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Short study of unmanned cargo multicopters with simulation

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Abstract

In this article, we study new trend of how cargo air vehicles (CAV) are becoming general usage in military to carry different materials. They have some benefits when compared against traditional helicopters and airplanes as example they are cheap and versatile. They can be used to transport medical, food and ammunition supplies to military personnel without loss of life and with a very little maintenance capacity.

We will present general structure of multicopters and we will show different solutions to unmanned transport that have been developed in different countries for military usage.

Lastly we will present a simulation model for CAV, that can be used to estimate how long time it will take to deliver any amount of cargo with any number of CAVs. Usage is very simple all is needed is user to set CAV parameters to our system.

Keywords: cargo, UAV, CAV, military, simulation

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1. Introduction

The use of unmanned multicopters and airplanes in civil aviation as well as military aviation has become widespread in recent years. Unmanned aerial vehicles are widely used in search, imaging and surveillance missions. The reasons for their use are their ease of use, relative affordability, portability, low operating costs, and easy versatility. [1]

We focus on exploring the use of unmanned aircraft in freight transport, a rapidly growing trend many international players have been developing their own concepts for this purpose for recent years.

In Chapter 2, we introduce the main technology used in multicopters. In Chapter 3, we review some unmanned CAV solutions for military use for freight transportation. Chapter 4 introduces a simple simulator that models the CAVs load carrying time with respect to load weight. In Chapter 5, we will state the concluding remarks and future of CAVs.

2. Multicopter structure

This chapter discusses the technology of VTOL-capable CAVs. Aircraft capable of vertical take-off and landing are mainly multicopters, ie they have more than two rotors to produce the lifting power required by the equipment. The engines can be built to be pivotable, whereby a joint is formed between the fuselage and the engine, which allows the thrust to be pivoted in the direction required by the flight mode. The structure of the multicopter consists of the following units: fuselage and landing gear, propulsion system and steering system. The propulsion system comprises a motor, a battery and rotors. The control system includes a radio transmitter and receiver, a GPS receiver and the required ground station. The autopilot is also part of the control system. [2, pp.33]

2.1. Frame structure and materials

A multicopter is built around the fuselage. The frame consists of landing gear and the frame itself. The main function of the fuselage is to receive the stresses on the multicopter. The shape of the body and its structure generally define the type of use for which it is designed. When choosing a frame structure, the design must take into account the structure's safety, durability, usability and, above all, performance. A well-designed multicopter is based on a correctly chosen size, shape and the fuselage material itself. The choice of frame material must take into account the intended use, as well as the weight and durability of the selected material. Fig. 1 [3] shows the most common configurations of multicopters. The configuration chosen also affects the size of the multicopter, i.e. the diameter. The diameter is usually measured between the shafts of the outermost motors. The larger the diameter, the greater the lifting force and the payload. [2, pp.33-36]

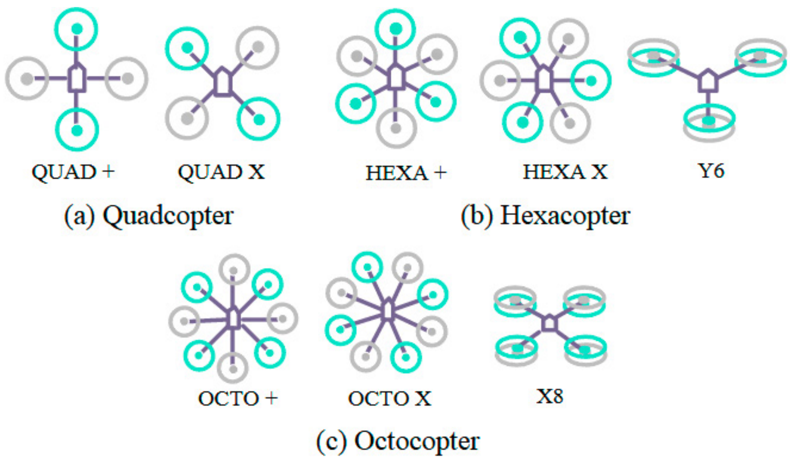

Fig. 1. Some basic configurations of multicopters [3].

2.2. Engines and propulsion system

The propulsion system consists of rotors, motor, battery and ESC (Electronic Speed Controller). This system is the main subsystem of the multicopter that determines its performance. Performance includes flight time, payload, flight speed, and distance traveled. All components of this subsystem must be compatible with each other. [2, pp.57]

The control of multicopters is based on the control of the rotational speeds of the rotors, whereby the size of the propeller is directly related to the maneuverability of the multicopter. As the size of the blades increases, their moment of inertia also increases, resulting in a slower steering response of the multicopter as a result of the greater moment of inertia. Possible materials for the propellers are carbon fiber, plastic and wood. In general, the aim is to use carbon fiber because of its good properties. Although carbon fiber propellers are expensive compared to plastic, the benefits are relatively large. Carbon fiber propellers are used because they are quieter and more rigid. The carbon fiber propeller does not generate as much vibration because it is lighter and more durable than other materials. [2, pp. 38-39] Fig. 1 shows the direction of rotation of the motors in different colors. When an even number of motors is selected, half of the rotors can rotate in the other direction, thus reversing the torque caused by the motors.

2.3. Communication and control system

Multicopters are controlled via a radio controller, with the most common frequency being 2.4 GHz. The movements commanded from the radio controller are transmitted to a multicopter receiver, which decrypts the transmission and transmits the control command to the flight control circuit. This transmits the command to the speed controllers and further to the motors. Eventually, the multicopter moves according to the desired command. The 2.4 GHz frequency has been selected for use because the frequency does not have as much interference and has low power consumption, and due to the short wavelength, the antennas can be short. In addition, the frequency has been found to be fast and accurate. There are also some disadvantages, as the control signal does not pass through obstacles such as hills and buildings. A multicopter works best in direct line of sight. However, this challenge can be eliminated by increasing the transmission power of the radio controller. At least four channels are required to control the multicopter so that the aircraft can fly in all directions. In general, there are also accessories, such as a camera, which takes one of the four channels, in which case a transmitter with more than four channels, for example eight channels, is involved. [2, pp.47-49]

The autopilot is also part of the control system and its features include that the multicopter can fly a pre-planned route without control commands. The autopilot may be completely self-contained or may require some action from the pilot, such as take-off and landing. The autopilot is built from both software and the hardware itself. The software component acts as the brain of a multicopter, whose job is to process the information sent and received. The equipment consists of the following components: GPS receiver (Global Positioning System), inertial measurement unit (IMU), altitude sensor and control computer. The GPS receiver receives the location information of the multicopter. The IMU measures the flight of the aircraft along three axes and strives to keep the aircraft straight. The accelerometer measures the advancement of the multicopter and the gyroscope position information. The altimeter operates either ultrasonically or barometrically. The control computer is responsible for transmitting messages between the systems and instructing the control signal. [2, pp.50]

2.4. Assistive sensors

Especially in an urban area where buildings are interfering with the propagation of the GPS signal, it is important that the multicopter does not collide with obstacles in front of it. Buildings cause multipath propagation into the GPS signal, which degrades the location information of the multicopter. [4] Trees and different terrain are also a problem when a multicopter lands. For this reason, auxiliary sensors have had to be added to the multicopters to avoid collisions.

One of the most commonly used sensors is the ultrasonic sensor. Ultrasound, is sound that is above the human hearing range, i.e., above 20 kHz. The purpose of the ultrasonic sensor is to measure the distance to obstacles or the ground in the vicinity of the multicopter. [2, pp.157] The weakness of an ultrasonic sensor is that it can only measure distances at close range. In addition, ultrasound from a soft object is not reflected properly. If the object to be measured is not perpendicular to the sensor, the sound may not be reflected back to the receiver. [2, pp.157]

Many methods can be used to measure height. This is possible with, among other things, a GPS signal, a barometer, ultrasound and a laser. The operating principle of the barometer is simple and does not depend on electronics. The barometer measures the difference in air pressure. In order for the measurement to be reliable, a known ground air pressure must be set in the barometer. A barometer is a good backup system if other altitude measurement systems are out of order.

Utilizing a laser as a multicopter sensor is also really common. It is accurate and the principle of operation simple. The laser beam is sent from the multicopter as a pulse. When a beam hits an object, such as the ground, radiation from the ground is reflected back to the receiver in the multicopter. The method is commonly referred to as ToF (Time of Flight). The time of the beam from the transmitter to the target and back to the receiver can be measured and this is used to calculate the distance to the target with the formula: $S = (ct)/2$, where S is the distance, c is the speed of light and t is the round trip time. The laser can also be transmitted as a continuous signal, in which case the laser beam is transmitted modulated in phase difference. From the radius returning to the receiver, the changed phase is measured and the distance to the object is calculated. However, this method is more complex than the ToF method and requires more signal processing. [5]

3. Unmanned delivery of cargo in military

In addition to commercial CAV operations, the armies of different countries have also developed their own CAV systems. On the military side, too, development has been rapid and has only taken place in recent years. Back in 2011, a study conducted for the U.S. military found that transporting goods through CAV is not cost-effective. At the same time, it is stated that the greatest benefit of UAVs in the field of logistics will be in transport control and guarding. The study saw the benefits of UAVs in particular as protection for convoys when goods are moved from one base to another. The UAV can be used to investigate the route in the event of a possible IED (Improvised Explosive Device) or other threat. The study concludes that a UAV is more useful as a platform for a camera or other sensor than for transporting goods. [6]

By the 2020s, however, research [6] has become obsolete and technological solutions have evolved. This has also enabled the development of the CAV for the armed forces of different countries. In the early years of UAV enthusiasm, military operators have focused on developing for themselves surveillance, guarding and reconnaissance capabilities. The focus has been on leveraging new UAV technology and cameras. Once initial interest has waned, there will be time for various government actors to develop and design other applications for the UAV. The military development of CAVs has taken first Steps in the very last few years, and at the time of this study, no military CAV system is yet in place. Next, we discuss the concepts that have been developed by different countries.

3.1. USA

According to an analysis released in April 2019, the motive of the U.S. Army for the development of the CAV is that they do not want to carry equipment on a front-line manned aircraft such as a helicopter. The fear is that the aircraft will be shut down and thus lose an expensive helicopter, as well as a long-trained pilot. The experience of the U.S. ground forces in Afghanistan shows that the CAV could be a solution to support front-line fighting forces. The idea of the U.S. Army is to facilitate equipment deliveries and develop CAV operations similar to those planned by Amazon [7] and DHL [8]. The troops on the front line would order the products they need and delivery would be fast and flexible. The troops fighting on the front line have a huge amount of equipment to carry on with them, which impairs the mobility of the troops. If some of this equipment could be transported to the site only when necessary, the mobility of troops would be significantly improved. [9]

The design of the US Army concept has been based on the premise that CAV should be able to carry a payload of 130 to 630 kilograms. The minimum delivery distance is stated to be 80 kilometers and the CAV should be capable of VTOL operation. The CAV should operate autonomously, i.e., avoid obstacles and find a suitable landing site, in addition, the CAV system should be able to optimize the route to the destination. The CAV power source has been left open, but is believed to be electric, fuel-powered, or a hybrid. This concept of the U.S. Army is called the Joint Tactical Autonomous Aerial Resupply System (JTAARS). [9]

Equipment for front-line troops can also be transported by helicopter, but it is slow, expensive and risky. Based on the experience in Afghanistan, it was found that the required material could only be delivered with a delay of several days. In addition to this, the delivery of small items of equipment is perceived as a waste of large transport helicopters. It would have a huge capacity, but it is not usually necessary to use the full capacity for these deliveries. It is also possible that some more important task in the operation of the helicopter will take precedence over equipment deliveries, such as the transfer of troops from one location to another. In the view of the U.S. Army, the CAV could enable the continued movement of combat troops. In that case, there would be no need to stop to replenish the material, but it could be delivered to the front line just when it is needed. It would also be desirable for the CAV system to be ready for use 10 minutes after dismantling, with deployment binding to only two to four men. [9]

3.2. United Kingdom

There is an interesting concept of CAV in the UK. The CAV does not have its own engine but acts as a glider. Development work has already begun in 2017 and there are a few variations. This CAV called Silent Arrow GD-2000 is dropped from the ride of the transport plane, from where it gets its initial speed and altitude. The intended use is military or humanitarian assistance. Once dropped from a transport aircraft, it is guided to a destination utilizing commercial guidance applications, assisted by either GPS or radio guidance. The CAV can be dropped from a height of 300 to 7500 meters. This concept is still in the testing phase, but the system's payload weight of 740 kilograms and glide distance of up to 74 kilometers are promising. [10]

3.3. Canada

Canadian Avidrone Aerospace has introduced the CAV it developed in May 2019 Fig. 2 [11]. The CAV has a tandem rotor and the payload is carried in the frame between the rotors. The smaller version 210TL can carry 20 kilograms and the larger 490TL up to 40 kilograms payload. The range of both is up to 97 kilometers, with a cruising speed of 100 km / h. The manufacturer states that the CAV has an operating time of up to more than an hour. CAVs are made of carbon fiber to maximize the lightness of the structure. The CAV is electrically powered and has three-bladed rotors, which provide better lifting force and also reduce vibration caused by the rotors. This CAV is versatile, as it can also be used as a sensor tray, ie it can be equipped with different cameras. According to the manufacturer, the CAV is ready for use in three minutes. The manufacturer also states that it has entered into agreements with military operators. [12]

Fig. 2. Avidrone 210TL [11].

3.4. Israel

As early as 2017, Israeli Aeronautics released one version of the CAV it developed, called the Pegasus 120. The CAV is a multicopter model that operates on four or eight rotors. Its maximum take-off weight is 120 kilograms of which the payload is 75 kilograms. The maximum operating distance is 10 kilometers. The top speed of the CAV is

80 km/h. This CAV uses the same ground station as the Orbiter 2 reconnaissance aircraft. Israelis say that delivering equipment with CAV is much safer and more cost-effective than with a helicopter. This Pegasus 120 has been developed to carry all kinds of goods, including water, fuel, medicine and ammunition. [13]

The Israeli Blue Bird has also developed a CAV version of the ThunderB UAV released in 2015 in June 2018. Originally, this UAV was designed for surveillance and security missions. The ThunderB is a fixed-wing aircraft, but with additional rotors, it makes it VTOL-capable. These four additional rotors are electric. The tip distance of the CAV's wings is 4 meters and the payload can be carried at 4 kilograms. This CAV operates at an altitude of almost 2,000 meters and has a speed of 60 to 130 km/h. The range is a maximum of 150 kilometers and the operating time varies from 12 hours up to 24 hours for a VTOL-capable one. This CAV is equipped with an internal combustion engine, which means that the operating time is relatively long. [14]

3.5. Turkey

Turkish UAV manufacturer Altinay presented two of its CAVs at a trade fair in Istanbul in September 2019. They are called Altinay Albatros and Altinay Sumru. The Albatros is specifically designed for CAV operations and can carry a payload of 50 to 150 kilograms, depending on the version. In appearance, the Albatros resembles a multicopter. The amount of payload can be scaled, as it is possible to connect these CAVs together, so that their individual payloads can be tripled if a maximum of three Albatrosses are combined. Which allows, for example, wounded evacuation. The company mentions various weapons and ammunition as other loads. The Albatross is powered by electric motors, which enable it to achieve a flight time of 60 minutes and a range of 30 kilometers. In Albatross, the Dual-type propeller solution Fig. 3. The flight speed is 60–100 km/h and the weight is 195–630 kilograms, depending on the version. [15]

Fig. 3. Altinay Albatros [15].

The Altinay Sumru, unlike the Albatross, is a hybrid model and has a total of four rotors and one propeller producing thrust depending on the flight mode. The Sumru has fixed wings, but thanks to the rotors it is VTOL capable. Its maximum weight is 120 kilograms, of which 40 kilograms can be a payload. The wingspan is about 5 meters and the maximum operating time is 6 hours. It reaches a top speed of 120 km/h and a maximum range of 80 km. [15]

3.6. China

The Chinese Star UAV System has developed a much larger CAV than the previous ones. Its test flights were successfully completed in late 2018. This CAV is based on the Pacific Aerospace P-750 XSTOL small aircraft. The CAV has a maximum take-off weight of 3400 kilograms, of which 1500 kilograms is payload. The wingspan is 12.8

meters and the CAV is powered by a 750-horsepower Pratt & Whitney PT6A-34 propeller turbine engine. The CAV has an operating time of up to 8 hours or an operating distance of up to 2000 kilometers. The cruising speed is 260 km/h, at an altitude of 6000 meters. [16] Because the use of this CAV requires a runway, its use is not as simple as that of smaller VTOL-capable CAVs. A CAV of this size could be suitable for the transfer of equipment or goods between military bases.

4. Simple unmanned delivery simulator

The quantities required in the simulator are maximum speed, payload, battery life, charging time, and operating range. The variables can be the number of drones, the total load to be transported, the headwind and the delivery distance. The loading and unloading time of the load is freely defined by the user. The total weight of the material to be transferred must be determined and it is assumed that it can be divided into parts in drone transport tanks. The simulator calculates the battery charge status and tells you when to charge it. The simulator works with respect to battery charging and flying so that even if there are multiple drones in use, they will be flying or charging at the same time.

UCAV				
Max speed	72	km/h	11	m/s
Cargo weight	1	kg	1000	g
Battery time	30	min	1800	s
Charging time	60	min	3600	s
Load + unload time	60	s	60	s
Max operating dis.	9,9	km	9900	m

Fig. 4. Quantities.

VARIABLES			
Tot. cargo weight		789	kg
Number of UCAVs		99	pcs
Headwind		9	m/s
Delivery distance		4	km

Fig. 5. Variables.

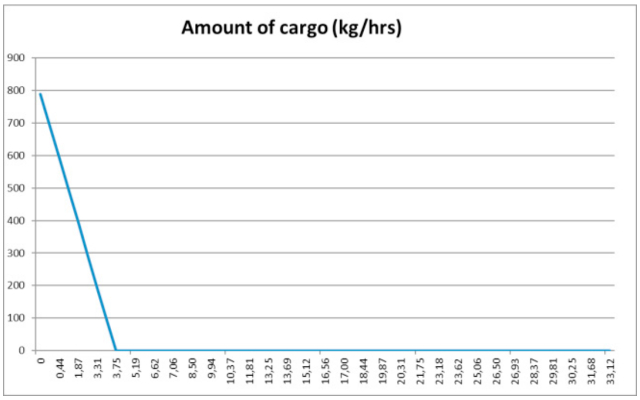

Fig. 6. Simulated delivery.

5. Discussion

CAV drones for freight transport make a strong entry, both for civilian and military use. This paper presents the basic characteristics of VTOL-capable multicopters and their current state in military use. CAV devices will become more common in military use due to their affordability, reliability and versatility. They can naturally be used to transport medical, food and ammunition supplies to those who need them without loss of life and with very little maintenance capacity.

The paper presented a simple simulator that can be used to estimate the time taken to transport goods using CAV systems.

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