SECTION

5

UAV CLASSES AND SUBSYSTEMS

Unmanned Aerial Vehicles (UAVs)

UAV Applications

INTRODUCTION

This section will focus on the classes of UAVs and their operational principles. In essence, you will gain an understanding of how these UAVs function. Furthermore, you will be introduced to the various systems required for UAV operation and their primary roles. Most notably, you will learn about the components that constitute these UAVs you come into contract with regularly. Let us commence our exploration of this topic.

At the end of this section, you will be able to:

- Analyse the features of Unmanned Aerial Vehicles (UAVs).
- Explain the principles of operation of UAVs.

Key Ideas

- *UAVs (Unmanned Aerial vehicles)* are not designed to have a pilot on board.
- *Concept of operation* is the way an aircraft works
- *Rotor* is a rotating part of a mechanical device that generates lift.
- *VTOL (Vertical Take-Off and Landing)* aircrafts can take off and land vertically like helicopters do.
- *Propulsion* is the force that is generated by an aircraft's engine(s)

INTRODUCTION TO UNMANNED AERIAL VEHICLES

Unmanned Aerial Vehicles (UAVs), commonly known as drones, are aircrafts that do not have a pilot on board. They are either controlled remotely or operated automatically using programmed or inputted commands.

Types of UAVs

There are two main types of UAVs. They are:

1. Fixed -wing UAVs
2. Rotary-wing UAVs

Fixed-Wing UAVs: A fixed-wing drone is a type of unmanned aerial vehicle (UAV) that is built similar to a regular aeroplane, and relies on fixed wings to generate lift.

Rotary drones are recognised for their hovering capability, agility, and ease of control, making them ideal for close inspections, photography, and indoor flights. Fixed-wing drones on the other hand, emerge as a drone pilot's best friend for covering large distances, long-duration flights, and high-speed operations.

As a result, they can fly for long periods between recharges since they do not require a lot of energy to stay in the air because they make use of the aerodynamic lift provided by their wing. They can typically fly for longer periods.

These UAVs require space or the use of special equipment such as catapult or launches for take-off and landing. They consume relatively less energy and fly much faster than other types of UAVs, reaching high altitudes and carrying considerable payloads.

Figure 5.1: Picture of a fixed wing UAV

Concept of operation: Fixed-wing UAVs look just like conventional aeroplanes. They have a wing, which is responsible for the generation of most of the lift that keeps the aircraft aloft. A propeller provides the thrust that moves the plane forward. Without forward movement, the plane cannot fly because it is necessary to have a relative velocity between the aircraft and the surrounding air. Some configurations use a pusher propeller, while others use a tractor configuration. Roll is provided by ailerons, pitch by the elevator and yaw control by the rudder.

Rotary wing UAVs: These UAVs have rotors that rotate in an approximately horizontal plane, providing all or most of the lift. There are two main types of rotary wing UAVs: Multirotor and Single rotor UAV.

Multirotor UAV: They are the most commonly used UAVs by professionals and hobbyists. They derive their name from the fact that they have rotors with blades or propellers attached to them that spin to generate lift which normally faces upwards.

If three rotors are used, they are called tri-copters: four-quadcopters; six-hexa-copter; eight-octocopters.

They are useful for lifting objects in small or congested spaces.

The multirotor drone has simple structures and is easy to control and operate because of its flight controller, making it suitable for drone beginners.

The highly manoeuvrable multirotor drone can hover in the air and take off or land vertically. It can operate in narrow spaces because of its vertical take-off and landing (VTOL) capabilities, making it suitable for a variety of environmental operations. It is ideal for photography and videography.

Multirotor UAVs are usually small in size and versatile, bringing unlimited convenience to drone pilots. However, they have relatively shorter flight times. They require a lot of energy to remain aloft, and are, therefore, not suitable for large scale aerial mapping and long endurance monitoring and inspections.

Figure 5.2: Picture of Multi-rotor UAV's

Concept of operation: The rotor draws on the principles of aerodynamics to make the UAV move. A drone uses rotors for propulsion and control. The power of the rotor is mainly composed of motors, electric speed controller (ESC) and propellers, also known as the propulsion system of an UAV. When the drone starts, electricity from the battery is transmitted through the arm to the propulsion system that spins the motors and propellers, which converts electricity into kinetic energy. Lift is generated by the rotation of the propellers.

The drone's multiple rotors are designed to spin in different directions and at the same speed. This allows them to counteract the rotational forces exerted by each other on the body of the drone, thus keeping it stable.

Single-Rotor UAV's: These UAVs look very similar to helicopters in their design and structure. They are equipped with a large rotor at the top and a small rotor on a tail boom to control their direction. They are usually powered by gas engines and can therefore fly for a longer time compared with multi-rotor UAVs.

They can carry relatively heavy payloads and hover in place for extended periods of time. They can take off and land in small spaces, as they do not require a runway.

On the down side, these UAVs have many moving parts and travel at slower speeds than other UAVs. In addition, they generate a lot of noise and present operational hazards because of their large rotor.

Figure 5.3: Picture of single rotor UAV

Concept of operation: Single-rotor UAVs are similar in most respects to conventional helicopters. They have a single main rotor system responsible for generating the lift that keeps the aircraft in the air. This rotor is also used for changing the direction of motion of the aircraft. An anti-torque rotor (used to counteract the rotational force generated by the main rotor) attached to the tail boom provides yaw control for coordination of turns.

Hybrid VTOL UAVs: VTOL stands for Vertical Take-Off and Landing. Hybrid VTOL drone types merge the benefits of fixed-wing and rotor-based designs.

This drone type has rotors attached to the fixed wings, allowing it to hover and take off and land vertically. These rotors are responsible for take-off and landing, as well as for transitioning from vertical to horizontal flight.

For prolonged periods of horizontal flight, a propeller at the front (tractor) or rear (pusher) of the fuselage is used.

Hybrid UAVs have relatively long flight times and can carry larger payloads. They lend themselves to use in search and rescue operations as they can land in tight spaces while still covering large areas.

Figure 5.4:Picture of Hybrid VTOL UAV :

Concept of operation: Hybrid UAVs combine the benefits of multi-rotors and fixed-wing UAVs. In forward flight, the UAV functions as a fixed-wing. The multi-rotors are used for take-off and landing and for transitioning from vertical flight to horizontal flight.

Rockets: A rocket produces thrust by burning fuel. Most rocket engines turn the fuel into hot gas. Pushing the gas out of the back of the engine makes the rocket move forward. A rocket is different from a jet engine. A jet engine requires oxygen from the air to work. A rocket engine carries everything it needs. That is why a rocket engine works in space, where there is no air.

Figure 5.5: A picture of rocket

Concept of operation: Rockets work on the principles of Sir Isaac Newton's third law of Motion says that for every action, there is an equal and opposite reaction. Thus, when the rocket pushes out its exhaust, the exhaust also pushes the rocket. The rocket pushes the exhaust backwards. The exhaust makes the rocket move forward.

This rule can be experienced on Earth as well. For instance, if a person stands on a skateboard and throws a bowling ball, the person and the ball will move in opposite directions. Because the person is heavier, the bowling ball will move farther.

Activity 5.1

1. Watch the video below

   https://youtu.be/BitFG9mnTwY

2. As you watch the video, look out for the various classes of UAV's using their features. Share your observations with a friend.
3. Focus on one UAV type; using the internet as a resource, draw and label the parts of that UAV type.

   Materials Needed

   a. Large sheets of paper
   b. Pens
   c. Pencils
   d. Erasers
   e. Rulers

4. Show your drawings to another group for review.
5. Prepare and present a PowerPoint presentation of the function of the assigned UAV

   Focus of the presentation

   a. Advantages of the UAV
   b. Disadvantages of the UAV
   c. Examples of the UAV type
   d. Common applications

6. Make a poster about the principles/concept of operation of the UAV assigned to your group.

Activity 5.2

1. Go on a field trip to a UAV testing facility near you to witness UAVs in action.

   Note: Your task is to take note of the following for a whole class discussion after the visit.

   Alternatively, watch these videos in preparation for the whole class discussion:

   https://www.youtube.com/watch?v=7s5TYFPP6Uw

   https://www.youtube.com/watch?v=H2JrtlbUnZo

   https://www.youtube.com/watch?v=tsjVQprGZEk

   https://www.youtube.com/watch?v=ANVnSFHkhBE

   a. How the UAV is operated
   b. How it is maintained
   c. How it is tested
   d. How it is applied in real-world setting

2. Discuss with your peers the concept of operation observed at the visited site.

Activity 5.3

1. Design a UAV of your choice

   Materials needed

   a. Cardboards
   b. Glue and tape
   c. Cutters
   d. Ruler
   e. Markers and pens

   If you require additional guidance on the step-by-step process, please go to the end of the section where there is guidance.

Caution: Make sure all safety protocols with the use of all these materials are adhered to.

Always call for the teacher for assistance when handling hot and electrical tools.

2. Make a water rocket to demonstrate the concept of operation of a rocket (LAW: For every action, there is an equal and opposite reaction)

Materials needed

a. Plastic water bottle
b. Cork
c. Bicycle pump
d. Water
e. Fins from Cardboard
f. Nose cone
g. Scissors
h. Cutters
i. If you require additional guidance on the step-by-step process, please go to the end of the section where there is guidance.

UAV SYSTEM COMPONENTS

UAV (Unmanned Aerial Vehicle) system includes the several key components that work together to ensure proper flight and operation. The broad UAV can be split into two main parts.

1. *The air system*. The air system consists of the UAV airframe, propulsion systems, flight controls, navigation and payload.
2. *Ground system* is made up of the ground control station, which comprises hardware and software components.

Air Systems Components

1. Airframe:

The airframe is the body of the UAV.

a. In a fixed-wing UAV, the airframe consists of
   - the wings,
   - fuselage
   - tail

b. The airframe of multi-copters is generally much simpler.
- They usually have arms on which brushless DC (Direct Current) motors are mounted with on-board electronics housed in a shell or composite plates.

c. Material properties play a very significant role in the design of UAVs. The most common materials used in UAVs are
- polystyrene foams,
- light wood,
- fibreglass,
- carbon fibre,
- aramids and
- aluminium.

d. On most industrial grade UAVs, the material used is carbon fibre. Sometimes fibreglass is used to insulate the carbon fibre material because carbon fibre is an electrical conductor.

Carbon fibre is a highly preferred aerospace material because of its high strength-to-weight ratio.

Carbon fibre is used to make parts of the UAV that bear lots of stresses when in operation like the landing gears, wings and propellers.

Aluminium is also used in UAVs because of its light weight.

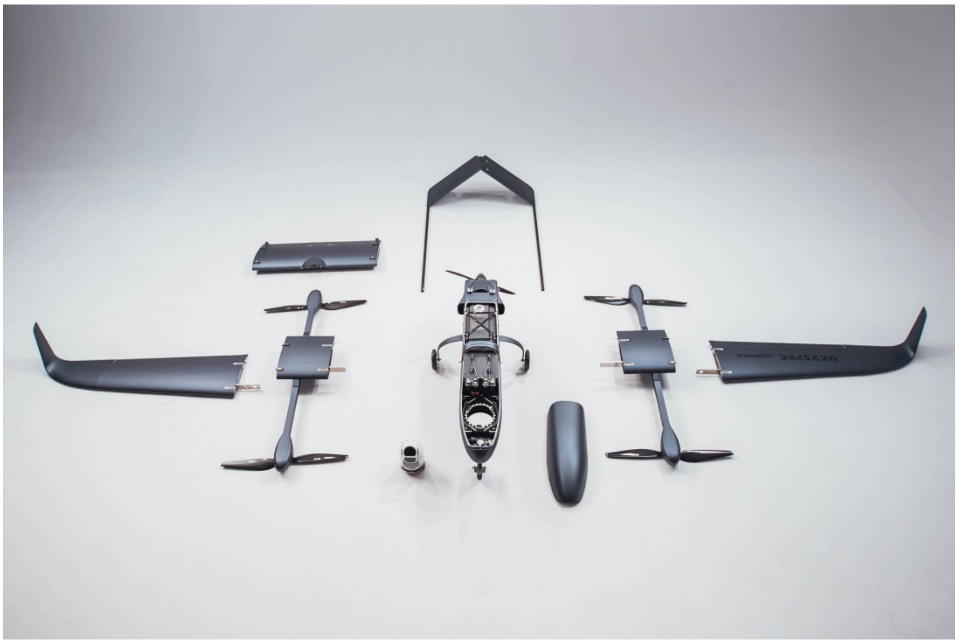

Figure 5.6: Picture of a disassembled airframe

2. Propulsion and Power

The propulsion system of a UAV may be electrically-powered or fuel-powered. The main aim of choosing the right propulsion system is to provide adequate thrust for the UAV. Each option has its advantages and disadvantages. Let us consider the options;

a. Electric propulsion

These systems are mostly employed on multirotor and small fixed-wing drones. The energy for propulsion is drawn from batteries, usually Lithium-based (Lithium-polymer or Lithium ion) batteries. The major components in electric propulsion systems are motors, propellers, electronic speed controllers and batteries.

i. *The batteries*: The batteries are the powerhouse of this kind of propulsion system. Most of the motors used in drones are brushless DC motors (BLDC) and they tend to draw a lot of current. It is therefore important that the battery being used for a UAV is able to supply the current to all connected components during all flight manoeuvres for the entire duration of the flight.

Lithium-ion batteries usually provide higher capacities than Lithium-polymer batteries of the same weight. However, Lithium-polymer batteries have very high discharge rates as compared with Lithium-ion batteries. So, the choice of which batteries to use depends on the type of UAV, the power requirements and design specifications.

There are some important battery parameters that a UAV designer must consider when choosing an appropriate battery.

- Battery Capacity: This refers to how much charge is stored in the battery. Battery capacity is usually rated in milliamp-hour (mAh). It gives an indication of how much current a battery can supply for a certain amount of time. For example, a Lithium-polymer battery of 8000 mAh capacity implies that the battery can supply 8A of current for a duration of 1 hour before being depleted. Now if the battery is required to supply more current, say 16A of current, then it will be depleted in less amount of time, which is 30 minutes.
- Series and Parallel arrangement: Batteries are a combination of cells. Each cell has a nominal voltage. For rechargeable cells, the voltage increases when the battery is fully charged and decreases as the battery is depleted.

  For most Li-Po and Lithium-ion (Li-ion) cells used in UAV batteries, the nominal cell voltage is 3.7V.

  These cells are connected in series and parallel configurations to make batteries.

  Cells arranged in series are designated with an S and cells arranged in parallel are designated with P.

When cells are arranged in series, the battery formed has a voltage equal to the sum of the voltages of the individual cells, but the capacity does not add up. For example, a 2S Li-Po battery has a nominal voltage of 7.4V, that is;

When cells are connected in parallel however, the capacity of the resulting battery is the sum of the capacities of the individual cells, but the voltage does not add up. It remains the same.

Generally, we connect cells in series to increase the battery voltage and parallel connection is done to increase the battery capacity and current output.

Figure 5.7: Lithium Polymer battery

Figure 5.8: Lithium-ion cell

ii. *The electronic speed controller (ESC)*: The ESC takes power from the battery and gives it to the motor depending on the immediate power requirement as needed by the flight controller, which is the “brain” of the UAV.

The ESC receives a PWM (pulse width modulation) signal from the flight controller. This PWM signal is an electronic signal containing information on how much current the ESC should send to the motor.

Note that electronic speed controllers are power-rated. That is, they are rated by current and voltage. It is hence important to ensure that the ESC being used in a UAV can transmit all the power requirements of the motor without exceeding its maximum ratings.

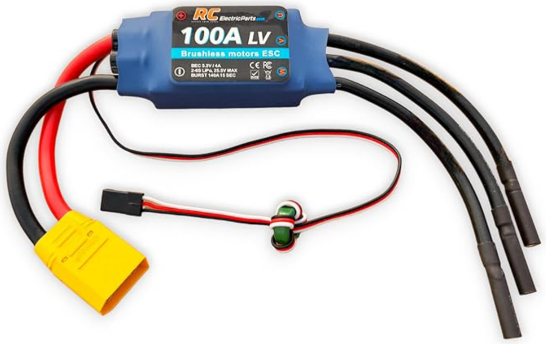

Figure 5.9: Electronic Speed Controller

iii. *The brushless motor*: The motor is the component that converts the electrical energy from the battery to mechanical energy to rotate a propeller to generate thrust.

It is made up of a stator and a rotor. The stator is the part of the motor that does not spin when the motor is running while the rotor is the part that rotates when power is supplied to the motor.

They are usually DC motors since the power supplied by the battery is Direct Current (DC).

They may be brushed DC motors or brushless DC motors. Brushed DC motors are simpler and usually cheaper; however, they are rarely used in UAVs because their brushes wear off after prolonged high RPMs (Revolutions per minute) as usually required to produce adequate thrust in UAVs.

Brushless DC motors on the other hand are able to tolerate long durations of high RPM rotation because they have no brushes instead, they employ external circuitry that creates a magnetic field that magnetises specific coils in turns to create a "rotating" magnetic field.

Brushless DC motors are more expensive than brushed DC motors but can generate high mechanical power.

Brushless DC motors are given a KV rating. Note that this KV does not mean kilovolt. KV is a measure of the relationship between the speed of a brushless motor and the voltage applied to it. It can be defined as the speed in RPM for every unit volt applied to the motor. So, a brushless motor with a 1000 KV rating supplied with 1V will spin at 1000 RPM. If it is supplied with 1.5V, it will spin at 1500 RPM. It is usually the case that motors of high RPM are used with propellers of small diameters.

Figure 5.10: Brushless motor

iv. *Propellers*: They are components that are mounted on motors to be spun to generate thrust force to move the UAV.

They may be made of

- wood,
- APC (Advanced Precision Composites)
- plastic or
- carbon fibre.

Propellers for UAVs are rated based on their diameter and geometric pitch. The geometric pitch refers to the theoretical distance the propeller moves forward in one complete rotation. The propeller chosen must match the motor it is to be used with.

Figure 5.11: A propeller mounted on a brushless motor

Generally, electric propulsion systems are less complicated, quick and cheaper to implement when compared to internal combustion engines. They do, however, lack endurance due to their lower energy densities when compared with fuel-based propulsion systems.

It is also important to note that the overall performance of the propulsion system is dependent on the combination of the motor, battery, electronic speed controller and propeller. It does not depend solely on one component.

b. Engine-Based Propulsion Systems

These are propulsion systems that use petroleum fuels as a power source. The fuel maybe petrol (gasoline) or Jet-A (a type of fuel commonly used in commercial and military jet aircrafts). These propulsion systems primarily consist of an engine, an ignition system, fuel, propellers and a tachometer.

Fuel refers to a material that can be burned to generate heat energy. Fuel is the main energy source of this type of propulsion system. It may be petrol or Jet-A.

Petrol is used mostly in piston engines while Jet-A is used in gas turbine engines. The fuel contains chemical energy that is burnt in the engine to produce thrust.

The quality of fuel must be considered with choosing fuel grade because even the same kinds of fuel may have differences in chemical composition. For example, petrol acquired from different sources may have different octane numbers which affect the performance of the engine. It is therefore important that fuel for engines be acquired from a trusted source.

The engine is the powerhouse of fuel-based propulsion systems.

Generally, the fuel is mixed with air and injected into the engine. The ignition system, which is usually powered by a battery, ignites the air-fuel mixture to create an explosion. The explosion causes a sudden expansion of the air in the combustion chamber of the engine. In a piston engine, the energy from the expanding gases is harnessed to push on a piston in the combustion chamber which moves a crankshaft to generate mechanical power to spin a propeller and generate thrust.

In a gas turbine engine, some energy from the expanding gases is harnessed by a turbine to turn a compressor, the rest of the gases are expelled from the exhaust of the gas turbine engine at high speed to produce thrust.

Figure 5.12: A gasoline twin engine

Figure 5.13: A UAV with gas engine mounted in front

Flight Controls, Instruments and Navigation

Flight controller

The flight controller is the brain of the UAV. All components on the drone are connected to the flight controller either directly or indirectly. The flight controller is responsible for making all autonomous decisions of the drone. It is also the main component that allows the UAV to maintain its stability in flight.

Without the flight controller, most UAVs, especially multi-rotors, would be incapable of maintaining stable flight. All instruments, sensors and actuators are usually connected to the flight controller.

A typical UAV has an inertial measurement unit (IMU), barometer, airspeed sensor and a GPS module connected to the UAV.

An IMU *is an instrument used to measure and report on an object's specific force (acceleration) and angular rate (angular velocity) in three dimensions*. The IMU contains 3-axis accelerometers, 3-axis gyroscopes and sometimes 3-axis magnetometers. *The accelerometers* measure the acceleration of the UAV in all 3 axes.

The accelerometers can detect vibrations on the drone that may be detrimental to the airframe of the drone and give a good indication of the gravitational forces acting on the UAV.

The gyroscopes measure the angular velocity of the UAV about the three coordinate axes. It measures the roll rate, pitch rate and yaw rate.

Through the sensor fusion of the accelerometer and gyroscope data, the IMU can provide the UAV with attitude readings. To illustrate, if a fixed-wing drone in flight is suddenly hit by a gust of wind and its attitude changes, the change in attitude will be detected by the IMU and the data sent to the flight controller. The flight controller will then actuate the necessary servos to make corrections to the attitude.

The GPS provides position awareness to the drone. GPS data also can also provide altitude readings, date and time.

The drone can also infer its ground speed from the GPS data it receives. The ground speed refers to the speed of the drone relative to a stationary ground observer. The ground speed indicates the distance covered by the UAV.

It is also necessary for the UAV to know its airspeed, especially with fixed-wing air vehicles. The airspeed is the speed of the UAV relative to the ambient air.

Figure 5.14: A picture of a flight controller kit for RC planes

Payload

Every UAV has a purpose. It may be carrying a high-resolution camera for surveillance or mapping. It may be armed to carry out military strikes or it may be fitted with a magnetometer sensor for mineral exploration. The payload refers to all these added components (camera, magnetometer, missiles) that make the UAV fit for its intended task. Without the payload, the UAV has no particular purpose.

Figure 5.15: Picture of the payload of a quadcopter

Figure 5.16: Picture of MQ-9A with camera and missiles

UAV COMMUNICATION SYSTEMS

It is very important to maintain a communication link constantly between the UAV and the operator on ground. This is to ensure that the operator is always aware of the status of the UAV while in flight.

Information like:

- battery percentage left,
- engine RPM,
- airspeed,
- ground speed,
- altitude,
- attitude,
- location and
- power consumption are important for the UAV operator on the ground to make critical operation decisions.

It is also necessary for the UAV operator to be able to send commands for the UAV to execute while it is airborne. The communication system allows the operator and the UAV to exchange information.

Radio transmitters and receivers are the commonest and easiest way to send commands to a drone.

The most common transmitters are handheld devices with two thumb joysticks, some buttons and some antennas. It may also have a liquid crystal display to put out some relevant information.

The receiver mostly comes in a smaller package also with antenna and output pins. The number of output pins is determined by the number of channels of the receiver.

The number of channels simply means how many individual components on the drone that the receiver can control.

Radio transmitters and receivers that have been paired provide an easy way to send instructions to a drone but they usually tend to be one-way communication systems as they are only able to send information to the drone.

Figure 5.17: A picture of Radio transmitter for ground communication

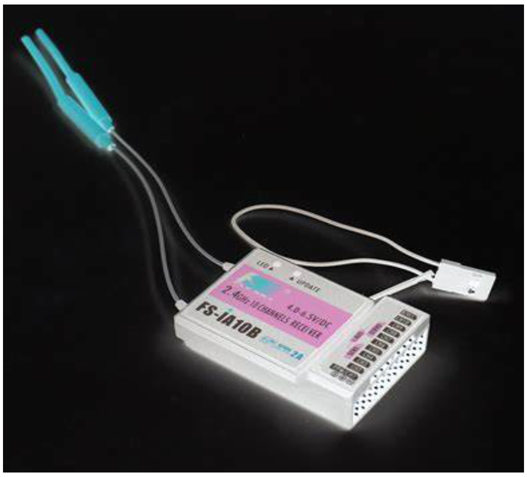

Figure 5.18: A picture of a receiver for air communication

A telemetry module allows for two-way communication between the drone and the operator.

Information such as flight speed, altitude, battery power remaining, etc., is carried on radio waves of a particular frequency.

The telemetry modules on the UAV and those on the ground should be operating at the same frequency and paired to be able to communicate with each other.

Information about the UAV received by the telemetry module on the ground is displayed on a screen for the UAV pilot to see and take appropriate actions.

Figure 5.19: Air and ground Telemetry module

Ground System Components

1. Ground control station:

The ground control station is the major part of the ground system of the UAV. It is the centre for command and control of the drone. The ground control station is the portal for the UAV pilot to give instructions to the drone. The ground control station has hardware and software components.

The hardware components usually consist of a computer (handheld or desktop), a joystick and a telemetry package for communication. It is advisable to have a power source to power the computer. The power source could be from a nearby wall socket or a generator that can be moved around.

The software component consists of a computer application for operating the drone (like Mission Planner and Q-Ground control software).

The ground control software provides an interface for the drone pilot to plan a flight route for the drone using latitude and longitude coordinates. Instructions for the drone to perform at each point is issued in the software. The software also provides information on the health status of the drone. Issues with the compass, GPS signal reception, vibrations as indicated by the accelerometer and other important parameters are indicated on the screen for the drone operator to rectify.

The telemetry hardware is connected to the computer and it takes all the commands from the software and sends them to the UAV via wireless signals. The telemetry module also receives information from the drone and sends them to the ground control software to be displayed on a screen so that the drone pilot knows the speed, altitude, heading, position and other vital information about the drone.

Even though the UAV can fly automatically when given a flight route, certain drone operations like surveillance and military patrol, may not have a predetermined flight route so one may not plan a flight route ahead of the mission. Consider, for example, a law enforcement agency using a drone to follow a crime suspect. Since the drone pilot cannot anticipate the path of the suspect, he or she cannot plan the flight ahead. In this case the UAV pilot will have to take control of the drone and fly it manually. The joystick or other controller may be used in this situation.

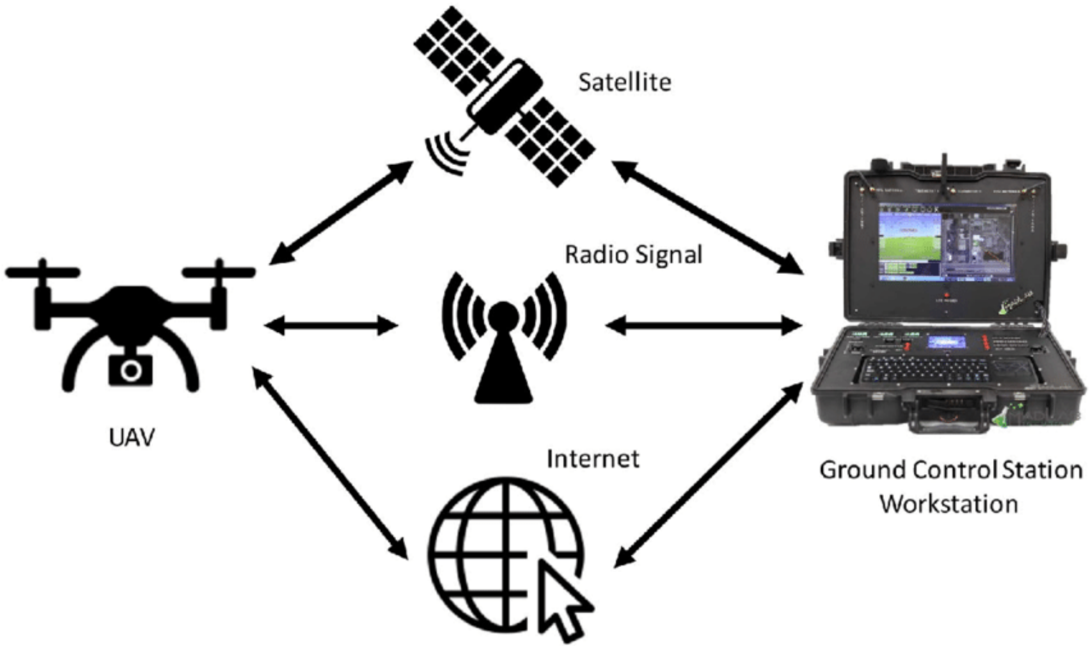

Figure 5.20: UAV communication system with ground control

2. Launch and Recovery Systems

The way a drone takes off is usually determined by its type. The commonest ways by which drones take off are rolling take-off, vertical take-off and catapult or hand-launch.

a. **Rolling take-off:** It is used for fixed wing drones with landing gear wheels. The drone taxis to take-off position on a runway then accelerates on the runway to gain speed. Once the drone reaches rotation speed then the pilot initiates pitch control inputs to take-off.

Rotation speed in aviation refers to the speed on a tarmac that an aircraft reaches before it takes off. This UAV launch method requires a runway to be executed, however, for drone operations that must take place in remote areas, a runway is most likely not a readily available facility and thus limits the use of drones that require rolling take-off.

Figure 5.21: A picture of a rolling take off of a reaper UAV.

b. Vertical take-off: It is used for drones that have mechanisms to lift off vertically from a stationary position. Drones that use this type of take-off method do not require runways to operate and are very convenient to use in remote areas. Quadcopters and helicopters are examples of air vehicles that use this type of take-off. They can also land vertically. Generally, they are called vertical take-off and landing (VTOL) aircraft.

Figure 5.22: : UAV vertical take-off and landing

c. Hand/catapult launch: Hand launching, as the name implies, is where a UAV is armed and thrown forward to take-off. Since the drone has to be thrown by hand, hand-launch take-off is limited by the mass of the drone. Drones heavier than 6kg are difficult to properly launch by hand since they are quite heavy. For heavier drones, catapult-launch works better because it is mechanised and does not need a human to launch it. Hand and catapult launched drones usually do not have landing gears and may recover alternatively on their bellies, by a parachute or some other mechanism.

Figure 5.23: UAV catapult launch by Zipline

Activity 5.4

1. Your teacher will show you a pre built UAV or a model UAV
   Note: In the absence of the models you can also watch these videos

Videos:

https://youtu.be/eH0WhuwKtE0

https://youtu.be/jOugJpQfUDU

2. Take a gallery walk around the class and look at displayed printed images of all these individual components or identify from the pre-built or model shown.
3. Discuss the major components of the UAV system with your group
4. Find out the functions and importance of each component and discuss it with your peers

Activity 5.5

1. Watch this video

https://youtu.be/bTC2DmOG32U

2. Describe the interdependence between UAV ground and airborne systems (Note: You can use the internet for more information)
3. Prepare a PowerPoint presentation of the information gathered

Activity 5.6

1. Plan a mission with your group to be executed by a UAV

2. Make a list and select the suitable combination of electronic components for the mission.
3. Make a presentation on the link between the airborne and ground system communication for your chosen mission
4. Suggest additional features that can be used to optimise any one of the following designs
   a. Quadcopter
   b. Fixed-wing UAV
   c. Hybrid UAV

Review Questions

1. You are participating in a schools' project where your team is tasked with developing a presentation on Unmanned Aerial Vehicles (UAVs). Your goal is to identify and describe the features of one model of each of the UAV types. Your presentation should help your classmates understand the distinct features and typical uses of each type.

   The following guide may help you organise your ideas

   a. Identification and Description
      i. Identify a specific model or example of each UAV type
      ii. Describe the main features and design characteristics that distinguishes it from the others

   b. Typical uses
      i. Explain the typical applications or missions for which each UAV type is best suited. Provide real-world examples where possible

   c. Advantages and Limitations
      i. Discuss the advantages and limitations of each type of UAV in terms of performance and operational considerations

2. You are part of a team designing a new UAV for a project at your school. Your task is to identify the main components of the UAV and explain its functions. Additionally, highlight the ground system components such as the launch and recovery system.

Answers To Review Questions

Question 1

Fixed-Wing UAV:

1. Identification and Description:
   a. Example: DJI Mavic Fixed-Wing UAV.
   b. Features: Resembles a traditional airplane with a rigid wing structure, designed for sustained flight.
2. Typical Uses:
   a. Applications: Long-range surveillance, mapping, and agricultural monitoring.
   b. Real-World Example: Used in large-scale agricultural surveys to monitor crop health over extensive areas.
3. Advantages and Limitations:
   a. Advantages: Long flight times, efficient coverage of large areas, stable flight in wind.
   b. Limitations: Requires runway or catapult for take-off and landing, less manoeuvrable at low speeds or in confined spaces.

Multi-Rotor UAV:

1. Identification and Description:
   a. Example: DJI Phantom 4.
   b. Features: Multiple rotors (typically four, six, or eight), capable of vertical takeoff and landing, highly manoeuvrable.
2. Typical Uses:
   a. Applications: Aerial photography, videography, inspection of infrastructure, search and rescue.
   b. Real-World Example: Used by photographers to capture aerial shots of real estate properties.
3. Advantages and Limitations:
   a. Advantages: Easy to operate, precise hovering capabilities, versatile in various environments.
   b. Limitations: Limited flight time due to battery life, reduced range compared to fixed-wing UAVs.

Single-Rotor UAV:

1. Identification and Description:
   a. Example: Align T-Rex 700.

    b. Features: Single main rotor and a tail rotor for stability, similar to a traditional helicopter.

2. Typical Uses:
    a. Applications: Surveying, delivery of small packages, agricultural spraying.
    b. Real-World Example: Used in agriculture for precision spraying of pesticides.
3. Advantages and Limitations:
    a. Advantages: Longer flight times compared to multi-rotor, better efficiency, higher payload capacity.
    b. Limitations: More complex mechanics, higher maintenance, greater risk of damage from rotor strikes.

Hybrid UAV:

1. Identification and Description:
    a. Example: Vertical Take-off and Landing (VTOL) UAVs like the Quantum Systems Trinity F90+.
    b. Features: Combines elements of fixed-wing and multi-rotor designs, capable of vertical take-off and horizontal flight.
2. Typical Uses:
    a. Applications: Long-range surveillance with vertical take-off capabilities, mapping, and surveying.
    b. Real-World Example: Used in environmental monitoring for seamless transition between hover and forward flight.
3. Advantages and Limitations:
    a. Advantages: Versatile, capable of both hovering and long-distance flight, can operate in varied environments.
    b. Limitations: More complex design, potentially higher cost, requires more advanced control systems.

Question 2

a. *Airframe*: The structure of the UAV, which holds all the other components together. It is designed to be lightweight and aerodynamic to allow for efficient flight. The airframe consists of the wings, fuselage, control surfaces (rudder, ailerons, flaps, elevators) and tail.

b. *Propulsion and Power System*: Propulsion includes the motors and propellers that generate thrust to lift and move the UAV through the air. The power typically, a battery, provides the electrical energy required to power the motors, flight controller, and other electronic components of the UAV.

c. *Flight Control and navigation system*: The brain of the UAV that processes inputs from the pilot or autonomous systems and controls the motors to keep the UAV stable and on course. Devices such as GPS, cameras, accelerometers, and gyroscopes that gather data about the UAV's environment and position, helping with navigation and mission-specific tasks.

d. *Communication System*: Allows the UAV to send and receive data to and from a ground control station or other devices, enabling remote control and data transmission.

e. *Ground Control Station*: The facility or equipment used by the operator to control the UAV remotely. It includes screens, joysticks, and communication systems to monitor and direct the UAV during its mission.

f. *Launch and recovery System*: The mechanism or equipment used to get the UAV into the air. This could be a hand launch, catapult, or runway depending on the type of UAV. The method used to bring the UAV back to the ground safely after its mission. This could involve a controlled landing, parachute deployment, or net capture

Step-By-Step Instructions for Practical Activities

If you think you might want some additional support with practical activities, please use these step-by-step guides to help you.

Step-by-step guide to Designing an Unmanned Aerial Vehicle (UAV)

1. Define Objectives and Requirements

1.1 Mission Objectives:

- Determine the primary purpose of the UAV (e.g., surveillance, delivery, agriculture, research).
- Identify specific tasks it needs to perform.

1.2 Performance Requirements:

- Define key performance metrics such as range, endurance, payload capacity, speed, and altitude.
- Consider environmental factors like weather conditions and operating environments.

1.3 Regulatory and Safety Considerations:

- Research and understand relevant regulations and standards (e.g., GCAA rules for commercial UAVs).
- Incorporate safety features and fail-safes.

2. Conceptual Design

2.1 Design Configuration:

- Choose the UAV configuration (e.g., fixed-wing, rotary-wing, hybrid).
- Select the type of propulsion system (e.g., electric motors, internal combustion engines).

2.2 Preliminary Sketches:

- Create basic sketches and diagrams to visualise the UAV's overall design.
- Determine the layout of major components (e.g., wings, fuselage, control surfaces).

3. Detailed Design and Analysis

3.1 Aerodynamic Design:

- Use aerodynamic modelling tools to design the UAV's shape for optimal flight performance.
- Perform Computational Fluid Dynamics (CFD) simulations to refine the design.

3.2 Structural Design:

- Design the frame and components considering strength, weight, and material properties.
- Use finite element analysis (FEA) to assess structural integrity.

3.3 Propulsion System:

- Choose and design the propulsion system, including motors, propellers, and batteries or fuel systems.
- Ensure compatibility and efficiency.

3.4 Avionics and Control Systems:

- Select flight control hardware (e.g., flight controller, GPS, sensors).
- Develop or integrate software for autonomous flight, navigation, and control.

4. Prototype Development

4.1 Building the Prototype:

- Fabricate or assemble the UAV based on the detailed design.
- Ensure high-quality construction and adherence to design specifications.

4.2 Integration and Testing:

- Install and integrate all components, including avionics, propulsion, and control systems.
- Conduct bench tests to verify individual components and systems.

5. Flight Testing

5.1 Ground Testing:

- Perform initial ground tests to check for system functionality, calibration, and safety.

5.2 Flight Testing:

- Conduct test flights to evaluate performance, stability, and handling.
- Collect data to identify and address issues or areas for improvement.

6. Iteration and Improvement

6.1 Data Analysis:

- Analyse test flight data to assess performance against requirements.
- Identify any design or performance issues.

6.2 Design Iterations:

- Refine and modify the design based on testing results.
- Make necessary adjustments to improve performance and reliability.

7. Finalisation and Production

7.1 Final Design Review:

- Conduct a comprehensive review of the final design.
- Ensure all design requirements and regulations are met.

7.2 Production Planning:

- Develop a plan for manufacturing and assembly.
- Source materials and components.

7.3 Quality Assurance:

- Implement quality control procedures to ensure each UAV meets design specifications and safety standards.

8. Deployment and Operation

8.1 Operational Training:

- Train operators on the UAV's usage, maintenance, and safety procedures.

8.2 Maintenance and Support:

- Establish a maintenance schedule and support infrastructure.
- Provide ongoing updates and support as needed.

9. Documentation and Reporting

9.1 Documentation:

- Prepare detailed documentation including design specifications, testing reports, and operational guidelines.

9.2 Reporting:

- Create reports on the development process, testing results, and any regulatory compliance.

Tools and Resources

- **Design Software:** CAD tools (e.g., SolidWorks, AutoCAD), CFD software, and FEA software.
- **Simulation Tools:** Flight simulation software for virtual testing.
- **Prototyping Resources:** 3D printers, CNC machines, and fabrication tools.

Step-by-step guide to making a simple water rocket

1. Prepare the Bottle

a. **Clean the Bottle**: Make sure the bottle is empty and clean. Remove any labels if desired.

b. **Check the Bottle**: Ensure the bottle is free from cracks or damage.

2. Create the Rocket Nose Cone

a. **Select a Nose Cone**: Use a cork that fits snugly into the bottle's neck, or create a nose cone from plastic or foam.

b. **Modify the Nose Cone**: If using a cork, you may need to drill a hole through the centre to fit the nozzle or valve. For a plastic cone, ensure it fits securely and tapers to reduce air resistance.

3. Prepare the Nozzle

a. **Create the Nozzle**: If using PVC pipe or plastic tubing, cut it to the desired length. Drill a hole in the cork or attach the tubing to the nozzle area.

b. **Attach the Nozzle**: Secure the nozzle to the cork or nose cone with adhesive or by fitting it into a drilled hole.

4. Attach Fins and Stabilisers

a. **Design Fins**: Cut out fins from plastic or cardboard. You'll need at least three or four fins for stability.

b. **Attach Fins**: Secure the fins to the bottom of the bottle using duct tape or strong adhesive. Ensure they are evenly spaced and symmetrical.

5. Prepare for Launch

a. **Fill the Bottle**: Fill the bottle about one-third full with water. The water acts as the propellant.

b. **Seal the Bottle**: Insert the cork or nose cone tightly into the bottle's neck. Ensure it's well-sealed to prevent leaks.

6. Set Up the Launch Platform

a. **Build a Platform**: Create a stable launch platform with a guide to hold the rocket in place. A simple option is a stand or frame that supports the rocket and allows it to be directed upward.

b. **Attach the Pump**: If using a bicycle pump, fit it to the nozzle or valve.

7. Launch the Rocket

a. **Safety First**: Wear safety glasses and ensure that everyone is at a safe distance.

b. **Pressurise the Rocket**: Pump air into the bottle through the nozzle. As the pressure builds up, the water will be forced out, creating thrust.

c. **Release**: Once sufficient pressure is built, the rocket will launch. The force of the water exiting the nozzle propels the rocket upward.

8. Observe and Analyse

a. **Observe the Flight**: Watch the rocket's flight and note its behaviour.

b. **Analyse the Results**: Consider how changing the amount of water or pressure affects the rocket's performance. Discuss the principles of action and reaction as described by Newton's Third Law.

Tips for Success

- **Safety**: Always launch in an open area away from people, animals, and delicate objects. Ensure that the rocket is stable and securely attached to the launch platform.
- **Adjustments**: Experiment with different amounts of water and air pressure to see how they affect the flight.
- **Experiment**: Try modifying the fins or nozzle design to optimise performance.

Conclusion

Building and launching a water rocket is an engaging and educational way to explore the principles of rocketry. By following these steps, you can create a simple yet effective demonstration of basic physical concepts.

EXTENDED READING

1. DJI Official Website
2. UAV Coach: Types of Drones
3. Quantum Systems: VTOL UAVs

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GLOSSARY

Ambient air The natural state of air in the outdoor environment.

Aramids A class of heat-resistant and strong synthetic fibres, typically used in aerospace and military applications.

High resolution camera A camera that takes images with a great amount of detail

Polystyrene foam A type of plastic that is lightweight and easy to shape. It is commonly used to make things like foam cups, packaging materials and disposable food containers

Tachometer An instrument which measures the rotation speed of a shaft or disk.

ACKNOWLEDGEMENTS

Ghana Education Service (GES)

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