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# CONCEPTUAL DESIGN, MODELLING AND SIMULATION OF A NEW UAV MULTICOPTER

***Abstract:*** *The paper aims to present the design of new models of modular multicopter UAV, where shape and performance are adapted to the current requirements of the profile market, the needs of users, and have a different aesthetic from what currently exists, which ensures good performance at a competitive price. The drone is designed to meet performance requirements such as planned flight duration (hover), system efficiency, maximum load, and maximum flight distance. Flying autonomy increases with drone configuration: a larger number of modules require more motors that allow a higher travel speed, and therefore a greater distance travelled by the drone. The 3D modelling of the drone was obtained using Autodesk Fusion 360 program for three configurations: tricopter, quadcopter and hexacopter.*

***Key words:*** *conceptual design, modular construction, requirements list, drone configuration, 3D modelling, quadcopter, hexacopter.*

## 1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are used both for large-scale commercial purposes and for many applications in various industries. With the growing demand for drones, the UAV market has grown substantially, offering a wide range of choices of such systems.

The main objective of this paper is to design a new modular UAV model, whose shape and performance should be adapted to the current requirements of the profile market and be in close accordance with the needs of users. This requires modelling a prototype in a CAD program.

The drone must be easy to assemble, allow easy replacement of damaged components, and allow a high degree of customization. Finally, the UAV can be used both for recreational purposes and for taking professional photos and videos or transporting small packages.

The research started with UAV components and market, followed by identifying what the user’s needs may be, then choosing the right components, producing the aerodynamic calculations, and ending with the computer design of the final drone.

The general list of UAV parts:

- Frame;
- Motor;
- Propeller;
- Electronic Speed Controller (ESC);
- Batteries;
- Flight controller;
- Radio transmitter/receiver;
- Gimbal.

## 2. USE OF MULTICOPTER UAVs

Recreational use of UAVs is operating drones for personal interests, hobby, and entertainment.

Recreational flying is defined as follows:

- The pilot will not be paid or receive any compensation for the flight;
- The flight may not be performed as a service, paid or unpaid, for any person or organization;
- The flight must be operated within visual limits;
- The flight must comply with a community set of safety guidelines.

The most common uses of recreational drones are:

- Photography and video recording;
- Training flight;
- Speed competitions [1].

The professional use of UAVs involves operating drones to provide various services, for a fee, to consumers.

The most common uses of professional drones are to take specialised photos and videos, usually by individuals or small media companies.

In today's drone market there is a huge diversity, from toy UAVs, designed mainly for children, with small size and capabilities, to semi-professional drones, generally used by adults for recreational purposes, especially for aerial photography and video.

This paper presents the design process of a multicopter with a modular airframe, allowing for easy and low-cost replacement of damaged parts, and its development over time by adding or replacing improved parts and functions. Modularisation of the multicopter will also allow it to be stored in space-constrained areas.

Modular parts will be made of low-cost materials that offer good shock resistance. The components will be designed in such a way that they can also be produced using 3-dimensional (3D) printing technologies.

Modularisation of the multicopter will allow it to use a variety of rotors, which can be assembled using magnets. The drone will thus be able to go from three rotors (tricopter) to four (quadcopter) or six (hexacopter), depending on the user's needs.

The Table 1 identifies the requirements the product is intended to meet.

By identifying the primary characteristics of the product, the technical and economic decisions to be taken later in the design and calculation phase will be based [2], [3].

*Table 1*

**List of requirements**

| **Requirements** | | |
|---|---|---|
| **Mandatory requirements** | **Fulfilling technical functions** | 1. Lifting a maximum mass of 400g.<br>2. Autonomy of 15 minutes. |
| | **Achieving operational safety** | 1. Integration of an automated landing system in case of battery discharge.<br>2. Integration of an automatic return to departure in case of loss of signal. |
| | **Economic feasibility** | 1. Technological design, use of an efficient and safe execution process.<br>2. Means of processing. |
| **Optional requirements** | **Technologies for semi-finished products and final execution** | 1. Allow the use of 3D printing technologies.<br>2. Allow the use of templates and moulds in the production of parts. |
| | **Maintenance requirements** | 1. Visual inspection every time it is used.<br>2. Self-diagnosis before each use. |
| | **Costs** | 1. Production cost efficiency.<br>2. The cost of the final product to be competitive in the market. |
| | **Compliance with ergonomic requirements** | 1. The design to allow replacement of worn/destroyed parts and improvement of the drone over time.<br>2. The design allows for efficient storage. |

## 3. CONSTRUCTIVE STUDY VARIANTS

This paper deals with the design of a modular drone that allows the user to improve and repair it at the lowest possible cost. Therefore, the focus is both on creating a stand-alone module that can fly and take pictures and video, but also on integrating it into a complex drone with a central module to which three, four and six separate modules can be attached respectively.

### 3.1 Load factor

The traction/weight ratio, called the load factor (n = T/G), is the main dynamic characteristic that will determine the flight profile of the drone. To maintain a constant flight, the load factor must be equal to 1 (Figure 1, a). However, in order to take off, the value of the ratio must exceed 1, in order to obtain a vertical acceleration. During flight, the drone's angle of attack (ie the alpha angle in Figure 1, b) causes the traction vector to have vertical and horizontal components [4]. This requires the load factor to be at least 1.3 for a maximum angle of attack of approximately 40 degrees.

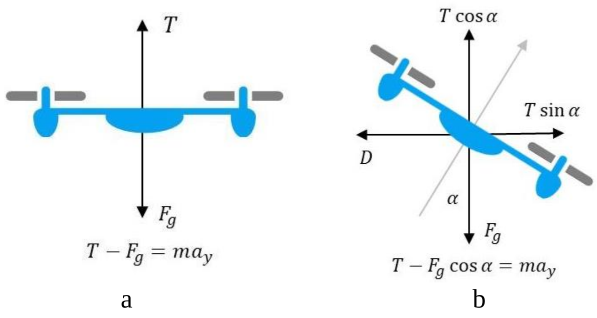


**Figure 1** a-Forces acting on the drone in constant flight; b- Forces acting on the drone during the flight from a certain angle of attack.

The design variants chosen for the study are:

- Independent module;
- Tricopter;
- Quadcopter;
- Hexacopter

### 3.2 Multicopter frame

The material chosen for the drone frame is called Orgasol® Invent Smooth and is a polyamide powder used in powder bed fusion.

Mechanical properties of Orgasol® Invent Smooth:

- Young's modulus: 1.68 GPa;
- Poisson's ratio: 0.4;
- Shear modulus: 600 MPa;
- Density: 0.96 g/cm$^3$.

Strength properties of Orgasol® Invent Smooth:

- Yield strength: 47 MPa;
- Tensile strength: 48 MPa.

Orgasol® Invent Smooth powder is used in Selective Laser Sintering (SLS) to produce complex polyamide parts. Thanks to its unique patented polymerisation process, it has outstanding viscosity stability and an unmatched low refresh rate.

The use of the powder in rapid manufacturing allows excellent contour resolution and surface finish to be achieved due to its unique particle shape and narrow particle size distribution.

Advantages of the powder:

- Very good smooth finish (no further treatment);
- Very low refresh rate;
- Excellent colour stability.

Applications and uses [5]:

- Consumer goods;
- Functional prototypes
- Products for everyday life;
- Various industries;

• Production series.

Powder bed fusion is an additive manufacturing method, also known as Selective Laser Sintering (SLS). SLS uses a high-power laser to sinter small polymer powder particles into a solid structure based on a 3D model.

3D printing with SLS has been a popular choice for engineers and manufacturers for decades. The low cost per part, high productivity and established materials make the technology ideal for a wide range of applications, from rapid prototyping to small batch production or custom components.

Recent advances in machinery, materials and software have made SLS printing accessible to a wider range of companies, allowing more and more manufacturers to use these tools.

The steps for powder bed fusion are:

1. Printing: The powder is dispersed in a thin layer over a platform inside the build chamber. The printer preheats the powder to a temperature slightly below the melting point of the raw material, which facilitates raising the laser temperature in certain regions of the powder bed as it draws the pattern to solidify a part. The laser scans a cross-section of the 3D model, heating the powder to a temperature just below or at the material's melting point. This mechanically fuses the particles together to create a solid part. The unfused powder supports the part during printing and eliminates the need for dedicated support structures. The platen then descends one layer into the build chamber, typically between 50 and 200 microns, and the process is repeated for each layer until the parts are complete.
2. Cooling: After printing, the build chamber must cool slightly inside the print enclosure and then outside the printer to ensure optimal mechanical properties and to avoid part deformation.
3. Post-processing: Finished parts should be removed from the build chamber, separated, and cleaned of excess powder. The powder can be recycled, and the printed parts can be further processed by blasting.

Because the uncoated powder supports the piece during printing, there is no need for dedicated support structures. This makes SLS ideal for complex geometries, including cutouts, thin walls, and negative features.

Parts produced using SLS 3D printing have excellent mechanical characteristics, with similar strength to injection moulded parts [7].

### 3.3 Multicopter motor

The engine chosen for the drone is the NeuMotors 4613/5D [6]. This is a brushless direct current (BLDC) motor with the specifications in Table 2.

Dimensions: 53 mm diameter, 30 mm length, 209 g.

*Table 2*

**NeuMotors 4613/5D specifications**

| Motor | Max Cont. Watts | Max Peak Watts | Max Volts | Max Amps |
|---|---|---|---|---|
| 4613/5D | 1,500 | 3,000 | 21 | 144 |

### 3.4 Multicopter propeller

The propeller used for the drone in this paper is the Aeronaut Cam Carbon Light, with a diameter of 13 inches (33 cm) and a pitch of 5 inches (13 cm). The thread diameter for the motor shaft is 8 mm. The propeller is made of carbon fibre.

### 3.5 Multicopter ESC

The Electronic Speed Controller (ESC) chosen for the drone supports up to 50 amps of current and a mass of up to 65 g.

### 3.6 Multicopter batteries

The batteries chosen have a capacity of 1800 mAh, a 6S configuration, 3.7 V, 25 C and a mass of 27.4 g.

The size of the batteries is 57×29×10 mm (L×W×H).

### 3.7 Flight controller and radio transmitter/receiver

The flight controller remains at the user's discretion. It is ideal to have an integrated GPS.

Both the transmitter and the receiver are at the user's choice.

### 3.8 Gimbal

For the drone in this paper, two types of gimbals were made.

The first type of gimbal is designed specifically for cameras. In addition, an adapter for a GoPro camera has been made.

The second gimbal is a type of a robotic arm, to make it easier to carry parcels and other items, depending on the user's wishes.

Both gimbals are purchased separately and can be attached one at a time to the attachment system on the drone's centrepiece.

## 4. AERODYNAMIC COMPUTATIONS

Computations were made using the online program https://www.ecalc.ch/xcoptercalc.php, for several drone design variants:

• Stand-alone module with control surfaces;
• Independent module with vector propulsion;
• Drone in tricopter configuration;
• Drone in quadcopter configuration;
• Drone in hexacopter configuration.

For the three drone configurations, calculations were performed both without payload (simple configuration), with gimbal and gimbal and camera respectively. In this paper, the camera used is a GoPro.

### 4.1 Independent module with control surfaces

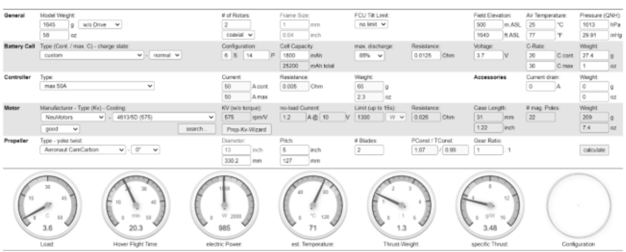

**Figure 2** Results for stand-alone module with control surfaces.

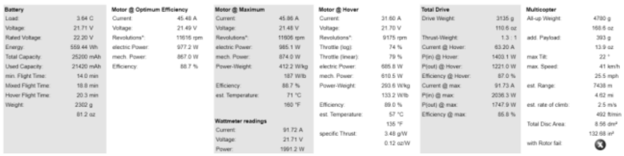

**Figure 2** Results for stand-alone module (continued).

From Figure 2, the glide time is very good, over 20 minutes. The maximum speed is also 41 km/h and the flight distance is over 7 kilometres. The climb speed is 2.5 m/s. Figure 3 shows the autonomy estimation chart for stand-alone module with control surfaces.

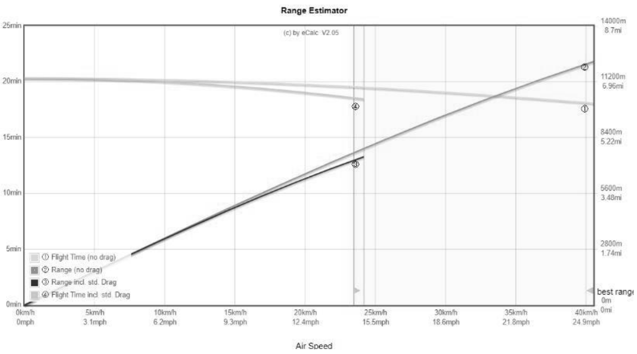


**Figure 3** Autonomy estimation chart for stand-alone module with control surfaces.

From the graph, the time of flight (both with standard friction and without friction) remains relatively constant when the speed of travel does not exceed 10 km/h. Above this speed, the flight time decreases progressively, but not below 17 minutes.

Range (both with standard friction and without friction) increases directly in proportion to flight speed. Thus, at a speed of 25 km/h, a range of over 7000 metres is achieved, if drag is considered.

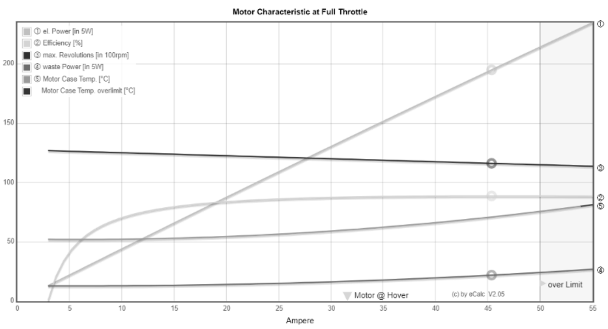


**Figure 4** Graph of engine characteristics at maximum speed for independent module with control surfaces.

From the graph above, the electrical power of the motor increases directly proportional to the current intensity (Figure 4).

The motor efficiency increases in direct proportion to the amperage up to about 7 A and then remains relatively constant until the operating limit is reached. The optimum efficiency is about 88%.

Motor speed decreases quite slightly relative to increasing current.

The electrical power lost through the motor increases very little with increasing amperage.

The temperature of the enclosure remains approximately constant until 15 A is reached, then gradually increases. Above 53 A, the operating limit of the motor is exceeded (above 70°C).

### 4.2 Independent module with vectorial propulsion

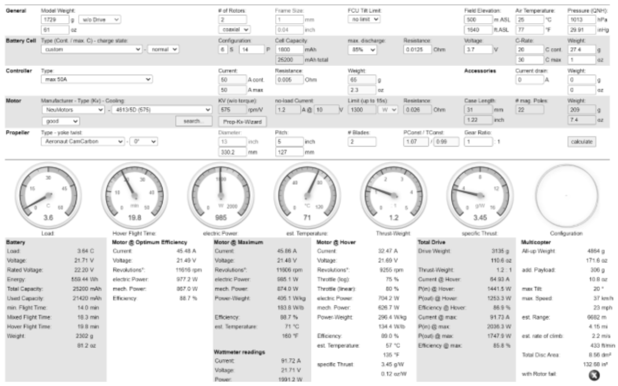

**Figure 5** Results for the independent module with vectorial propulsion.

From Figure 6, the glide time is very good, almost 20 minutes. The maximum speed is also 37 km/h and the flight distance is over 6.5 kilometres. The climb speed is 2.2 m/s.

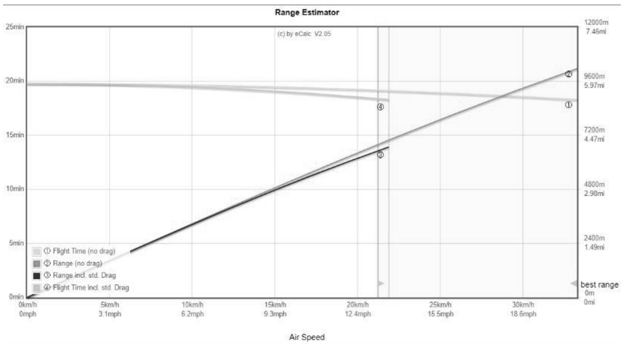


**Figure 6** Autonomy estimation chart for the independent module with vectorial propulsion.

From the graph, the time of flight (both with standard friction and without friction) remains relatively constant when the speed of travel does not exceed 10 km/h. Above this speed, the flight time decreases progressively, but not below 17 minutes.

Range (both with standard friction and without friction) increases directly in proportion to flight speed. Thus, at a speed of 22 km/h, a range of over 6500 metres is achieved, if drag is considered.

From the graph below, the electrical power of the motor increases in direct proportion to the current intensity.

The motor efficiency increases directly proportional to the amperage up to about 7 A and then remains relatively constant until the operating limit is reached. Optimum efficiency is about 88%.

Motor speed decreases quite slightly relative to increasing current.

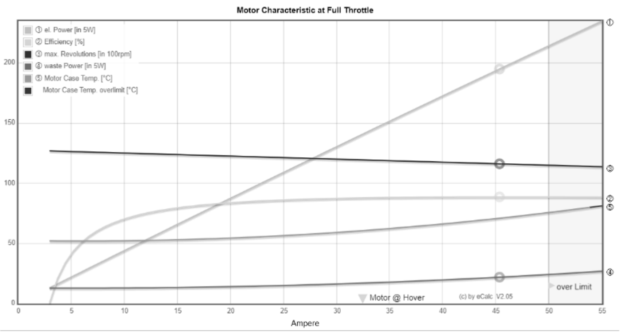


**Figure 7** Graph of engine characteristics at maximum speed for the independent module with vectorial propulsion.

The electrical power lost through the motor increases very little with increasing amperage.

The temperature of the enclosure remains approximately constant until 15 A is reached, then gradually increases. Above 53 A, the operating limit of the motor is exceeded (above 70°C).

Comparing the two solutions for the stand-alone module, the module using the control surfaces performs better. It is also easier to manufacture and repair over the lifetime of the drone, being a simpler and cheaper system.

### 4.3 Specifications according to configurations

Table 3 gives the flight time for the three variants.

*Table 3*

**Flight time for the three configurations**

| | Tricopter | Quadcopter | Hexacopter |
|---|---|---|---|
| Simple | 18 min | 18.7 min | 19.5 min |
| With gimbal | 17.5 min | 18.4 min | 19.2 min |
| With gimbal and camera | 17.1 min | 18.1 min | 19 min |
| With transport system | 17.6 min | 18.4 min | 19.3 min |

An increase in flight time is observed with the use of a larger number of modules, as this allows more batteries to be added to the central module.

*Table 4*

**Additional payload for the three configurations**

| | Tricopter | Quadcopter | Hexacopter |
|---|---|---|---|
| Simple | 658 g | 925 g | 1285 g |
| With gimbal | 636 g | 905 g | 1267 g |
| With gimbal and camera | 659 g | 930 g | 1294 g |
| With transport system | 664 g | 932 g | 1295 g |

Transport capacity improves as the number of modules used in the drone increases. In the hexacopter, the additional payload is almost double that of the tricopter. This is possible due to the higher number of motors (Table 4).

When calculating the additional load for the gimbal, this value reflects the maximum mass of a camera that the drone can lift.

For the case of the transport system, the drone can carry small packages not exceeding 1295 g (for the maximum hexacopter configuration).

*Table 5*

**Flight range for the three configurations**

| | Tricopter | Quadcopter | Hexacopter |
|---|---|---|---|
| Simple | 4865m | 5058m | 5284m |
| With gimbal | 4738m | 4963m | 5221m |
| With gimbal and camera | 4626m | 4879m | 5166m |
| With transport system | 4747m | 4970m | 5226m |

Flight range also increases as the drone configuration changes. More modules mean more motors, which allows more batteries to be used and a higher travel speed, thus increasing the distance the drone can fly (Table 5).

It is also clear that the specifications improve with each module added to the drone. Thus, the hexacopter configuration has a longer flight time, range, and additional payload than the quadcopter, which in turn exceeds the specifications achieved by the three-module configuration.

## 5. 3D MODELLING OF THE DRONE

The CAD modelling of the drone was done in Autodesk Fusion 360. The construction of the drone started with the construction of the stand-alone module. To fly, it needs two propellers and two motors respectively, mounted coaxially to cancel the momentum.

The module's casing must also allow the insertion of batteries, ESCs, flight controller and radio receiver. All of these have been chosen so that they can be easily incorporated into the housing. ESCs can also be mounted on the circular arms connecting the motor to the outside of the housing (Figure 8). However, the two propellers with motors are not enough to guide the drone.

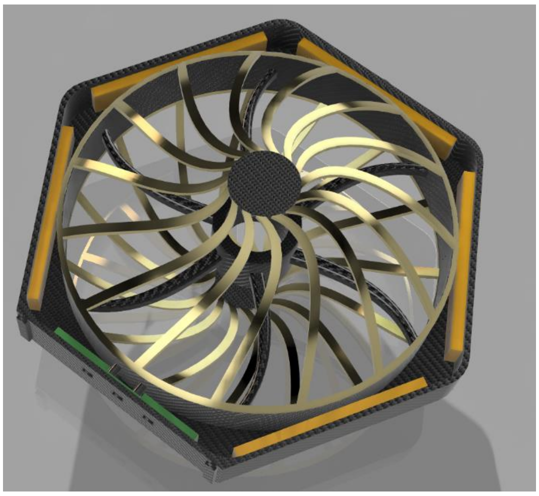

**Figure 8** Module incorporating the batteries (in orange), the ESCs (in green), radio receiver and flight controller.

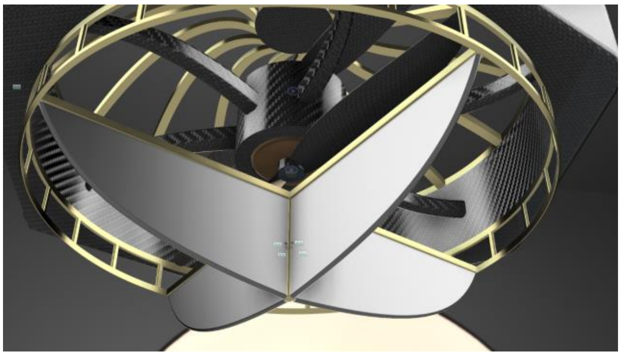

**Figure 9** Control surfaces (flaps)

Coaxial multicopters have two counter-rotating motors and two or even four individual flaps (4 individual servo motors/wingers can be used, but the fins on opposite sides of the vehicle will move together) to provide roll, yaw, and pitch motion (Figure 9).

The yaw motion of the drone is controlled by adjusting the speeds of the two motors. For example, accelerating the motor clockwise while decelerating the motor counter clockwise will cause the vehicle to spin counter clockwise.

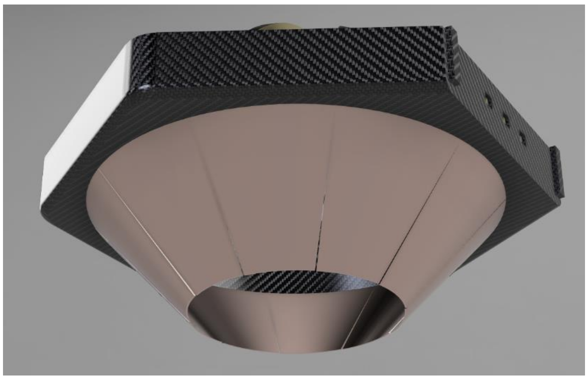

**Figure 10** Independent module with vector traction.

Another solution is vector traction. This is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of thrust of the engine(s) to control the attitude or angular velocity of the vehicle (Figure 10).

In this case, the specific shape of an aircraft's engine exhaust nozzle has been taken, which will allow for the roll, yaw, and pitch movements of the drone.

The module also features a camera (Figure 11), which allows photos and videos to be taken and sent to the user.

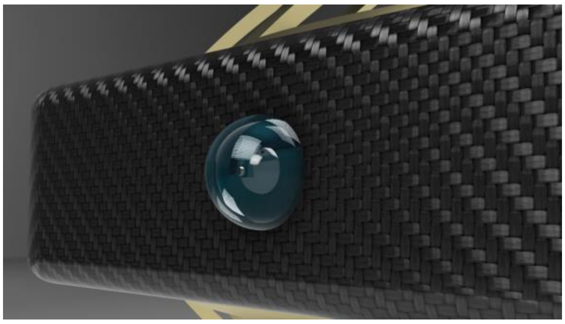

**Figure 11** Camera on independent module.

When attaching the drone to the central module, the cameras function as a collision avoidance system, with the user able to attach their own camera to the drone's gimbal (Figure 12).

The lower part of the module can be detached and replaced with a protective cover identical to the upper part. This, together with strong magnets integrated on one edge of the hexagonal housing, allows the module to be connected to a centrepiece (Figure 14).

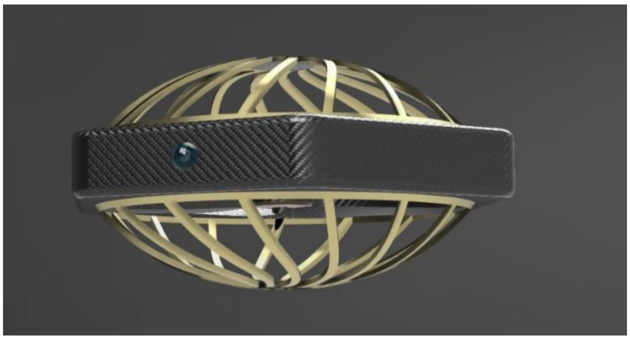

**Figure 12** Modified module for connection to the central module.

This shape allows the propellers and motors to be protected in the event of damage to the drone, and the protective covers can be easily replaced by the user at low cost.

The modules are hexagonal in shape because its symmetry allows several modules to be easily connected to a central body, resulting in a drone with better capabilities (Figure 13).

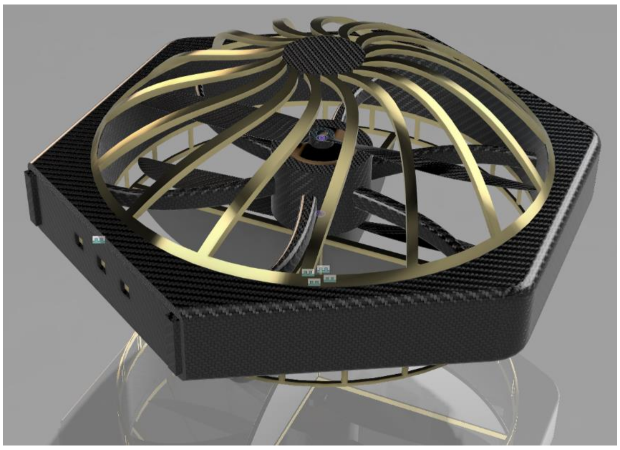

**Figure 13** Fully equipped independent module.

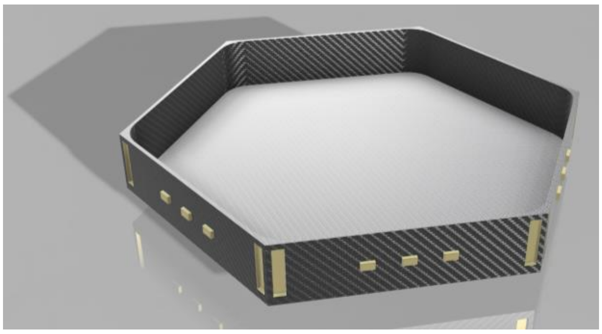

**Figure 14** Magnets on the central module.

The core module allows the addition of up to 85 batteries inside, which will improve the drone's performance in all three configurations.

At the bottom of the centre module, there is a tether system, to which a camera gimbal or transport system can be attached (Figure 15).

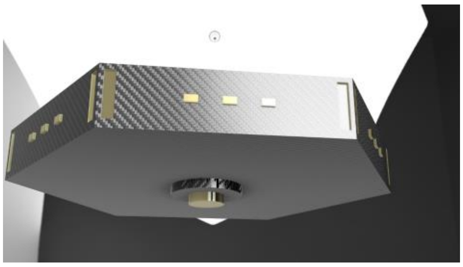

**Figure 15** Central module clamping system.

The landing gear is also on the central module (Figure 16).

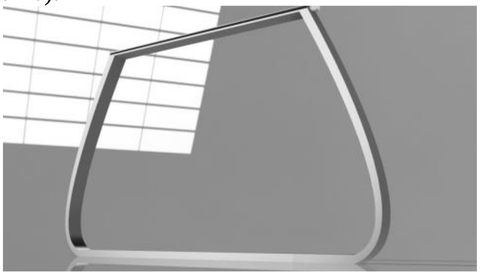

**Figure 16** Landing gear.

The gimbal system for attaching a camera was also developed (Figure 17), as well as an adaptor for a GoPro camera, which allows mounting it on the gimbal system (Figure 18).

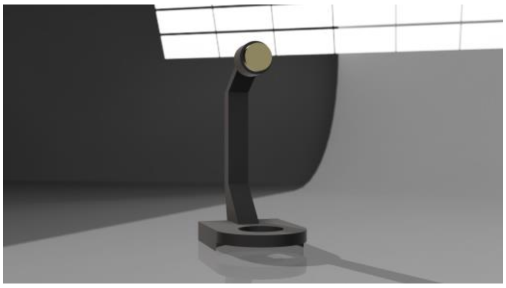

**Figure 17** Gimbal fixing system.

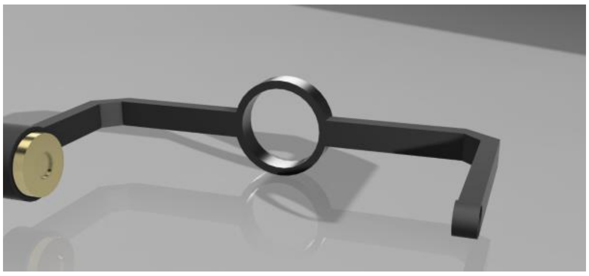

**Figure 18** Camera fixing system

A transport system for small parcels has also been developed (Figure 19).

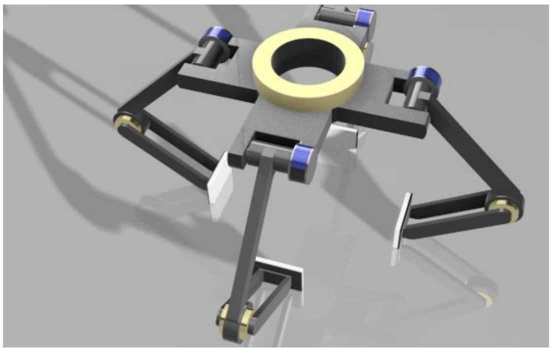

**Figure 19** Transport system

Figure 20 shows a fully equipped quadcopter and Figure 21 shows a hexacopter with a transport system.

**Figure 20** Landing gear, gimbal mounting system with GoPro camera, in quadcopter configuration.

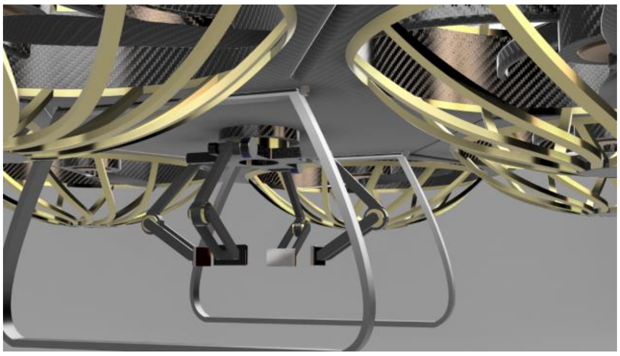

**Figure 21** Hexacopter configuration with transport system for small parcels.

Figures 22, 23 and 24 show the different configurations of the drone.

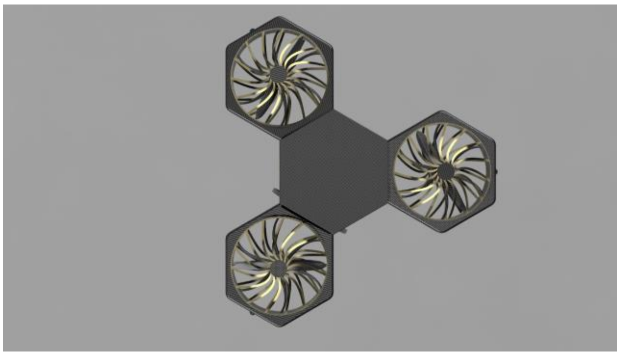

**Figure 22** Drone in tricopter configuration.

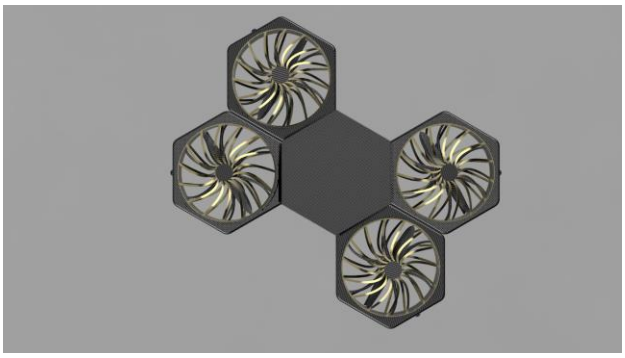

**Figure 23** Drone in quadcopter configuration.

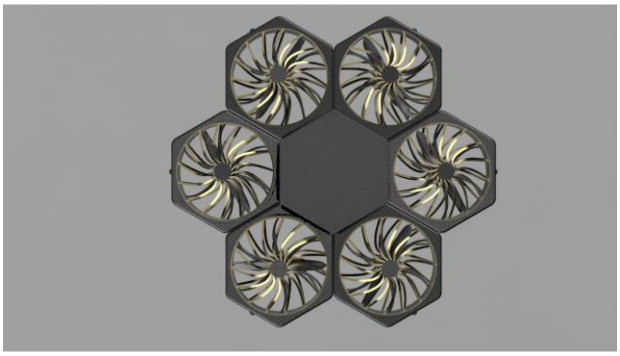

**Figure 24** Drone in hexacopter configuration.

## 6. CONCLUSIONS

To conclude this paper, it can be noted that the objectives have been achieved:

- The stand-alone module can be used by UAV enthusiasts; the components can be easily replaced in case they get damaged in crashes; also photos and videos can be taken with the built-in camera;
- For professional use, three, four or six independent modules can be connected to a central module, which will allow the transport of a gimbal and the attachment of a professional camera;
- In the transport industry, the drone could be used in tricopter, quadcopter or hexacopter configuration to transport small parcels.

Moreover, as the drone's housing is made by SLS, this allows parts to be replaced easily and cheaply, as these repairs can be carried out by the user without the need to call a specialised repair centre.

In the end, the important points of the list of requirements were achieved:

- Depending on the configuration of the drone, it can lift larger masses for a longer period of time;
- The average autonomy is 18 minutes;
- The drone allows the integration of sensors and systems to ensure safe operation;
- The housing is made by an additive manufacturing process;
- The design allows both easy replacement of worn parts and efficient storage of the drone due to the symmetrical shape of the module housings.

Given the features presented, but also the low costs of acquisition, operation and maintenance, the new UAV multicopter designed in this paper has achieved all the proposed objectives.

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