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Unmanned Aerial Vehicles (UAVs): Advancing Flight Technology for Diverse Applications

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An Unmanned Aerial Vehicle (UAV), commonly referred to as a drone, is a type of aircraft that operates without a human pilot on board. Instead, it is remotely controlled from a Ground Station using radio frequency communication. UAVs utilize aerofoils, which are wings or surfaces designed to generate lift, based on Bernoulli's principle. This principle states that as the speed of a fluid or air increases, the static pressure or potential energy decreases concurrently. This aerodynamic principle is fundamental in enabling UAVs to achieve flight and maneuver through the air.

Aerofoil

An airfoil, also known as an aerofoil, is the cross-sectional shape of an object capable of generating significant lift force when it moves through a gas, such as air. Examples of objects that use airfoil shapes include airplane wings, sails, propeller blades, and turbine blades. The airfoil's design allows it to produce lift force, which acts vertically upward, enabling the object to fly or remain airborne.

When an object with an airfoil shape moves through the air, it divides the airflow into two parts. The upper part of the airfoil experiences higher velocity airflow, resulting in lower pressure according to Bernoulli's principle. In contrast, the lower part of the airfoil experiences lower velocity airflow, leading to relatively higher pressure according to Bernoulli's principle. This pressure difference between the upper and lower sides of the airfoil creates the lift force, which acts vertically upward, allowing the object to achieve flight or lift heavy loads in the case of helicopters or quadcopter drones with rotating propellers.

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Types of drones

Drones are classified into three different types as per design. Those are:

1. Rotary Wing
2. Fixed Wing
3. Hybrid

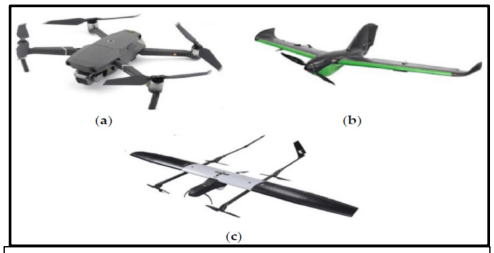

Fig: Types of Drones: (a) rotary wing, (b) fixed wing, (c) hybrid

Rotary wing UAV

A Rotary Wing UAV, also referred to as a rotary wing unmanned aerial vehicle, is a type of UAV that employs rotating blades aligned parallel to the ground to generate vertical thrust. This vertical lift capability is achieved through the aerodynamic forces generated by the rotating blades as they displace air downward, allowing the UAV to achieve lift and maintain stable flight. Unlike fixed-wing UAVs that rely on forward motion to generate lift, rotary wing UAVs can perform vertical takeoffs and landings (VTOL), hover in a stationary position, and execute precise maneuvers in various directions. The rotary wing UAV's design offers exceptional agility and versatility, making it well-suited for applications requiring close-quarters operations, low-speed flight, and tasks that demand the ability to hover in a specific location. Typical examples of rotary wing UAVs include helicopters and multirotordrones.

Helicopter UAVs are unmanned aircraft that operate based on the same flight principles as manned helicopters. They utilize spinning rotors to generate both lift and thrust, allowing them to achieve vertical takeoffs, landings, and hover in a stable position. These UAVs are primarily categorized based on their propeller tilt mechanism.

The design and specification of a helicopter UAV's propeller blade are crucial for its performance. There are two main specifications for propeller blades:

1. **Length**: The length of the propeller refers to the distance from one corner of the blade to the opposite corner or simply the diameter of the propeller.
2. **Pitch**: The pitch of a propeller blade represents the theoretical distance the propeller would move forward in one complete revolution. It effectively controls the speed of the air that exits the back of the propeller. Notably, the pitch of a propeller blade varies along its surface from one end to the other.

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These characteristics of the propeller blades play a vital role in determining the efficiency and performance of the helicopter UAV, as well as its ability to maintain stability and control during flight.

Helicopter UAVs are primarily classified into two main types:

1. **Fixed Pitch Helicopter UAVs**:
    - These UAVs are equipped with propellers that have a fixed pitch, meaning the angle of the propeller blades cannot be adjusted or varied during operation.
    - Helicopters equipped with fixed pitch propellers are referred to as fixed pitch helicopters.
    - Due to the fixed pitch design, controlling these helicopters can be challenging, and they offer limited manoeuvrability.
    - As a result of their fixed pitch configuration and limited control capabilities, they are not well-suited for practical real-life applications.
2. **Variable Pitch Helicopter UAVs**

    These are equipped with propellers featuring a variable pitch, enabling the angle of the blades to be adjusted during flight. These UAVs are referred to as Variable Pitch Helicopters.

Key features and advantages of Variable Pitch Helicopter UAVs include:

- **Adaptability**: The ability to adjust the propeller pitch during flight enhances adaptability and responsiveness. This allows the UAV to efficiently perform a wide range of flight maneuvers and tasks.
- **Real-life Applications**: Variable Pitch Helicopters are highly practical and versatile, making them suitable for various real-life applications, including aerial photography, surveying, surveillance, and even delivery services.
- **Stable Flight**: The variable pitch system, in conjunction with adjusting the engine or motor speed, allows for more precise control over lift and thrust, leading to a smoother and more stable flight experience.
- **Manoeuvrability**: The variable pitch design enhances manoeuvrability, enabling the UAV to perform complex aerial movements with greater agility and control.

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- **Payload Capacity**: Variable Pitch Helicopter UAVs are capable of carrying sufficient payload due to their improved control and stability, making them viable for transporting equipment, sensors, or cargo.

Multirotor UAVs

Multirotor UAVs, also known as multicopper or multirotors, are mechanically simple aerial vehicles that are controlled by varying the speed of multiple downward thrusting motor/propeller units.

Key features of Multirotor UAVs include:

- **Rotors and Lift Generation**: These UAVs utilize multiple rotors with fixed-pitch spinning blades to generate lift. The upward thrust generated by the rotors counteracts the forces of gravity and drag acting on the aircraft.
- **Control and Manoeuvrability**: By adjusting the speed of the individual rotors, the drone's ascent, hover, or descent can be precisely controlled. The varying thrust allows the drone to maneuver in different directions and achieve stable flight.
- **Types of Multirotor UAVs**: Multirotor UAVs can be classified into various types based on the number of rotors they have. Common examples include tricopters (3 rotors and propellers), quadcopters (4 rotors and propellers), hexacopters (6 rotors and propellers), and octocopters (8 rotors and propellers).
- **Versatility**: Multirotor UAVs are versatile and find applications in various fields, including aerial photography, surveillance, mapping, inspection, and search and rescue operations.

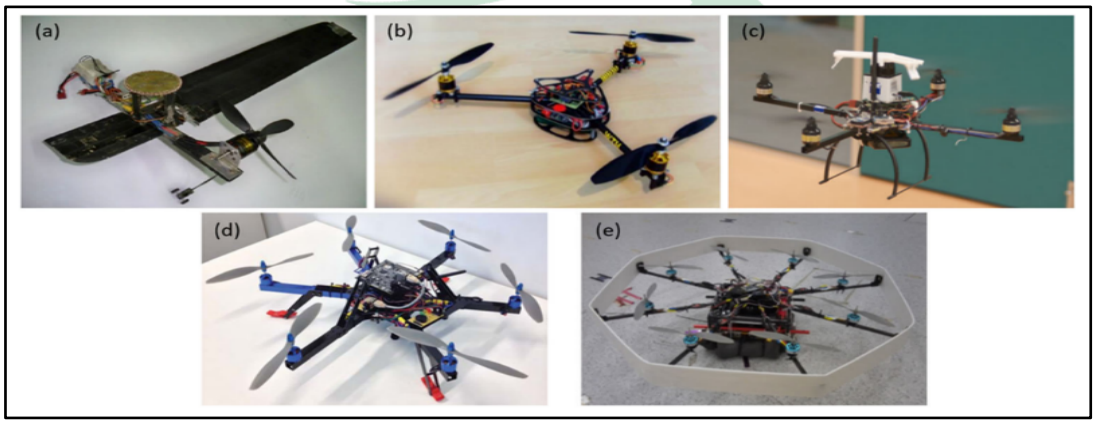

Fig: Commonly used Multirotor UAVs: (a) Monocopter, (b) Tricopter, (c) Quadrotor, (d) Hexacopter, (e) Octocopter; Source: Idrissi *et al*, 2022

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The simplicity of their mechanical design, along with their ability to hover and perform precise maneuvers, makes multirotor UAVs popular choices for a wide range of tasks, especially in scenarios where stable flight, close-quarters operation, and flexibility are essential.

Fixed-wing UAVs

Fixed-wing UAVs are unmanned aircraft that operate based on the same principles as conventional airplanes. They are machines that are heavier than air and capable of sustained flight due to the lift generated by their wings.

Key features of Fixed-wing UAVs include:

- **Lift Generation**: Fixed-wing aircraft generate lift by utilizing the forward motion (airspeed) and the shape of their wings. As the aircraft moves through the air, the wings create lift, an upward force that keeps the UAV airborne.
- **Non-Rotary Wings**: Unlike rotary-wing aircraft, where the wings form a rotor mounted on a spinning shaft or "mast," fixed-wing UAVs have static wings that do not rotate during flight.
- **Efficient Forward Flight**: Fixed-wing UAVs are well-suited for efficient forward flight, which allows them to cover large distances and remain airborne for extended periods.
- **Glide and Soar**: Once a fixed-wing UAV is in the air, it can glide and soar without continuous propulsion, conserving energy and enabling longer flight times.
- **Limited Hovering Capability**: Unlike rotary-wing UAVs, fixed-wing UAVs have limited or no hovering capability, as they rely on forward motion to generate lift.

Fixed-wing UAVs are widely used in various applications, including aerial surveillance, mapping, agriculture, environmental monitoring, and package delivery. Their ability to cover large areas efficiently and maintain stable flight makes them valuable tools in many industries.

Hybrid UAVs

Hybrid UAVs are unmanned aerial vehicles that possess the unique capability to take off vertically like a helicopter and then transition to fixed-wing flight, resembling an airplane during cruise mode. This hybrid functionality offers several advantages:

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- **Vertical Takeoff and Landing (VTOL)**: Hybrid UAVs can take off and land vertically, similar to multirotor drones. This allows them to operate from confined spaces or areas with limited runways, offering increased flexibility in deployment.

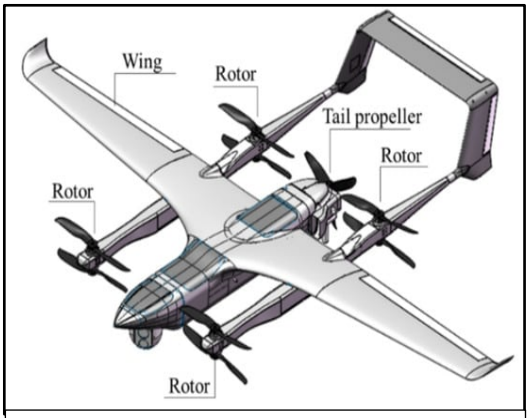

Fig: Hybrid wing VTOL UAV

- **Transition to Fixed-wing Flight**: After vertical take-off, the hybrid UAV switches its flight mode to fixed-wing configuration. It accomplishes this by rotating its primary propeller, which is initially mounted parallel to the ground, to a vertical position, generating forward thrust akin to an airplane.
- **Efficient Cruise Mode**: During fixed-wing flight, the hybrid UAV benefits from the aerodynamic efficiency of an airplane, enabling it to cover longer distances and remain airborne for extended durations with reduced power consumption.
- **Glide and Landing**: To conclude its flight, the hybrid UAV switches off and locks the motors responsible for vertical take-off. It then glides and flies like an airplane during the descent phase. Just before landing, it slows down the vertical-mounted propeller and reactivates the parallel-mounted propellers to facilitate a controlled vertical landing, similar to a multirotor drone.
- **Versatility**: Hybrid UAVs combine the advantages of both multirotor and fixed-wing drones. They can operate in various environments, perform longer-range missions, and land in tight spaces, making them suitable for a wide range of applications, such as surveillance, mapping, search and rescue, and environmental monitoring.

The versatility and capabilities of hybrid UAVs make them valuable tools in situations where the advantages of vertical take-off and fixed-wing flight are both required, providing a flexible and efficient solution for diverse aerial missions.

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