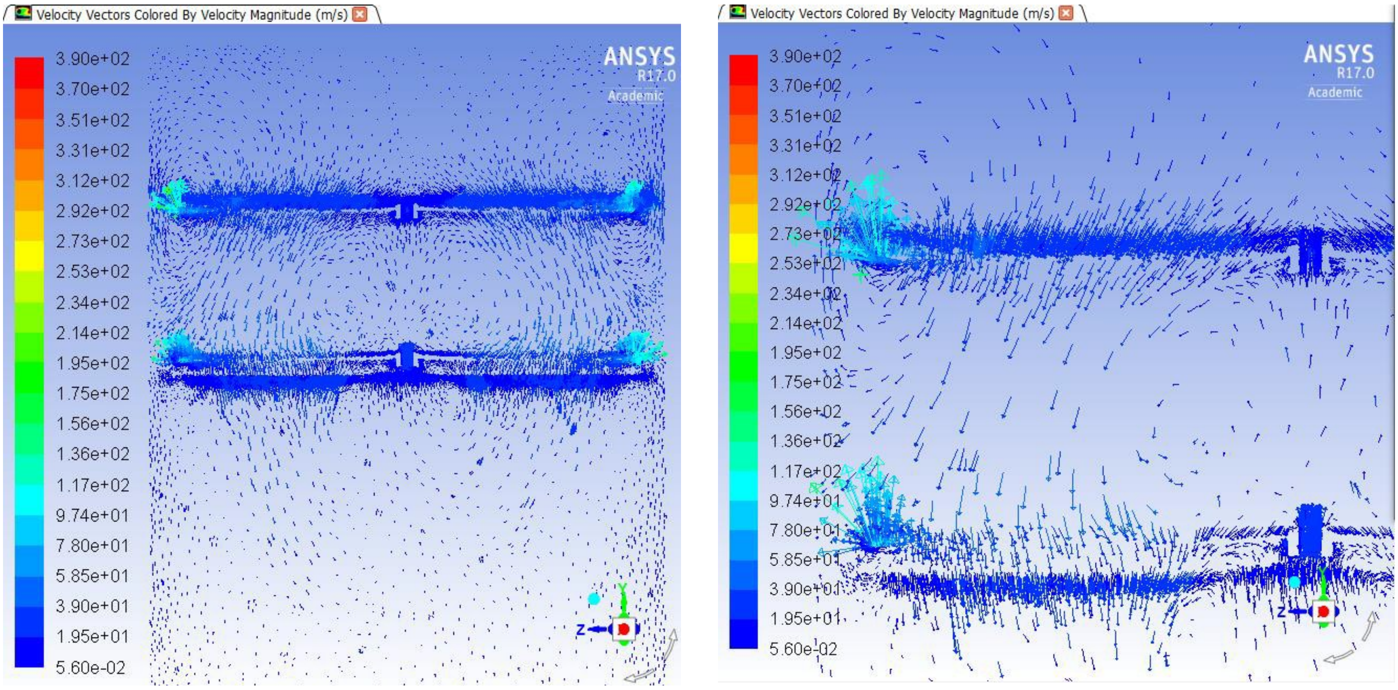
The simulation has been conducted with the upper and lower face and the average velocity of the compared area. Fig. 3 shows the measure plan and propellers applied for the simulation in ANSYS. It has been seen that the highest velocity is generated at the tips of the propellers.

Fig. 4a presents the generated velocity and the flow of air for the rotational speed of 13,467 rpm and distance between blades of 25 mm. Fig. 4b shows the details of the velocity and air flow. It can be seen that a higher velocity occurs at the top and most of the vortexes are generated at the tips of the propeller.

Fig. 5 represents the velocity and air flow with 70 mm distance between the blades. It can be seen that the generated vortexes are greater compared to the 25 mm distance whereas the airflow has less velocity. The result is less thrust generation but higher turbulence in the region between the propellers.

The results of the simulations show that the distance of 25 mm generates the highest lift capacity and should be taken for the design. Fig. 6 represents the results and indicates the optimum distance of 25 mm at which the generated trust is maximum.

Fig. 7 shows the noise generation which is an important parameter for the drone operation due to the nose limitations in certain areas.



a) b)

Fig. 5. (a) the velocity and air flow (distance between blades is 70 mm; rotational speed is 13,467 rpm); (b) detailed illustration.

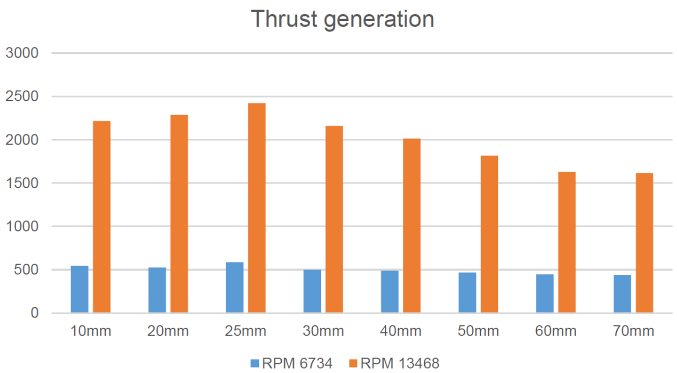


Fig. 6. Trust generation.

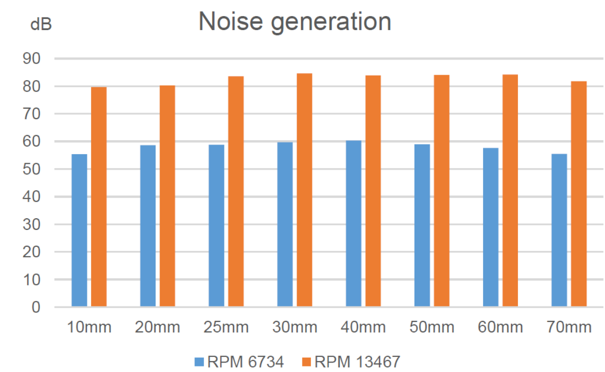


Fig. 7. Nose generation.

TABLE I. THE DRONE SPECIFICATION

Weight	3000 g
Flight time (50%)	12 min
Payload	2000 g
Max rotational speed	13468 rpm
Flight size	495mm×425mm×215mm (without GPS antenna)
Folded size	290mm×264mm×150mm
Cost	About 460€ (without R/C controller and charger)

V. CONCLUSION

The Y6 concept has been chosen for the drone design for educational use where the students can study the principles of construction, operation and control. Due to the three-arm design, the drone can be configured to be portable and light weight and the high thrust of the 6 motors permits high payload performance. The higher number of motors improves the reliability of the drone operation as the drone can still be flown and controlled under a single motor failure. The proposed drone has a high wind stability and 120° angle for observation between the arms which makes it applicable for various areas excluding racing. The drone complies the current German law for non-commercial flying and future regulations from the EASA.

The ANSYS simulation provides an analysis of the optimum distance between the propellers that generates the maximum thrust. In addition, the noise generated by the drone during the operation has been analysed to comply the regulations. The drone specification is shown in Table I. The estimated cost of the device is below 500€. The drone is foldable in order to provide convenience in storage and transportation.

Drone technology is based on a multitude of overlapping technological subject areas and allows the opportunity for engineers to develop in a way that has not previously been amenable or available to most educational establishments. This purpose built educational drone provides a great facility to enable students to learn from a wide variety of differing subject areas.

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