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

MARIA SÖNMEZ1, CRISTINA-ELISABETA PELIN2, MIHAI GEORGESCU1, GEORGE PELIN2, MARIA DANIELA STELESCU1, MIHAELA NITUICA (VILSAN)1, GEORGE STOIAN2, LAURENTIA ALEXANDRESCU1, DANA GURAU1

1The National Research & Development Institute for Textiles & Leather - Leather and Footwear Research Institute Division, 93 Ion Minulescu St., district 3, Bucharest, Romania, maria.sonmez@icpi.ro

2INCAS – National Institute for Aerospace Research “Elie Carafoli”, Iuliu Maniu Blvd.220, Bucharest 061136, Romania, pelin.cristina@incas.ro

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, infrared 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...
Unmanned Aerial Vehicles – Classification, Types of Composite Materials Used in Their Structure and Applications

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; Elmesiry 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 / photovoltaic panels, hydrogen fuel cell, etc.) (Elmesiry 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 (Ramadioni 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/)

<table>
<thead>
<tr>
<th>Size</th>
<th>Weight</th>
<th>Length</th>
<th>Propeller Diameter</th>
<th>Short description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very small or “nano” drones</strong></td>
<td></td>
<td></td>
<td></td>
<td>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</td>
</tr>
<tr>
<td><strong>Small</strong></td>
<td></td>
<td></td>
<td></td>
<td>Example: DJI Mini 2, 249g, length – 159mm, propeller diameter – 119mm, used for shooting</td>
</tr>
<tr>
<td>“Mini”</td>
<td>200g</td>
<td>≤50 Mm</td>
<td>51 mm</td>
<td>DJI Mavic 2 Enterprise advanced, 1.1 kg, length-322mm, propeller diameter – 22cm, used for search/ rescue operations being equipped with thermal cameras, inspection of high power lines.</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td>1-20kg</td>
<td>Up to 300mm</td>
<td>150-640mm</td>
<td>Currently one of the largest drones in the world, is the cargo drone from Boeing called Cargo Air Vehicle (currently experimental), weighing 498.95 kg and a length of 533cm.</td>
</tr>
<tr>
<td><strong>Large</strong></td>
<td>20 kg or more</td>
<td>120 cm or more</td>
<td>64 cm or more</td>
<td></td>
</tr>
</tbody>
</table>

https://doi.org/10.24264/icams-2022.1.11
Furthermore, fibers and resins are used (classified as nano or mini drone) without compromising their resistance. The use of weight reduction is essential to build the body/structure of the drone (in general, communication systems, localization that increase weight and reduce flight time. Thus, their location (FlyMotion, 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.

---

**Table 2. Military drone classification based on size, weight, endurance**

<table>
<thead>
<tr>
<th>Class</th>
<th>Category</th>
<th>Description and examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I – nano, mini, small drones, (≤ 150 kg)</td>
<td>Tactics Espionage, Intelligence-Surveillance-Reconnaissance (ISR)</td>
<td><strong>Black Hornet PRS</strong> (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).</td>
</tr>
<tr>
<td>Class II, medium drones, (150-600 kg)</td>
<td>Tactics, used for medium range surveillance</td>
<td><strong>Fulmar-X</strong> 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 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 (<a href="https://www.militaryfactory.com/aircraft/detail.php?aircraft_id=1756">https://www.militaryfactory.com/aircraft/detail.php?aircraft_id=1756</a>).</td>
</tr>
<tr>
<td>Class III, large drone (≥ 600 kg)</td>
<td>Strategic</td>
<td><strong>MQ-1B Predator</strong> 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 h, Armament – 2 AGM-114 Hellfire laser-guided missiles (<a href="https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104469/mq-1b-predator/">https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104469/mq-1b-predator/</a>). <strong>WZ-7 Soar Dragon</strong> 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 – 24.86 m, flight of endurance – 10 h, payload capacity – 650 kg (Babashov, 2021).</td>
</tr>
</tbody>
</table>

---

https://doi.org/10.24264/icams-2022.1.11
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

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Fiber</th>
<th>Technology</th>
<th>UAV component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy resin</td>
<td>plain weave glass fiber (E-glass) and plain weave carbon fiber fabric</td>
<td>vacuum infusion</td>
<td>alternative materials for the airframe (Poopakdee and Thammawichai, 2021)</td>
</tr>
<tr>
<td>PLA GF20 PP GF30 PET CF15 PAHT CF15 CFRP*</td>
<td>Short carbon fiber (CF) and fiberglass (GF) (chopped)</td>
<td>fused filament fabrication process</td>
<td>landing gear (Lancea et al., 2022)</td>
</tr>
<tr>
<td>- - -</td>
<td>- - -</td>
<td>method of 4D printing of composites</td>
<td>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).</td>
</tr>
<tr>
<td>Epoxy</td>
<td>E-glass S-glass Aramid fibers</td>
<td>vacuum infusion</td>
<td>UAV frame (Ramadholni et al. 2020)</td>
</tr>
<tr>
<td>ABS</td>
<td>carbon fibre reinforced polymer (CFRP) layer</td>
<td>3D fusion deposition modeling (FDM) method</td>
<td>Fuselage parts of Quadcopter unmanned aerial vehicle (Galatas et al., 2018)</td>
</tr>
<tr>
<td>Continuous carbon fiber and two matrix materials – thermost set resulting in a unidirectional composite</td>
<td>layer-by-layer CFRC 3D printing 9m x 5m composite curing oven</td>
<td>frame structure of small UAV, the mass of the frame is 75 g (Azarov et al., 2019)</td>
<td></td>
</tr>
<tr>
<td>Low temperature pre-preg – combined with careful processing methods and carbon fibre-reinforced CNC direct mould tools</td>
<td></td>
<td>manufacture of all primary composite structures for a solar-powered UAV (wing, frame, etc.) (Richardson, 2018)</td>
<td></td>
</tr>
</tbody>
</table>

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

https://doi.org/10.24264/icams-2022.1.11
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.

Acknowledgement

This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS/CCCDI – UEFISCDI, project no. 601PED/26.07.2022, within PNCDI III.

REFERENCES


https://doi.org/10.24264/icams-2022.1.11
Unmanned Aerial Vehicles – Classification, Types of Composite Materials Used in Their Structure and Applications


FlyMotion (2021), “FLIR’s Black Hornet is the World’s Smallest Military Drone”, *News*.


*** https://www.theconcorwire.com/drone-sizes-explained-consumer-commercial-and-military-drone-sizes/

https://doi.org/10.24264/icams-2022.1.11