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The Basic Science of Drones

Explore the fundamental principles of drone flight, focusing on the physics behind quadcopters' motion, stability, and control through propeller manipulation.

Author (s): Dr. B A Kagali

Category: Engineering & Technology

Date: 01-January-2025

Volume1, Issue 1, pp 29 – 35 (2025)

https://www.springchronicle.org/home/article/the-basic-science-of-drones

Nowadays drones have become very common and popular all over the world. They have been used as flying toys, flying video cameras, small goods transporters and carriers of weapons in wars, just to name a few. Any aircraft or flying machine operated without a human pilot is called an unmanned aerial vehicle (UAV) or a drone, in common parlance. They can be guided autonomously or remotely by a human operator using onboard computers or robots. They can be of fixed wings type or spinning propeller type. The science of fixed wing drones is similar to that of airplanes. Hence, here we shall consider here the working principles of drones that make use of two or more spinning blades or propellers. The number of propellers can vary from two to eight. Higher number of propellers improve the stability of drones and load-carrying capacity but such drones need more battery power to drive the motors for good performance. In principle, one can have drones with only two propellers. They are called bicopters. Drones with three propellers are called triple copters. However, both are more complicated to operate and stabilize - hence, not very common. The most common configuration, the one involving four propellers is called a quadcopter (figure 1). Let us consider their operation in some detail.

Figure 1. A quadcopter

The first quadcopter drone was invented by the Breguet brothers, Jacques and Louis Breguet, along with Professor Charles Richet in 1907. In the beginning they were impossible to steer and required four men for stabilization during their brief hover of just two feet off the ground! Since then, drones have come a long way!

A typical quadcopter has four propellors at four corners of a sturdy frame. The speed and direction of rotation of each propeller are independently controlled for balance and movement of the drone. In a traditional quadcopter, all the four rotors are placed at an equal distance from each other.

To maintain the balance of the system, one pair of rotors rotates in a clockwise direction while the other pair rotates in an anticlockwise direction. To move up or hover at a particular height, all rotors should run at high speed. By changing the speed of selected rotors, drones can be moved forward, backwards, and side-to-side as discussed below.

Quadcopter Dynamics

One wonders how such a device can fly making all kinds of maneuverers, when one does not see any wings, any tail, and any rudder that we commonly associate with an airplane. How does it manage to go forward and backwards; move sideways and turn about a vertical axis passing through its center are some of the common questions one tends to ask. Let us see how we can find answers to such questions using basic physical principles.

The four specially shaped spinning blades (or propellers) at the corners are capable of spinning at different rates individually by a central control system. All of them do not spin in the same direction – if that were to happen it would cause the entire body of the drone to spin constantly in the opposite direction-following the law of conservation of angular momentum - something that we do not want. Hence, diagonally opposite blades along each diagonal (like 1 and 3) spin in one direction, while those along the other diagonal (like 2 and 4) spin in the opposite sense as shown in figure 2.

Figure 2. Top view of the rotating blades

Such an arrangement leads to cancellation of the net torque on the body of the drone – hence enabling the drone to move up or down; left or right without unwanted rotation.

If we want the drone to move up vertically, we just raise the spinning rates of all the four blades simultaneously. Then, the lifting force - known as thrust that is developed due to the rapid displacement of air mass downwards (again following Newton's third law for forces) counteracts the weight of the drone; and if the thrust exceeds the weight, the drone climbs up vertically. In the special case of the thrust balancing the weight, the drone simply stays at one position. Such a motion is called hovering. If one wishes to bring down the drone, the spinning rate of the blades is gradually reduced. Then the vehicle slowly comes down and touches the ground without any damage. It is believed that thrust is proportional to the square of the spin rates. The thrust is also

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proportional to the density of the air and the surface area of the blades. The blades, in advanced quadcopters, are specially designed to resemble airplane wings with curved top surfaces to enable greater lifting capacity.

Supposing we want the drone to move forward, then the two blades on the back side (opposite side to the direction of motion), marked with green circles (figure 3), are spun at a greater speed than those in the forward direction, marked with yellow circles in the figure. Following Newton's third law, the backside would receive a greater upward force than the front side. The net result is lifting up of the back portion compared to the front part. Please note that there will always be a resistive force, called drag, due to the air medium. It has to be overcome for the motion to take place.

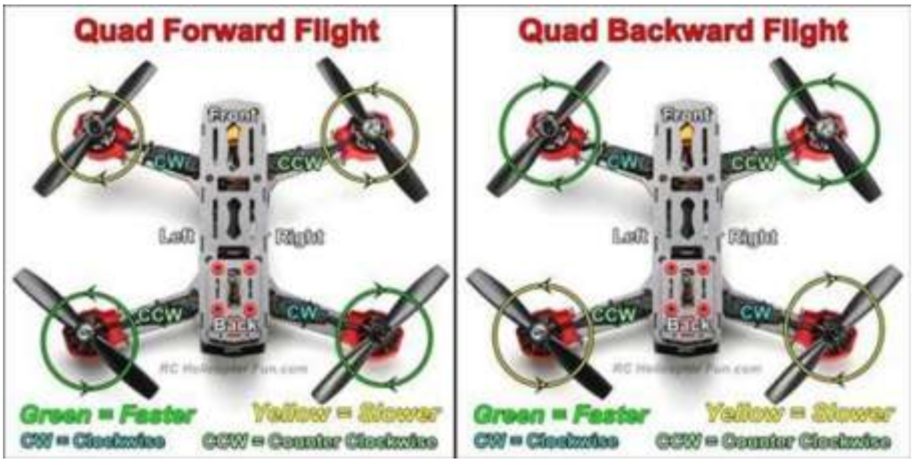

Figure 3. Forward and backward movements

Therefore, a component of the total force acting horizontally along the forward direction on the body emerges in addition to the vertical force component balancing the weight. This makes the drone move forward – with the forward edge slightly dipped compared to the backward edge! This can be noticed on a slowly flying quadcopter. Alternatively, a drone can be made to move backward from its hovering position, if the front blades are spun faster than the rear ones as shown in the right part of figure 3. This is a simple, but ingenious, idea employed for moving a quadcopter horizontally.

Similarly, movements to the left and right can be achieved by differentially spinning the right or left pair of blades. The speed of the linear motion depends on the difference

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in the spinning rates of the left and right pairs of blades over and above the hovering spin rates.

We also see a drone turning clockwise or anticlockwise about a vertical axis in addition to linear motions discussed above. Such turnings are called yaw motions. How are such turnings achieved? Let us say the blades with green circled blades are spinning faster in the anticlockwise manner while those coloured yellow are spinning slowly in the clockwise manner (figure 4). Remember that such diagonal pairing of blades is required for stability, as discussed earlier. Let us say we enhance the spinning rates of the green blades compared to the rates of the yellow ones, leading to a net angular motion of the blades in the anticlockwise manner. Hence, the body of the drone starts spinning or turning in the clockwise manner- again following Newton's third law for the conservation of angular momentum. It is amazing to realise that the spin rates control all possible motions of the drone! Alternatively, if the green-coloured blades are spun at a higher rate in the clockwise manner than the slower yellow blades turning in the anti clockwise manner, the body of the drone turns in the anticlockwise manner as illustrated in the right half of the same figure.

Figure 4. Yaw motions to the right and left

The main parts of a quadcopter

The central part of the drone houses batteries, control systems, motors, communication units, cameras etc. depending on the model. They are shown in Figure 5.

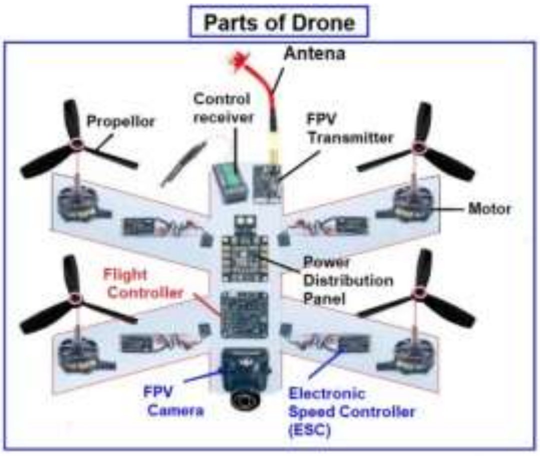

Figure 5. Parts of a Drone

The Frame of a drone should have sufficient strength to hold the propellers, motors, landing gear and cameras. It should be sturdy and offer less aerodynamic resistance.

The speed and load lifting ability of a drone depends on the shape, size, and number of propellers. Long propellers create huge thrust to carry heavy loads at a low speed and are less sensitive to changes in the speed of rotation. Shorter propellers can carry only lesser loads. They change rotation speeds quickly and require a high speed for more thrust.

Brushless and brushed type motors can be used for drones. A brushed motor is less expensive and useful for small-sized drones. Brushless type motors are powerful and energy very efficient. But they need Electronic Speed Controller (ESC) to control their speed. These brushless motors are widely used in racing freestyle drones, traffic surveys and aerial photography drones.

Electronic Speed Controller is used to connect the on- board battery to the electric motor for the power supply. It converts the signal from the flight controller to the revolution per minute (RPM) of motor.

Flight Controller (FC) is the computer processor which manages the balance and telecommunication controls using different transmitters. Sensors are located in this unit for the accelerometer, barometer, magnetometer, gyroscope and GPS units. The distance measurement can be carried out by an ultrasound sensor.

A high-power providing rechargeable Lithium Polymer (LiPo) battery is used in most drones. When the pilot or autonomous system gives the drone a command, the flight controller sends signals to the motors to spin the propellers at the desired rates.

A digital camera records and stores data following the given instructions. It can also transmit the data to the drone operator in real time.

Of course, there are very many smaller parts and variations over this basic quadcopter design, such as those with greater number arms and those with more number of specially crafted blades etc.

In conclusion, it is nice to understand how manipulating the spinning rates of blades leads to drone motion at the basic level!

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Author (s)

Dr. Basavaraj Kagali

Former Chairman and Professor
Department of Physics, Bangalore University
President of Karnataka Physics Association