# Playbook Module
# A-2: Essential Drone Knowledge

**Level:** Beginner
**Pre-requisites:** None
**Learning Objectives:**

- Learn the basics behind drones,
- basic history, technology, flight, safety, how a drone flies.

## Table of Contents

## Chapter 1: Introduction

This required module introduces you to the basics about drones. Each chapter in this module covers one key area. You will explore the history of drones (Chapter 2), the basic technology that makes drones possible and how it has evolved (Chapter 3), how drones fly (Chapter 4), Safety and Ethical issues (Chapter 5), the development of regulations to allow commercial and consumer drones to fly in the United states (Chapter 6), and where the current drone industry is heading (Chapter 7).

You must complete all chapters to get credit for completing this module.

## Chapter 2: History of Drones

To start to understand the development of drones, we first need to define what a drone is.

The Oxford dictionary defines a drone as *"a remote-controlled, pilotless aircraft or small flying device*." In most military organizations, you will hear the term "UAV" which stands for "Unmanned Aerial Vehicle" and/or "UAS" Unmanned Aircraft System". However, the news media has tended to use the word "drone" for anything flying without a pilot on board. The term drone is common today in the commercial and consumer markets.

So, how do these differ?

An Unmanned Aerial Vehicle (UAV) applies only to an aircraft that can fly autonomously or remotely. It does not apply to any of the other accessories and equipment that make it work. Although the terms "UAV" and "drone" are used interchangeably in practically all articles, websites, and news, we should make a distinction that not all drones are UAVs. On the other hand, we can make the safe assumption that all UAVs are drones.

An Unmanned Aerial System (UAS) is, in simple terms, everything that makes a UAV work including the aircraft, its GPS module, ground control module, transmission systems, camera, all the software, and the person on the ground controlling the drone. To put it simply, a UAV is simply a component of a UAS.

**Why "drone"?**

The word "drone" comes from the role of and sound that worker bees make. They are mindless flying objects that make a buzzing sound. The word "drone" was first used for an unmanned aerial vehicle in 1946 and advances in drone technology in the past few years have made the term much more common. And, while they may have no mind of their own, they may soon be connected to yours, as this BBC story about drones that can be controlled by brainwaves shows.

**Military History of Drone Technology**

Some historians trace drones back to the mid-1800's when European armies used unmanned balloon aircraft to deliver bombs. The invention of the fixed-wing aircraft in 1903 spurred a new generation of drones. In 1917, during the First World War, the US developed drone weapons, but these innovative weapons were not actually put in use until after the end of the war in 1918. Then, most of them were flying bombs - precursors to the modern cruise missile.

Drones emerged in the modern era in WWII as surveillance aircraft and flying bombs (the precursors of today's cruise missiles). In the post-WWII years, the cold war increased the use of unmanned systems. Existing aircraft were converted to remotely piloted aircraft to be used in target practice. The US and the USSR used drones extensively for spying and surveillance. A famous example is the D-21 drone, built to ride on top of the Lockheed A-12, the predecessor of the SR-71, and then launch in mid-flight.

The modern military usage of drones really took off after the Israel Air Force used the Scout and Mastiff drones in its stunning defeat of the Syrian Army in 1982. Used equally as a weapon, reconnaissance tool, and decoy, the Israeli prototype tactics integrated drones into a modern battlefield scenario. The lesson inspired the US and other military powers to invest heavily in drone research and development.


**Scout UAV**

The US began an extensive development of military drones in the early 1980's. In a process that culminated with the Predator MQ-10 drone system, the US gradually added systems, weapons, and sophisticated precision controls to its drone arsenal. Drone systems emerged as a favored way of delivering a precision strike with some human control over the event at the point of contact. Today, drones have a central role in the US military arsenal. They have proven effective and reliable across a wide range of climates, terrains, and battlefield environments. As technology has improved, drones have become smaller and smaller, evolving from their full-sized aircraft predecessors.

**Commercial History of Drone Technology**

Military advances have also fed a continuous line of civilian and commercial applications. Military usage of drones included surveillance of territory and reconnaissance to locate enemy positions and troop movements. Public and private organizations have followed the military example.

The catalyst for growth in the private sector occured in the mid-2010's when the first volume consumer drone manufacturers - DJI and 3D Robotics - entered the market, offering cinematographers and photographers a new, less expensive, and easy way to carry cameras into the sky and capture aerial content in a way that previously would require the costly burden of renting time in an actual helicopter, paying for aviation fuel, and covering insurance costs. It was realized very quickly that off the shelf drones could do much more than take nice vacation photos or make TV commercials, and a heavy reinvestment by those leading manufacturers, their competitors, and newly formed software companies began to expand the role and ability of consumer drones to handle data collection that was once reserved for military and government use.

For example, government agencies used drones for border surveillance, and private businesses began to adopt them for site security monitoring, routine inspections, and other forms of aerial data collection in areas where it was previously too costly or too complex for existing capabilities.

Citations: Nevada Institute for Autonomous Systems, and The Pilot Institute,
History of Drones Refresher Quiz
What were the first uses of drones?

- Amazon package delivery
- Flying movie cameras
- World War I flying bombs
- Unmanned balloons dropping bombs
- The Predator MQ-10
- The D-21

## Chapter 3: Drone Technology Evolution

There have been several significant stages in the evolution of commercial drone technology. In a fundamental sense, the challenges began with the ability to fly drones reliably and regularly as needed. The drone industry achieved basic elements of flight, reliability, and equipment in the early stages of growth. The advanced stages came later and have continued the leading edge of research and development today.

Development of reliable controls and stable flight capability

This stage was the threshold for commercial drone utilization. The systems became reliable tools and predictable systems. The commercial use prices decreased to a level that businesses could buy and deploy systems in large volumes. Automation added simplicity to drone operation as many onboard systems were automated by advancing technology. The net result was drone systems that were easier to operate and available to a larger group of trained pilots.

Fundamentally, the advances in reliability and automation were a result of falling prices for sensors that detected orientation movement, pressure, heading, and location. As cell phone manufacturers continued to evolve smartphones to incorporate desired functions like app-based navigation, automatic orientation detection, and health monitoring, automobile manufacturers were starting to add obstacle recognition through computer vision and machine learning - in all cases continually making the chips and hardware to enable these advancements cheaper and cheaper.

Young researchers at universities in the US, Europe, and China started to incorporate these sensors into their experimental flight control systems. Complex algorithms for control loops were being developed around the usage of these new external devices, and before long, some of the world's first flight management units were making their way into consumer drones!

Upgrades for Onboard Cameras and Sensors

Many of the first commercial drones that included an onboard camera had only very basic motorized servos that would slowly tilt or reposition the direction of the camera. A significant technological advancement was needed in order to transform this capability into being able to provide reliable, actionable aerial imagery. This first came in the form of the multi-axis gimbal. A drone's gimbal is a motorized camera mount that has its own onboard orientation sensors, and combines data from those internal sources to that of the aircraft's orientation - removing vibration, and reacting in real time to remove or limit impacts from the vehicle's movement, while keeping the camera facing a desired point.

Improvements in cameras and sensors produced reliable imagery and reports. The reliability of the drone system ensured the accuracy of the data collected and that the system could duplicate its procedures exactly. Data processing went to normal desktop computers, and people could perform tasks routinely with automated systems and software analysis tools.

Scalability of Drone Usage

Individual "test" drones highlighting newer technology were of great interest to businesses, but before they could be brought into regular use, they had to become affordable, with good accuracy and ease of use. They needed to not only test successfully, but also go into real-time usage at the rate and level of action needed by the organization. When these systems started to provide acceptable costs, accuracy, productivity, and reduced risks in hazardous operations, companies began to use drones regularly for routine tasks such as rooftop inspections and aerial surveys.

Data Management and Machine Learning

Regular use of drones in essential functions produce lots of raw data and the sheer amount of data is really not manageable by people. Because of the growing need, companies and individuals started to integrate database management into the drone data collection systems. As the databases became large and complex, they turned to machine learning to optimize usage of the data. Utilizing machine learning algorithms, the machines could begin to signal changes, spot defects, identify patterns, and indicate trends.

Drone Systems Integration

Drone functions and data now blend data collection, analysis, and application seamlessly - essentially highly automating the drone's operation, data collection, and data analysis. In the 2013-2014 timeframe, the addition of smart on-board computers helped to automate operations to make complicated tasks easier to perform, such as flying the same pattern over and over again, collecting data, and/or taking photos. These innovations started to open more and more applications for drone usage.

Hazardous Uses

As drone usage grew, more attention was placed on deploying drones to collect data in conditions that could be hazardous for people to operate in. For example, mining and quarry operations added toxic fume detectors to an inspection routine so that drones could participate in programs that protect workers. Search and Rescue in rugged or hazardous conditions have benefitted from being able to send a drone in to provide real-time imagery and search capabilities. Even simple tasks, such as climbing up a ladder to inspect hail and storm damage to houses, is now being done by drones in a manner that is both faster and safer. In many areas, the common enabler is, "If it is unsafe for a human to go look at something, send in a drone."

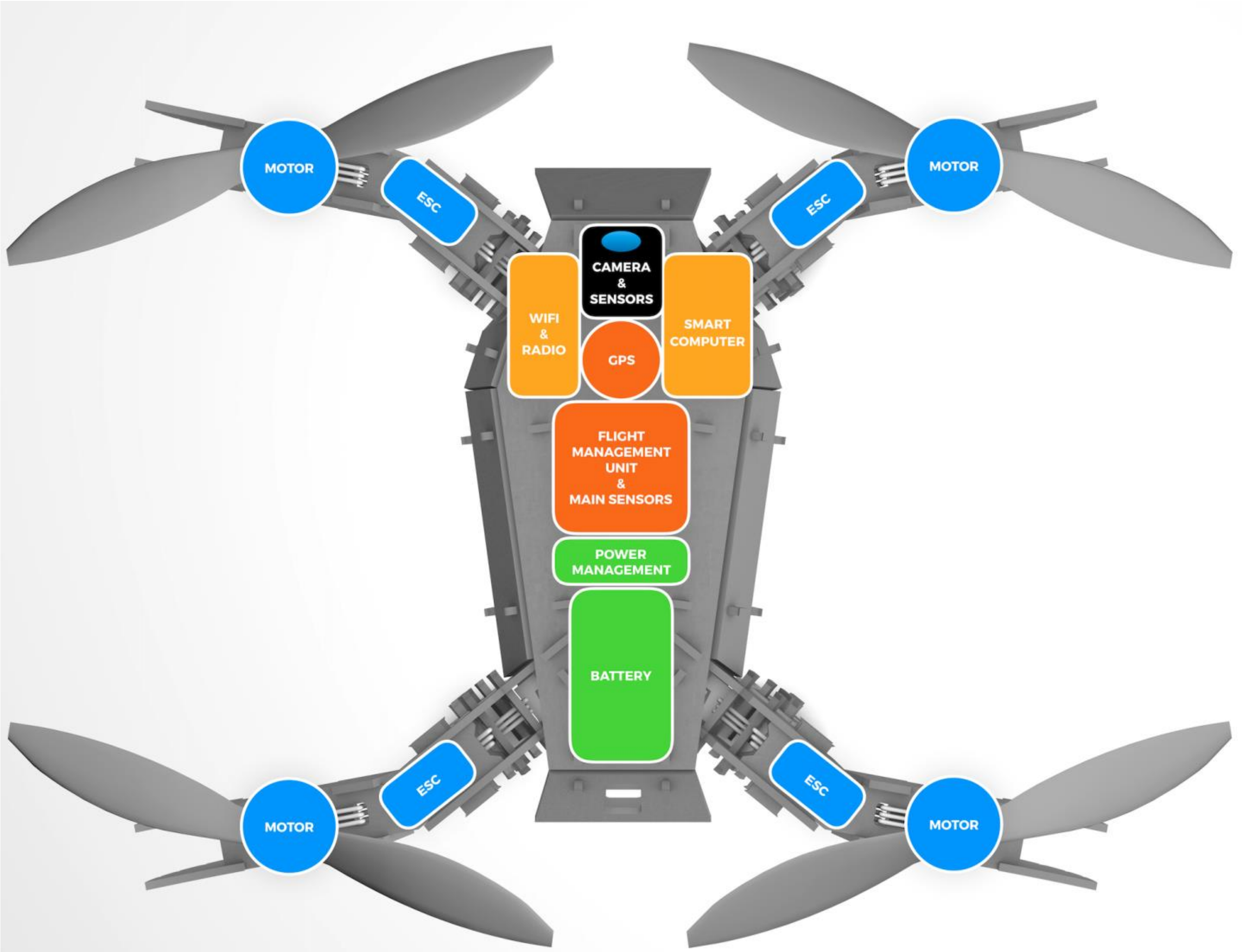
Which of the following are key stages of drone evolution?

- Reliable controls and stable flight capability
- Remote control model airplanes
- Drone Systems Integration
- Powerful, lightweight batteries

Overview of Drone Technologies

There are at least two major elements of a drone system that every drone has to have, other than a pilot. They are: An Aircraft and a Flight Controller.

**Aircraft system diagram**



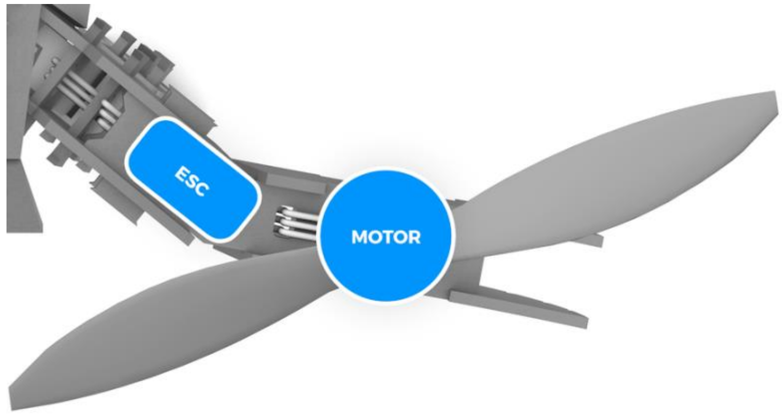

A typical drone air vehicle consists of:

- Multiple propulsion subsystems, each consisting of motors, propellers, and electronic speed controllers (ESC),
- A Power system, consisting of a power source (typically a battery), a power distribution system to get the right voltages to all the different electronic components, and wires,
- A Flight Management Unit (FMU), which provides real-time software control of the propulsion and communications systems,
- Various main sensors used for flight control including accelerometers, compass, gyroscope, horizon levels,
- A variety of additional plug-in components, such as optical flow sensors, Global Positioning System (GPS) receivers, different sensors and cameras, and,
- One or more Communications subsystems, including direct control radio receivers, and WiFi communications modules,
- All mounted to some sort of airframe.

Propulsion System

Typical drones have four rotor systems.  Each system has a motor, a propeller, and an Electronic Speed Controller (ESC).




Drones use rotors for propulsion and control. You can think of a rotor as a fan, because they work in pretty much the same way - spinning blades push air down. Of course, all forces come in pairs, which means that as the rotor pushes down on the air, the air pushes up on the rotor. This is the basic idea behind lift, which comes down to controlling the upward and downward force. The faster the rotors spin, the greater the lift, and vice-versa.

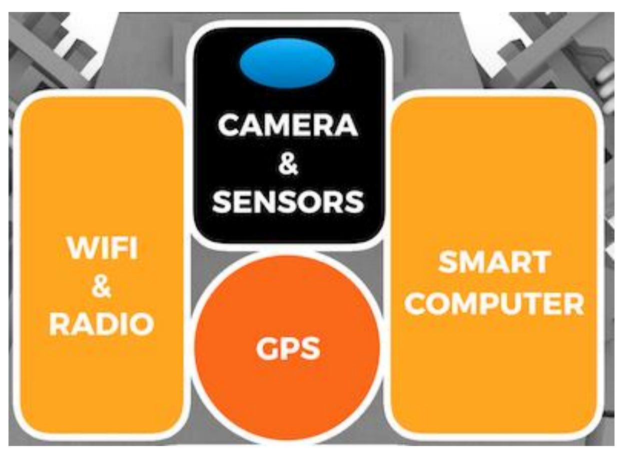
The ESC's control the speed of the motor and are used by the FMU to fly the aircraft.

Flight Management Unit

This is usually a single board that contains a real time flight control computer which runs the system and implements many of the advanced flight modes. These flight modes need to run in real-time and cannot wait for lots of back-and-forth radio commands  to the ground flight control system.  There is a dedicated radio communications channel from the joysticks and buttons for real-time interaction with the handheld flight controller. The main sensors are used to understand the orientation and movement of the aircraft, such as accelerometers, compass, gyroscope and horizon level.


Optional Components

Optional components vary depending on the manufacturer and expected uses of the drone. Almost all drones have some sort of camera, and different systems will add other sensors, such as LIDAR, Optical sensors, etc. to automatically detect obstacles and find the ground. In order to do so, many aircraft incorporate a small computer to assist the Flight Management Unit in handling these tasks. This is an important addition because the FMU should only be tasked with running code to keep the aircraft in the air. It is much better to have a second computer for more elaborate functions like camera controls and adds a layer of safety if one of these applications has a problem. Additional communications modules can be added to transmit imagery and other information.



Power System

The Power system consists of a Power storage device (usually a battery and a power distribution board), which adjusts voltages to the needs of the other components and the wiring that routes that power to those components.

The Power System adjusts, distributes, and manages power that is being delivered to the drone and all of its components. This works sort of like a highway that takes a large amount of vehicles moving quickly - in our case, electrons, and guides them onto smaller roads and through stoplights, so that the right amount of power reaches the proper components. Big motors and speed controllers need a lot more power than small LED lights and cameras. This power system is also smart and can run tests on itself to let the drone pilot know if there are any problems.


Handheld Flight Controller


A typical flight Controller is a hand-held device that provides a series of physical controls (buttons, joysticks, etc.) for the pilot to control the system. These are usually on dedicated radio communications channels so that the time lag from when a joystick is moved to when the signal arrives at the Drone and is implemented can be minimized. This is called “latency”. Longer latencies mean it is harder to fly the drone, as too much time may elapse between the movement of a joystick, and when the drone actually changes. In aircraft systems, there is a term called “Pilot Induced Oscillations” or PIO which is defined as *sustained or uncontrollable oscillations resulting from efforts of the pilot to control the aircraft* and occurs when the pilot of an aircraft inadvertently commands an often increasing series of corrections in opposite directions, each an attempt to cover the aircraft's reaction to the previous input with an over correction in the opposite direction. Good latencies for drones are measured in thousandths of a second. Long latencies can be one cause of PIO.

Smartphones and tablets are the most commonly used displays for seeing the flight information, camera feeds, and providing menus of services. They provide all of these and additional communications links like bluetooth and WiFi. Other times, the display is built into the hand-held flight controller.

Drone Technology Refresher Quiz
What are key elements of common drone technology?

- Pilot
- Flight Management Unit
- Good Weather
- Propulsion systems
- Power System
- Smartphone

# Chapter 4: How Drones Fly

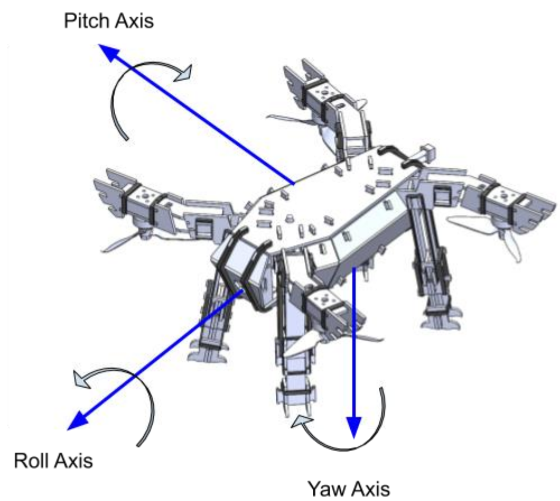
This Chapter covers the basic forces that affect drone flight and how a drone uses these forces to fly common maneuvers.

Let's start with the basic physics of motion. Sir Isaac Newton came up with three basic ideas for the physics of motion. These are now called Newton's Three Laws of Motion.

1. An object at rest tends to stay at rest, and an object in motion tends to stay in motion, with the same direction and speed. Motion (or lack of motion) can't change without some unbalanced force acting on the object.
2. The acceleration of an object produced by a force applied to that object is directly related to the magnitude (size) of the force and the direction of the force, and is inversely related to the mass of the object. Inversely means that the acceleration is greater for lighter objects and less for heavier objects.
3. For every action (force) there is an equal and opposite reaction (force).

Think of firing a cannon. The gunpowder explodes and exerts a force on the cannon ball that shoots the cannon ball out of the cannon. At the same time, there is an equal and opposite force on the cannon itself, pushing the cannon backwards. Law 2 then comes into effect since the cannon weighs so much more than the cannon ball, in that the cannon ball moves much farther than the cannon does.

The next critical concept is the drones coordinate system. To understand drone motions, we need a common reference. The standard axes or coordinate system for a drone (or any aircraft, ship or spacecraft for that matter) is shown below.




This is called a right-handed orthogonal coordinate system, where each axis is at 90 degrees (a right angle) from the other two axes. If you take your right hand, and point your thumb forward (x or Roll axis), your index finger straight out to the right (y or pitch axis) and your middle finger straight down (z or Yaw axis), those are the orthogonal axes.

An aircraft in flight is free to rotate in three dimensions:

- Yaw: nose left or right about an axis running straight down from the drone's body (the yaw axis)
- Pitch: nose up or down about an axis running parallel to the wings (the pitch axis)
- Roll: rotation about an axis running from tail to nose (the roll axis).

Positive roll is rolling to the right, lifting the left wings and lowering the right wings (clockwise) around this axis. Positive pitch is rotating (or pitching) up which raises the nose and lowers the tail (clockwise) around this axis. Positive Yaw is where the drone's nose turns to the right, or clockwise around this axis.

A drone's controls always work in the drone's coordinate system. But, remember that the drone flies over the earth, so you need to be concerned with what is called a local earth orthogonal coordinate system and the drone's coordinate system reference to the earth.

If your drone is level to the ground, so that the yaw axis points to the ground, and the Pitch and Roll axes are parallel with the ground, then forward flight moves the drone at the same altitude. But if your drone's nose is pointing straight down towards the ground, then forward flight moves the drone straight into the ground.

Just as you can look at your drone in the sky and make decisions on where you want to fly it, your drone has a variety of sensors so that it can understand it's orientation, location, altitude and movement on its own! This is truly what separates drones from other RC helicopters and airplanes. In fact, the many of the same sensors that are in your smartphone are the exact same sensors that you would find looking at the circuitry of your aircraft.

- GPS Sensor - tells the aircraft where it is on Earth by listening to satellite signals
- Electromagnetic Compass - lets the aircraft understand which direction it is facing
- Inertial Measurement Units (IMU) - several sensors that detect changes to the leveling of the aircraft and senses movement
- Altimeter - tells the aircraft what height the drone is above the ground.

The Flight Management Unit takes information from all of these sensors (and sometimes more) and incorporates them into complex mathematical control code loops to make decisions to stay in a hover and how to stay airborne with stability as you fly it!

Let's look at some common drone motions.

<u>Basic Flight:</u>

The rotors act like wings of an airplane. They generate thrust by rotating at fast speeds, pulling the air downwards and pushing the drone upwards, which keeps the drone in the air.

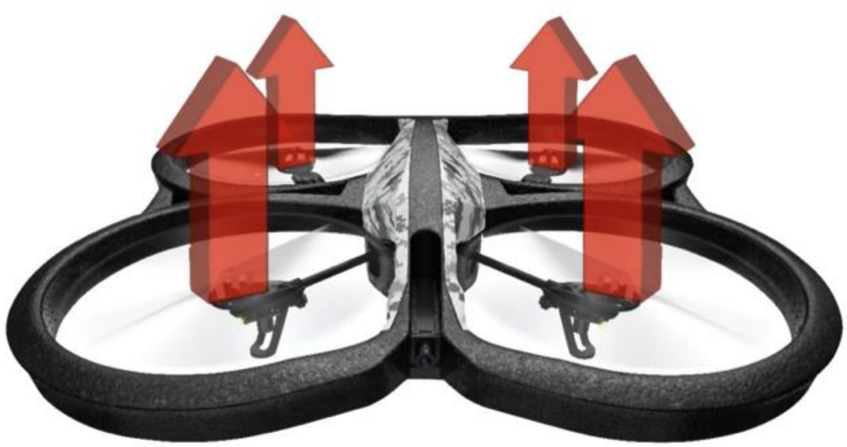
A drone can do three things in the vertical plane: hover, climb, or descend. To hover, the net thrust of the four rotors pushing the drone up must be equal to the gravitational force pulling it down. So, what about moving up, which pilots call climbing? Just increase the thrust (speed) of the four rotors so that there is a non-zero upward force that is greater than the weight.

Descending requires doing the exact opposite. Simply decrease the rotor thrust (speed) so the net force is downward.

Changing the thrust to cause a force that is not just straight up or down causes the drone to move in the direction of that thrust.

<u>Taking off:</u>

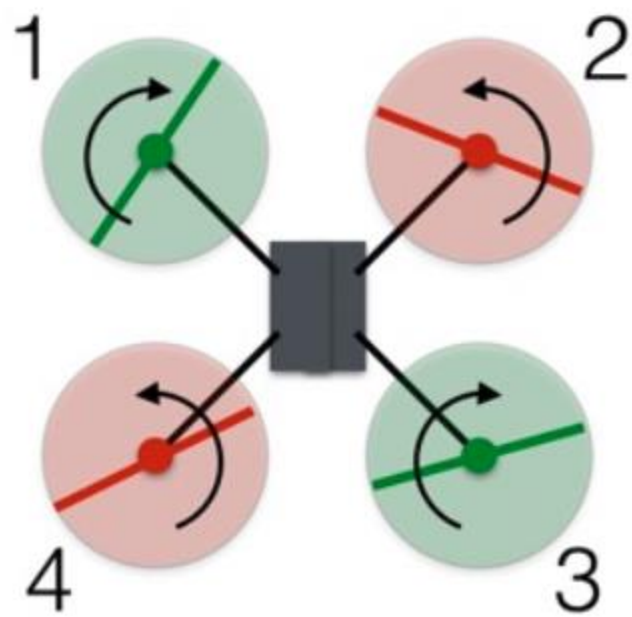
To rise above the ground, you need a net upward force that is greater than the force of the gravity and the weight of the drone.



Hover: Hovering is simple. Your rotors generate thrust that should equal the force of gravity on the weight of the drone. When those forces balance, the drone hovers.

Turning (Rotating):

Let's say you have a hovering drone pointed north and you want to rotate it to face east. How do you accomplish this by changing the power to the four rotors? Before answering, look at this diagram of the rotors (viewed from above) labeled 1 through 4.




Drones have to deal with something called their angular momentum which is driven by the force of the torque (the twisting motion) of the rotors. If you just have one horizontal propeller, like in a helicopter, the spinning of the rotor creates an angular force that tries to drag the aircraft along in the same direction as the motor/propeller is turning.

Most drones use several rotors (typically 4). To prevent the drone from spinning around (yaw motion), the rotors are set to rotate in opposite directions to balance the angular momentum. In this configuration, the red rotors are rotating counterclockwise and the green ones are rotating clockwise. With the two sets of rotors rotating in opposite directions at the same speed, the total angular momentum is zero. Newton's 1st law.

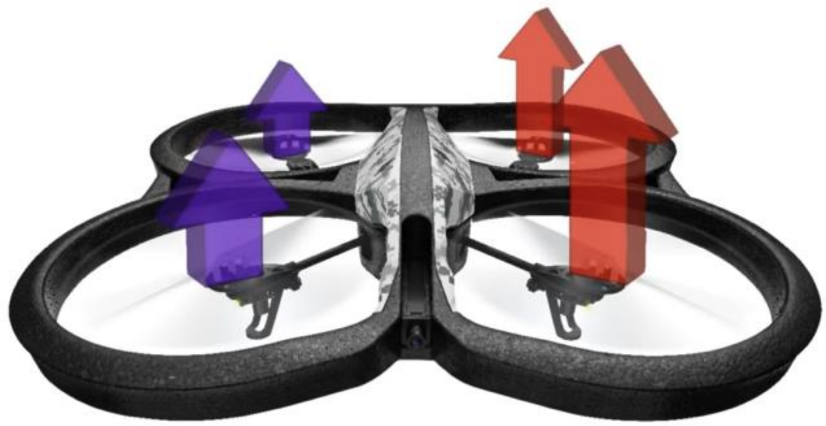
To execute a horizontal turn, you need to change the angular momentum of the drone. If you reduce the speed of rotor #1, then the drone starts to rotate (yaw) clockwise. BUT, if you just do that, you have also decreased the thrust of rotor #1, so that the arm of the drone with that rotor starts to drop. It is necessary to keep the total thrust the same to maintain a hover, AND change the angular momentum at the same time. You can do this by decreasing the speed for rotors 1 and 3 and increase the speed for rotors 2 and 4. The total vertical force remains the same, so the drone continues to hover, but the angular momentum is no longer zero for the drone, so the drone rotates.

Roll:

To roll to the left, the thrust of the right motors needs to increase and the thrust of the left motors needs to decrease.

Why do you need to do both? Can't you roll just by increasing the thrust of the left motors?

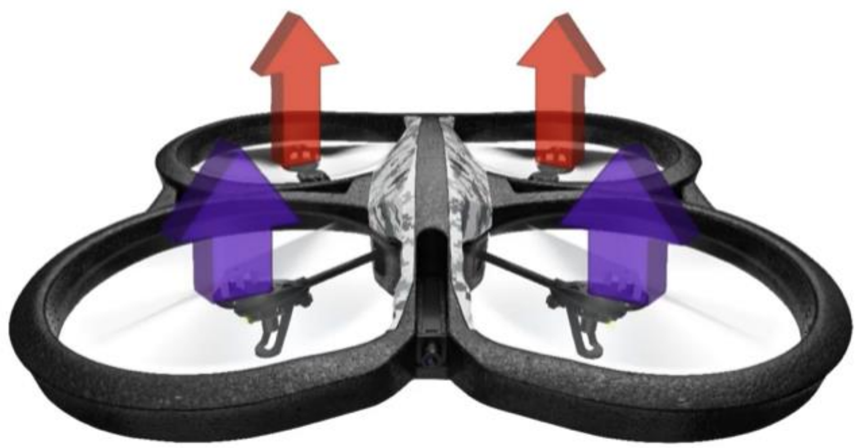
If you do this, your drone will roll AND rise up AND start to yaw because the total net upwards thrust has increased pulling you out of a hover, and the total net angular momentum is no longer zero.



Pitch:

How would you pitch the drone forward? To pitch the drone forward, increase the thrust of the two rear rotors while increasing the thrust of the two forward rotors.

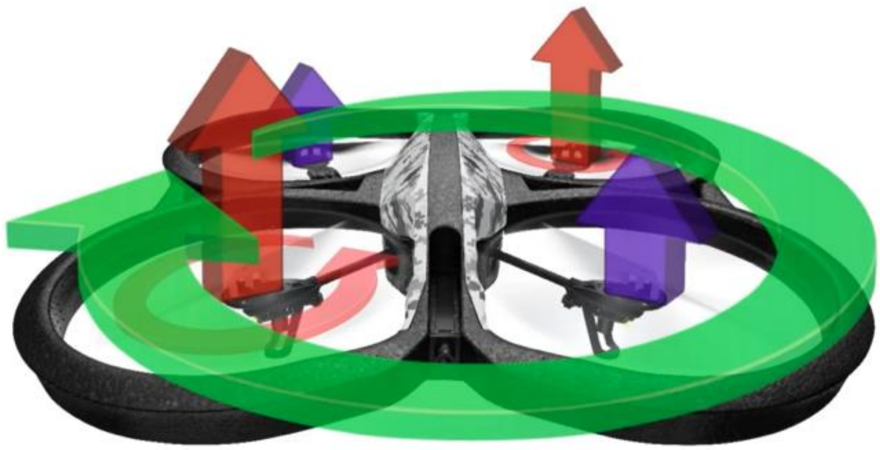
Why? To balance the angular momentum so the drone does not yaw.



Yaw:

How would you yaw the drone clockwise?  Increase the thrust of the right front and left rear rotors while decreasing the thrust of the other two rotors.

Why?   To create a counterclockwise Torque so that the angular momentum is not zero and the drone yaws.

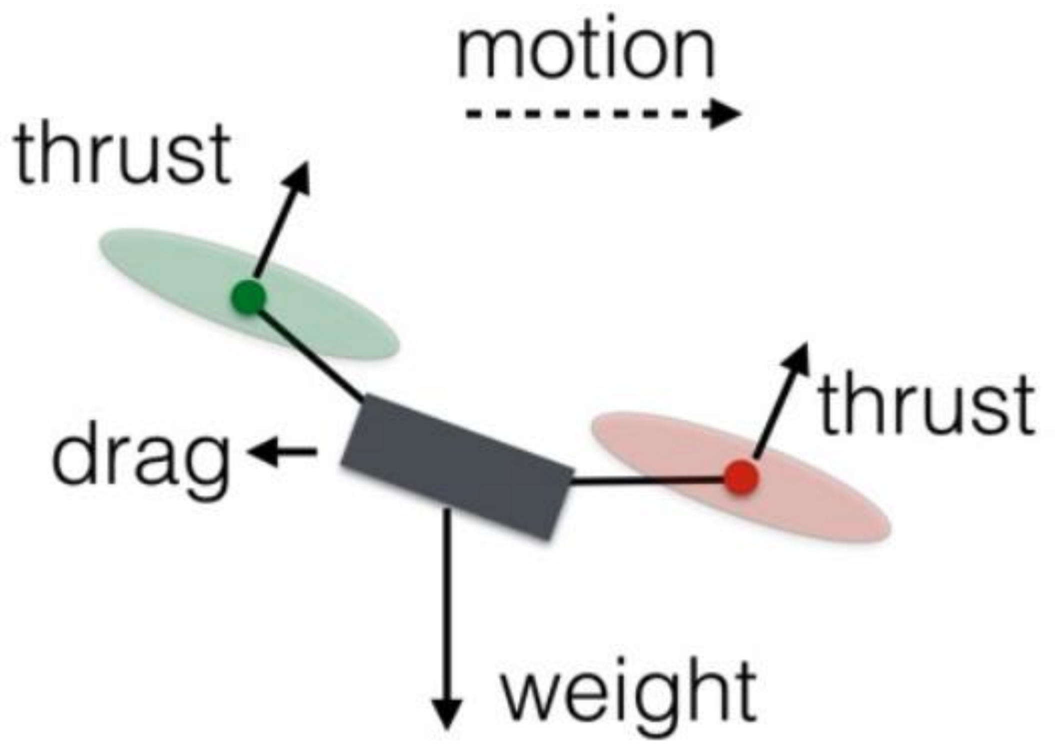


Forward and Sideways Movement

What is the difference between moving forward or backward?

None, because the drone is symmetrical. The same holds true for side-to-side motion. Basically, a quadcopter drone is like a car where every side is the front. This means that explaining how to move forward also explains how to move back or to either side.

In order to fly forward, you need a forward component of thrust from the rotors. Here is a side view (with forces) of a drone moving at a constant speed.




How do you get the drone into this position?

You could increase the speed of rotors 3 and 4 (the rear ones) and decrease the speed of rotors 1 and 2. The total thrust force will remain equal to the weight, so the drone will stay at the same vertical level. Also, since one of the rear rotors is spinning counterclockwise and the other clockwise, the increased rotation of those rotors will still produce zero angular momentum. The same holds true for the front rotors, and so the drone does not rotate. However, the greater force in the back of the drone means it will tilt forward. Now a slight increase in thrust for all rotors will produce a net thrust force that has a component to balance the weight along with a forward motion component.

By now, you've surely noticed that every movement is accomplished by changing the spin rate of one or more rotors. Doing that simply requires a controller that can increase or decrease the voltage to each motor. That's not too difficult to set up...but just imagine this -- you have a drone with 4 controllers. You'd need one controller for each motor power level. It would be extremely difficult to manually adjust each motor's power to achieve the desired motion.

However, if you have some type of computer control system (the Flight Management Unit and the hand-held flight controller), you can simply push a joystick with your thumb and let a computer handle all of that. An accelerometer and gyroscope in the drone can further increase the ease and stability of flight by making minute adjustments in the power to each rotor. Add a GPS system, and you can pretty much get rid of the human entirely.! So, you can see that flying a drone is pretty easy if you let the computer do all the work, but it's still nice to understand the physics behind it.

## Chapter 5: Safety and Ethical issues

Safety/Legal Considerations

A drone can be the cause of serious injury and even death! Every drone pilot must understand how to fly their drone safely to avoid accidentally hurting someone else. The Federal Aviation Administration (FAA) has published minimum safety rules to help prevent accidents. The current law in the United States requires the following:

1. Register your drone, mark it on the outside with the registration number, and carry proof of registration with you.
2. Fly only for recreational purposes.
3. Follow the safety guidelines of a community-based organization (such as the that provided in the Flight Safety and Regulatory Rules instructional module).
4. Fly your drone at or below 400 feet when in uncontrolled or "Class G" airspace. This is airspace where the FAA is not controlling manned air traffic. To determine what type of airspace you are in, refer to the mobile application that operates your drone (if so equipped) and/or use other drone-related mobile applications. Knowing your location and what airspace you're in will also help you avoid interfering with other aircraft.
5. Do NOT fly in controlled airspace (around and above many airports) unless:
    1. You receive an airspace authorization for operations in controlled airspace through LAANC (Low Altitude Authorization and Notification Capability), before you fly. Learn more about approved LAANC UAS Service Suppliers for recreational flyers.
    2. You are flying at a recreational flyer fixed site that has a written agreement with the FAA. The FAA has posted a list of approved sites and has depicted them as blue dots on this map. Each fixed site is limited to the altitude shown on this map, which varies by location.
6. Keep your drone within your line of sight or within the visual line-of-sight of a visual observer who is co-located and in direct communication with you.
7. Do NOT fly in airspace where flight is prohibited. Airspace restrictions can be found on our interactive map, and temporary flight restrictions can be found here. Drone operators are responsible for ensuring they comply with all airspace restrictions.
8. Never fly near other aircraft, especially near airports.
9. Never fly over groups of people, public events, or stadiums full of people.
10. Never fly near emergencies such as any type of accident response, law enforcement activities, firefighting, or hurricane recovery efforts.
11. Never fly under the influence of drugs or alcohol.

Recreational flyers should know that if they intentionally violate any of these safety requirements, and/or operate in a careless and reckless manner, they could be liable for criminal and/or civil penalties.

Ethical Considerations

The primary ethical issue surrounding drones is based on individual privacy. How would it make you feel if a drone flew over your house while you were sunbathing by the pool, hanging out with your family, or just watering the plants? Your answer would probably depend on who was flying the drone and for what purpose. But in general, if you are like everyone else, you probably have some privacy concerns.

Very simply put, you should never view or capture ANY imagery (still photos or live video) of anyone or any private property without the individual or owner’s permission. Furthermore, you should not fly over private property and should never harass anyone in any way with your drone. These are not just ethical issues, they can also be legal issues.

For example, the State of California has a law commonly called the “Paparazzi Law” which says that drones cannot fly above residences and invade privacy.

## Chapter 6: Development of commercial and consumer regulations in the United States

According to The Drone Enthusiast, in 2006 the FAA began a search for rules and systems that could make drones safe and practical for recreational and commercial usage. The issues included possible interference in the US commercial airspace, safety, and risks of operations near or above civilian populations.

The FAA issued the first initial commercial drone permit in 2006. Over the following eight years, the agency averaged two permits per year, which equaled the number of requests.

The year 2006 was important in the history of civilian drone use. The technology started to really transition from single rotor/fixed wing drones to the currently popular multi-rotor drone, and this was a major tipping point for the explosion in use of drones. Some federal agencies started to initiate drone systems for assistance in disaster relief, border enforcement, and fighting forest fires. Private corporations began using drones for essential tasks and functions such as federally mandated pipeline inspections, and to apply pesticides on crops. As unmanned aerial vehicle technology improved in the military sector, those same technological improvements jumped over to the private sector.

In 2013, Amazon announced a plan to develop a drone-based delivery system. The Amazon announcement came at a time when many companies had also begun using or experimenting with drones. The trends generated high levels of interest in drone operations, education, training, and commercial drone courses. Concurrently, many drone pilots and small companies were forming strategies to use their aircraft beyond recreational purposes - primarily in aerial cinematography and photography sectors. At that time, the only way an operator could fly a drone commercially was to file for a for a Section 333 Exemption to the current FAA rules, and to obtain a Certificate of Airworthiness. This was a complicated and very manual process that was burdensome to entrepreneurs who wanted to enter the space.

Thankfully, it wasn't long before the FAA recognized that drones were about to shape the future of aerial data capture. After many proposals, hearings, and changes to policy, the Small Unmanned Aircraft Rule (Part 107) was published and opened the floodgates to commercial drone operations at scale. As proof of the high level of interest, the FAA issued 1000 drone permits in 2015. The permit rate further increased to 3,100 in 2016. As of February, 2019, The FAA has almost 1.3 million registered drones in the United States and they say that there are hundreds of thousands of additional drones in use that have not been registered. The permit request rate continues to grow daily.

## Chapter 7: The Future of drones

There are few certainties about the future of such a complex industry such as UAVs, but some current research and commercial activity at drone testing sites indicate some likely directions. Trends indicate an expansion of drone use and drone use cases. There will be a greater demand for trained and certified operators, through commercial drone courses and practical training. Unmanned robotics systems like the BSA Drone are the sum of many components working together in unison. These components, their function, and the research behind them is the embodiment of the largest technological movement in education. The future of drone usage and drone technology will likely continue to grow to include the below-listed areas, and beyond!

- Emergency response
- Unmanned survey and mapping
- Hazardous duties and critical infrastructure inspections
- Commercial deliveries
- Commercial passenger transport and personal transportation -future of urban mobility
- artificial intelligence and augmented reality

UAVs are an intrinsic component of autonomous robotics, and their continued development has not only opened many doors for greater refinement and expansion of cool tech like higher resolution cameras, but is ultimately paving the way for a future where robotic systems become an essential part of everyday life. As artificial intelligence further augments our human capabilities by enriching our lives and lowering risk, one thing is certain - many of the ideas and innovations that will transform our future are in the minds and hands of our children.