UNMANNED AERIAL VEHICLES – CLASSIFICATION, TYPES OF COMPOSITE MATERIALS USED IN THEIR STRUCTURE AND APPLICATIONS

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Unmanned aerial vehicles (UAV) or drones, due to their versatility can be used in a wide range of applications, from army missions to industrial ones. With all these capabilities, the widespread use of drones in smart cities is limited, due to problems and concerns related to safety (their crash for technical reasons, collision in the air with other planes, extreme natural weather), confidentiality (hackers can use malicious applications to exploit and obtain personal data / profiles of people using the wireless location method) and security (thanks to the technology inside the drone-GPS, Wi-Fi that could be hacked/destroyed by attackers). Currently there are many types of drones classified by size, weight, altitude, endurance, landing method (VTOL, HTOL), etc. However, these parameters vary depending on the application of the drone. The performance of drones is focused on the type of built-in electronics but also on the material used to make it. All modern drones are equipped with a series of sensors and other communication systems, increasing inevitably the total weight and reducing the flight time. Therefore, weight reduction is a vital parameter to build the drone's body/structure (generally using thermosetting fibers and resins) without compromising their resistance. Thus, high strength-to-weight ratio, facilitates maneuverability, reduces energy consumption, increases the ability to carry more payload, flight time, etc. The use of composites compared to aluminum reduces weight by 15-45%, increases corrosion, fatigue, impact resistance, reduces noise and vibrations. The composites most used for manufacturing the structure of UAVs (fuselage, wing, landing gear) are: polymers reinforced with carbon fibers (CFRP), polymers reinforced with fiberglass (GFRP), boron and aramid fibers.

Keywords: UAV, composite, application.

INTRODUCTION

Unmanned aerial vehicles (UAVs), known as drones are defined as "dynamic remote controlled navigation equipment", capable of performing critical operations without risking human safety. Drones can fly in the air, over large areas but also areas difficult to reach by humans (Sivakumar and Naga Malleswari, 2021). An UAV can be operated remotely by pilots or programmed to operate without human assistance (autonomously) using autopilot and various IMUs (Inertial Measurement Unit) and GPS (Ochoa-de-Eribe-Landaberea *et al.*, 2022). UAVs are also equipped with radars, image enhancers, infra-red imaging technology (Shakhatreh *et al.*, 2019). Fixed-wing and multi-rotor UAVs are the most commonly used mainly in military and civilian applications. Drones with multiple rotors tend to be more popular, because they can vertical take-off and land (VTOL), no special tracks are required, they can fly at a fixed point, they are fast (agile) which makes them suitable for applications that require more precise maneuverability. However, they require more mechanical and electronic complexity which leads to higher maintenance costs, less payload capacity and higher power requirements (Townsend *et al.*, 2020). Fixed-wing drones have the advantage of a simpler structure, reduced

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maintenance costs, longer flight time, can carry a larger payload over longer distances using less energy. However, fixed-wing drones must accelerate horizontally along a track to take off or land (Horizontal take-off and landing – HTOL UAVs), cannot fly at a fixed point and tend to be much bulkier compared to multi-rotor ones (Cevher, 2019; Elmeseiry *et al*., 2021). There is also a unique type of drone that combines the fixed wings with the rotating ones (hybrid), offering the stability and maneuverability of a drone with a rotating wing but also the long flight range of a drone with a fixed wing, without the need for additional runways for take-off (Saeed *et al.*, 2018). The performance of drones is focused on the type of built-in electronics, on the material used to make it (frame, wing, etc.) but also on the energy source (battery, electric motor, combustion engine, solar / photovoltatic panels, hydrogen fuel cell, etc.) (Elmeseiry *et al*., 2021; Townsend *et al*., 2020). A crucial parameter that reduces flight time is weight (Shria and Mishra, 2022; Wang *et al.*, 2019). Weight reduction is a vital parameter to build the drone's body without compromising its resistance. Thus, high strength-to-weight ratio facilitates maneuverability, reduces energy consumption, improving flight time, etc. Currently most UAVs are made of carbon fiber reinforced polymers (CFRP), but there are studies that show that they can partially disrupt/attenuate RC signals (Ramadhoni *et al.*, 2020; Verma *et al.*, 2018). Composite materials are promising to reduce weight, but some of the manufacturing processes require both shape/size limitations and non-alignment of the fibers during processing (Geiger *et al.*, 2019).

The purpose of this review was to provide an overview of the types of existing UAVs, their applications as well as the progress made in the development of composite materials and the technologies used in their structure.

Drone Classification – Size, Weight and Use

This section presents a short classification of UAVs according to their size, weight and usefulness (consumer, commercial, and military drones respectively). Tables 1 and 2 show some representative examples of drones, each with its own technical characteristics.

Table 1. Consumer and Commercial UAV classification based on size and weight (Boeing, 2019; https://www.thecoronawire.com/drone-sizes-explained-consumer-commercial-and-military-drone-sizes/)

Size	Weight	Length	Diameter Propeller	Short description
Very small or "nano" drones	200g	≤150 Mm	51 mm	One of the smallest drones in the world is **the Cheerson CX-10**, with a length of 41mm, weight - 12g, *used for recreational purposes for children*
Small "*Mini*"	200-1000g	Up to 300mm	76-152 mm	Example: **DJI Mini 2**, 249g, length – 159mm, propeller diameter – 119 mm, *used for shooting*
Medium	1-20kg	300-1200mm	150-640mm	**DJI Mavic 2 Entreprise advanced**, 1.1 kg, length-322mm, propeller diameter – 22cm, *used for search /rescue operations being equipped with thermal cameras, inspection of high power lines.*
Large	20 kg or more	120 cm or more	64 cm or more	Currently one of the largest drones in the world, is the cargo drone from Boeing called **Cargo AirVehicle** (currently experimental), weighing 498.95 kg and a length of 533cm.

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Table 2. Millitary drone classification based on size, weight, endurance

Class	Category	Description and examples
Class I – nano, mini, small drones, (≤ 150 kg)	Tactics Espionage, Disaster Applications (earthquakes, hurricanes, terrorist attacks)	**Black Hornet PRS** (personal reconnaissance system) developed by Teledyne FLIR, (classified as nano or mini drone) finds applications in the defense sector. It is equipped with optical and thermal cameras, and transmits video images from distances up to 2 km. It has an endurance of up to 25 minutes, a length of 168 mm, rotor diameter – 123 mm, weight – under 33 grams. Due to its small size, this drone can enter narrow spaces, thus being useful in determining the number of victims, their location (FlyMotion, 2021).
	Tactics Intelligence-Surveillance-Reconnaissance (ISR)	**Fulmar-X** is a mini UAV developed by Thales Group to support surveillance missions for military and civilian operators. The main missions of Fulmar X include: border surveillance, intelligence, target acquisition, emergency and natural disasters response, monitoring of illegal traffic and critical infrastructure security. Fulmar X has a fixed wing structure made of carbon fiber composites, a length of 1.2 m, height – 0.5 m, wingspan – 3 m, maximum take-off weight – 19 kg. The aircraft can be equipped with a wide range of sensors such as a multispectral camera and a LIDAR (light detection and ranging) system. The payload carrying capacity of the Fulmar X is 8 kg. The UAV also has a combined electro-optical / infrared sensor for night operations and offers a real-time video transmission range of up to 90 km. Fulmar X has an endurance maximum of up to 12 h and can reach a maximum range of 800 km without refueling. The maximum altitude is 3000 m (https://www.militaryfactory.com/aircraft/detail.php?aircraft_id=1756).
Class II, medium drones, (150-600kg)	Tactics, used for medium range surveillance	**MQ-1B Predator** developed by General Atomics – is an armed aircraft, multi-mission, medium-altitude long-endurance (MALE) having the following characteristics: length – 8.22 m, height – 2.1 m, weight – 512 kg, maximum takeoff weight – 1020 kg, payload – 204 kg, maximum altitude – 7620 m, autonomy – 1240 km. Armament – 2 AGM-114 Hellfire laser-guided missiles (https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104469/mq-1b-predator/).
Class III, large drone (≥600 kg)	Strategic	**WZ-7 Soar Dragon** was designed by Chengdu Aircraft Industry Group and built by Guizhou Aircraft Industry Corporation. It is a High-Altitude Long Endurance (HALE) drone was deployed for the first time by the Chinese armed forces to conduct live combat training. It features a unique design using a tandem wing with one in the middle of the fuselage and one at the rear. The WZ-7 will be used by the Chinese military to conduct reconnaissance missions and can provide data for ballistic missile launcher units such as the DF-21D. It is equipped with advanced communication and jamming equipment. The drone can reach a speed of 750 km/ h, autonomy of maximum 7000 km, length – 14.33m, wingspan – 24.86m, flight of endurance – 10 h, payload capacity – 650 kg (Babashov, 2021).

Composite Materials Used in the Structure of UAVs

The use of UAVs in almost all fields has engaged scientists to conduct extensive research and development, from body design, components, control methods to improving energy efficiency. In the design and manufacture of drones are used different materials and technologies (e.g., additive manufacturing so-called 3D printing, fused deposition modelling-FDM or fused filament fabrication-FFF, etc.). Research has shown that weight reduction is an essential parameter in the design of the frame or component parts (Palinkas *et al*., 2022; Piljek *et al.*, 2022). All modern drones are equipped with a series of sensors, communication systems, localization that increase weight and reduce flight time. Thus, weight reduction is essential to build the body/structure of the drone (in general, thermoreactive fibers and resins are used) without compromising their resistance. The use

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of composites compared to aluminum reduces weight by 15-45%, noise and vibrations and improves resistance to corrosion, impact (in the case of collision with birds or other objects). The composites most used for the manufacture of UAVs (fuselage, wing, landing gear) are: polymers reinforced with carbon fibers (CFRP), polymers reinforced with fiberglass (GFRP), boron and aramid fibers (Shria and Mishra, 2022). In Figure 1, a 3D model made by INCAS is presented, highlighting the shape of the case having the role of protecting the electronic components (which are expensive).

Figure 1. UAV (drone) owned by INCAS: (a) model without encapsulation of the electronics, (b), (c) different form of the proposed encapsulation of the electronics

Table 3. Types of composite materials used in the UAVs structure

Matrix	Fiber	Technology	UAV component
Epoxy resin	plain weave glass fiber (E-glass) fabric and plain weave carbon fiber fabric	vacuum resin infusion	alternative materials for the airframe (Poopakdee and Thammawichai, 2021)
PLA GF20 PP GF30 PET CF15 PAHT CF15 CFRP*	Short carbon fiber (CF) and fiberglass (GF) (chopped)	fused filament fabrication process	landing gear (Lancea *et al*., 2022)
-	-	method of 4D printing of composites	manufacturing of adaptive compliant trailing edge (ACTE) morphing wing. The wing is a sandwich structure made of composite materials, with a flat upper/ lower sheet and a corrugated core. The corrugated core was made using 4D technique. The wing prototype has been tested and it has been shown that the wing can support the load for a medium-sized UAV (Hoa *et al*., 2022).
Epoxy	E-glass S-glass Aramid fibers	vacuum infusion	UAV frame (Ramadhoni *et al*. 2020)
ABS	carbon fibre reinforced polymer (CFRP) layer	3D fusion deposition modeling (FDM) method	Fuselage parts of Quadcopter unmanned aerial vehicle (Galatas *et al*., 2018)
Continuous carbon fiber and two matrix materials – thermoset resulting in a unidirectional composite		layer-by-layer CFRC 3D printing	frame structure of small UAV, the mass of the frame is 75 g (Azarov *et al*., 2019)
Low temperature pre-preg – combined with careful processing methods and carbon fibre-reinforced CNC direct mould tools		9m x 5m composite curing oven	manufacture of all primary composite structures for a solar-powered UAV (wing, frame, etc.) (Richardson, 2018)

*PLA – polylactic acid; PP – polypropylene; PET – polyethylene terephthalate; PA – polyamide; CFRP – High-quality carbon-fiber-reinforced polymer

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Drone Applications

For years, UAVs have played an important role in national security operations, in the military field, including in the prevention of terrorist threats and humanitarian assistance and disaster relief, due to their superior functionality to the people. Many countries and government agencies have invested huge sums/billions to improve their performance (Poopakdee and Thammawichai, 2021). Drones are definitely the most important technology that can be used in anti-terrorism operations being equipped with electro-optical cameras that can track both stationary / moving targets. Some drones are used exclusively for surveillance operations, but there are also drones designed for critical operations such as ammunition transport. Drones are also used to collect data about ongoing and life-threatening military missions with the help of their real-time intelligence, surveillance and reconnaissance (ISR) capabilities. Drones are increasingly finding applications in the civilian and military sectors (Nawaz *et al.*, 2019; Singhal *et al.*, 2018). The integration of commercial UAVs in smart cities is very difficult due to safety problems and concerns (their crash for technical reasons, collision in the air with other objects, extreme natural elements), confidentiality (hackers can use malicious applications to exploit and obtain personal data or profiles of people, using the wireless location method) and security (thanks to the technology inside the drone-GPS, Wi-Fi that could be hacked or destroyed by attackers). The rapidly growing number of drones can bring new challenges to the aviation industry, especially in air traffic control (Nguyen and Nguyen, 2021).

CONCLUSIONS

Although UAVs have been used for many years in military applications, their use for commercial purposes (package delivery) is still limited due to safety, security and privacy issues. The improvement of current technologies regarding the detection and avoidance of obstacles will create the future premises for drones to operate autonomously and safely in urban areas. Moreover, finding more cost-effective manufacturing materials and technologies with high productivity to achieve their lightweight and durable structures of UAV parts is still a challenge. Moreover, finding more cost-effective manufacturing materials and technologies with high productivity to achieve their lightweight and durable structures of UAV parts is still a challenge.

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