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HYBRID MULTICOPTER DESIGNS

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Abstract

Hybrid unmanned aerial vehicles are vehicles that employ more than one type of energy delivery system for powered flight. Hybrid drones are not restricted to using electrical power. Nevertheless, most such drones employ electric propulsion by implementing brushless three-phase electrical motors in their rotors due to the inherent high efficiency and ease of control of such devices.

Electrical energy for the motors is supplied by various sources such as batteries, hydrogen fuel cells, internal combustion engine electrical generators, etc. The current battery technology offers flight times from 10 minutes to 2 hours, depending on the payload and drone design. For longer flight times, a hybrid power system is required. The common hybrid drone design involves a combination of batteries and an internal combustion engine electrical generator.

The current article introduces two novel hybrid unmanned aerial vehicle designs. The first exhibits improved efficiency due to the implementation of a hybrid power system powering two horizontal tandem counter-rotating direct driven rotors and at least four electrically driven smaller horizontal attitude control rotors. The second presented herein invention offers the addition of a horizontal rotor or rotors, rendering the design a compound multicopter. The vertical rotor or rotors are also direct driven improving efficiency.

Introduction

Hybrid unmanned aerial vehicles (UAVs) are drones that utilize more than a single type of energy delivery system to enable the powered flight of the vehicle.

Although hybrid UAVs are not limited to electrical propulsion systems, most such vehicles rely solely on electric propulsion based on brushless three-phase electric motors. Brushless electric motors exhibit high efficiency and are easy to control.

The electrical energy supply for the motors is delivered from different sources such as batteries, hydrogen fuel cells, internal combustion engine electrical generators, etc. The current battery technology, most commonly used, is Li-ion or Li-poly batteries, securing energy densities in the range of 200–250 Wh/kg and flight times from 10 minutes to 2 hours, depending on the payload and drone design.

The most common hybrid drone combines batteries with an internal combustion engine generator [1–3]. The second most common variant employs a hydrogen fuel cell [4–5].

Internal combustion engine-based generators are cheaper in comparison with hydrogen fuel cells. Hence, these are implemented in the overwhelming number of hybrid drone cases. Two-stroke and four-stroke engines are common in such scenarios, although the four-stroke solutions are heavier. Despite their higher energy efficiency, they offer shorter flight times than the two-stroke designs. By running the internal combustion engine, the coupled electrical generator produces electrical energy that powers the electrical motors. The excess electrical energy produced by the generator is stored in a buffer on-board battery. During power surges, high currents are drawn from the battery. The latter is also employed in cases of emergency when the generator of the internal combustion engine fails.

It should be mentioned that besides hybrid unmanned aerial vehicles, land and sea-based drones powered by hybrid power supplies exist [6].

The current article introduces novel hybrid unmanned aerial vehicles employing improved efficiency due to not only a hybrid power system but also a hybrid propulsion system.

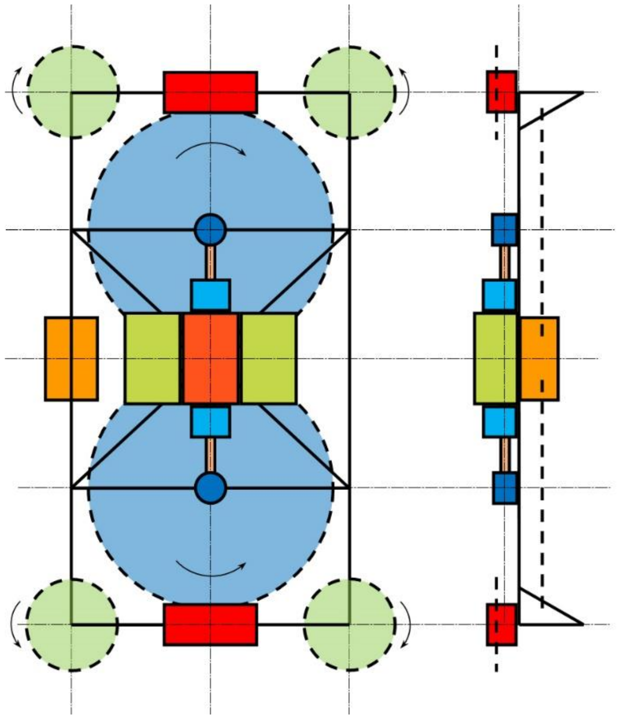

Fig. 1. Double-hybrid unmanned aerial vehicle, model XZ-15

Double-hybrid UAVs

A hybrid drone has many power sources and a single propulsion, namely brushless electrical motors. A double-hybrid adds a multitude of propulsion systems. The current material introduces two novel hybrid drone designs offering not only hybrid power sources but also hybrid propeller propulsion systems involving both propellers driven by brushless electrical motors and direct drive propellers. The efficiency of the power output of the directly driven propellers is significantly higher than that of the electrical motors coupled propellers due to the lack of power conversion through generators and motors, but their controllability is poor. On the other hand, the control of the brushless electrical motors is superior. By combining both types of propulsion and implementing the brushless electrical motor-driven propellers only for attitude control of the drone, we achieve higher flight efficiency, which translates into longer flight times, heavier payloads, longer ranges, etc.

Herein, we present two innovations: a hybrid multicopter having a tandem of direct-driven rotors and four electrically driven rotors [7] (see Fig. 1). The second invention is a similar design but with added vertical rotors for high-speed flight, thus creating the so-called compound multirotor [8] (see Fig. 2).

Double-hybrid hexa-rotor

The double-hybrid design shown in Fig. 1 is the model XZ-15 of the XZ unmanned aerial vehicle series developed at the Space Research and Technology Institute – Bulgarian Academy of Sciences in 2019. The model is a hexa-rotor multicopter having two major rotors positioned in the middle of the fuselage in counter-rotating co-planar tandem and four smaller rotors mounted at the airframe's corners. The large centre rotors are driven directly by the on-board internal combustion engine. This engine may be any type, but for higher efficiency, a two-stroke diesel engine or a four-stroke petrol variant may be employed. The XZ-15 UAV may be used for camera observations, remote sensing, cargo delivery, etc.

Another innovation is the positioning of the two large rotors, which are mounted under the fuselage, thus ensuring higher flight efficiency. This higher efficiency is due to unobstructed by the fuselage's high-speed airflow accelerated by the two major rotors. The two major rotors create the majority of the lift. They employ fixed-pitch propellers for simplicity, reliability, and weight savings and thus are unable to offer attitude control. The latter is secured by adding a minimum of four electrically driven rotors (in Fig. 1, there are four additional rotors). These electrically driven rotors are powered by the hybrid drone's power system. An electrical generator is coupled to the internal combustion engine and generates electrical power. The electrically driven rotors, using brushless three-phase motors, offer fast response and appropriate attitude control of the aerial vehicle.

Earlier inventions of double-hybrid UAVs do exist, such as the hybrid unmanned aerial vehicle having a single major rotor directly driven by an internal combustion engine and an additional four smaller electrically driven rotors [9]. This design is inferior to XZ-15 due to the implementation of a single major rotor instead of a counter-rotating tandem of rotors. This configuration offers lower efficiency. Another drawback of the previous designs is the standard mounting of the rotors over the fuselage, which yields lower efficiency.

Another earlier invention of a hybrid power plant for UAVs is presented in [10], where the concrete drone design is not disclosed.

The major drawback of previous designs is the lower efficiency due to the mounting of rotors over the airframe. Such an approach predisposes the high-speed rotor airflow to create drag in a downward direction when meeting the fuselage. Thus, the drone exhibits increased dynamic pressure, and consequently, higher power is required to sustain flight. A number of drawbacks follow, such as shorter range and flight times, less payload weight available, etc. The previous design's single major rotor approach creates a reactive moment that needs to be counteracted by the smaller electrically driven rotors, but their efficiency is much lower; thus, power is wasted. The tandem counter-rotating design creates virtually no reactive moment in the vertical axis.

XZ-15 (Fig. 1) is based on a rectangular airframe constructed in the horizontal plane. All rotors are horizontal. The major tandem rotors are directly driven through shafts from the internal combustion engine. The latter also drives two electrical generators. Two generators are proposed, instead of one, for redundancy and reliability. The generators provide electrical power for the four corner-mounted rotors and also to charge a buffer secondary battery. The drone also carries a payload.

Double-hybrid compound multicopter

In Fig. 2 is presented the double-hybrid compound multicopter design XZ-15C of the XZ unmanned aerial vehicle series. This model was developed in 2023 again at Space Research and Technology Institute – Bulgarian Academy of Sciences. The model is a septa-rotor multicopter design that differs from the XZ-15 in that it only has an additional seventh vertical rotor mounted at the tail of the fuselage. This additional rotor is directly driven from the internal combustion engine through a shaft and a clutch. The benefit of mounting vertical rotors in multicopters is that such multicopters achieve higher horizontal speeds. This type of multicopters is called compound multicopters. Another benefit is that the efficiency of horizontal flight increases due to lower aerodynamic drag of the fuselage and increased efficiency of the production of horizontal aerodynamic propulsion forces.

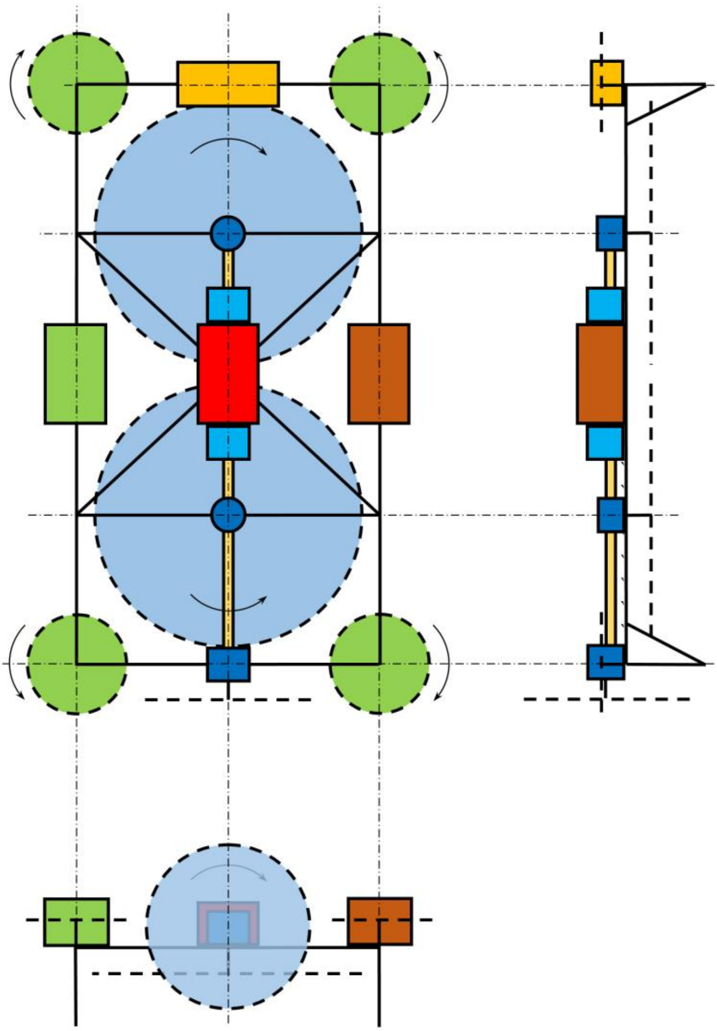

Fig. 2. Double-hybrid compound unmanned aerial vehicle XZ-15C

Conclusions

The introduction of directly driven tandem horizontal rotors in hybrid multicopters increases the efficiency of flight and thus prolongs flight time, extends range, and makes possible the transport of larger and heavier payloads. Further, by implementing vertical directly driven rotors in hybrid multicopters established the class of hybrid compound multicopters exhibiting superior performance to any other hybrid multicopter in terms of horizontal speed and efficiency of the horizontal flight.

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КОНСТРУКЦИИ НА ХИБРИДНИ МУЛТИКОПТЕРИ

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Резюме

Хибридните безпилотни летателни апарати използват повече от един вид източници на мощност за осигуряване на полета. Хибридните дронове не са ограничени до използване само на електрическа мощност. Въпреки това повечето такива дронове разчитат на електрическа енергия и безколекторни трифазни електродвигатели за задвижване на роторите, поради високия коефициент на полезно действие на този вид двигатели и не сложното им управление. Електрическа мощност за задвижване на моторите се предоставя

от разнообразни източници като батерии, водородни горивни клетки, двигатели с вътрешно горене, свързани с електрически генератори и др. Текущите технологии на електрически мултикоптери предлагат полетно време от 10 минути до 2 часа, в зависимост от дизайна на летателния апарат. За постигане на по-дълго полетно време се налага използването на хибридна енергийна система. Стандартният дизайн на хибриден дрон включва двигател с вътрешно горене, задвижващ електрически генератор.

Настоящата статия представя два иновативни хибридни мултикоптера. Първото изобретение гарантира подобрен коефициент на полезно действие поради използване на хибридна енергийна система и два хоризонтални ротора, въртящи се в противоположни посоки и задвижвани директно от двигателя с вътрешно горене. Управлението на полета се извършва от най-малко четири допълнителни ротора, задвижвани от електродвигатели. Второто изобретение предлага допълнителен вертикален ротор и така превръща конструкцията в хибриден съставен мултикоптер. Вертикалният ротор е също директно задвижван от двигателя с вътрешно горене.