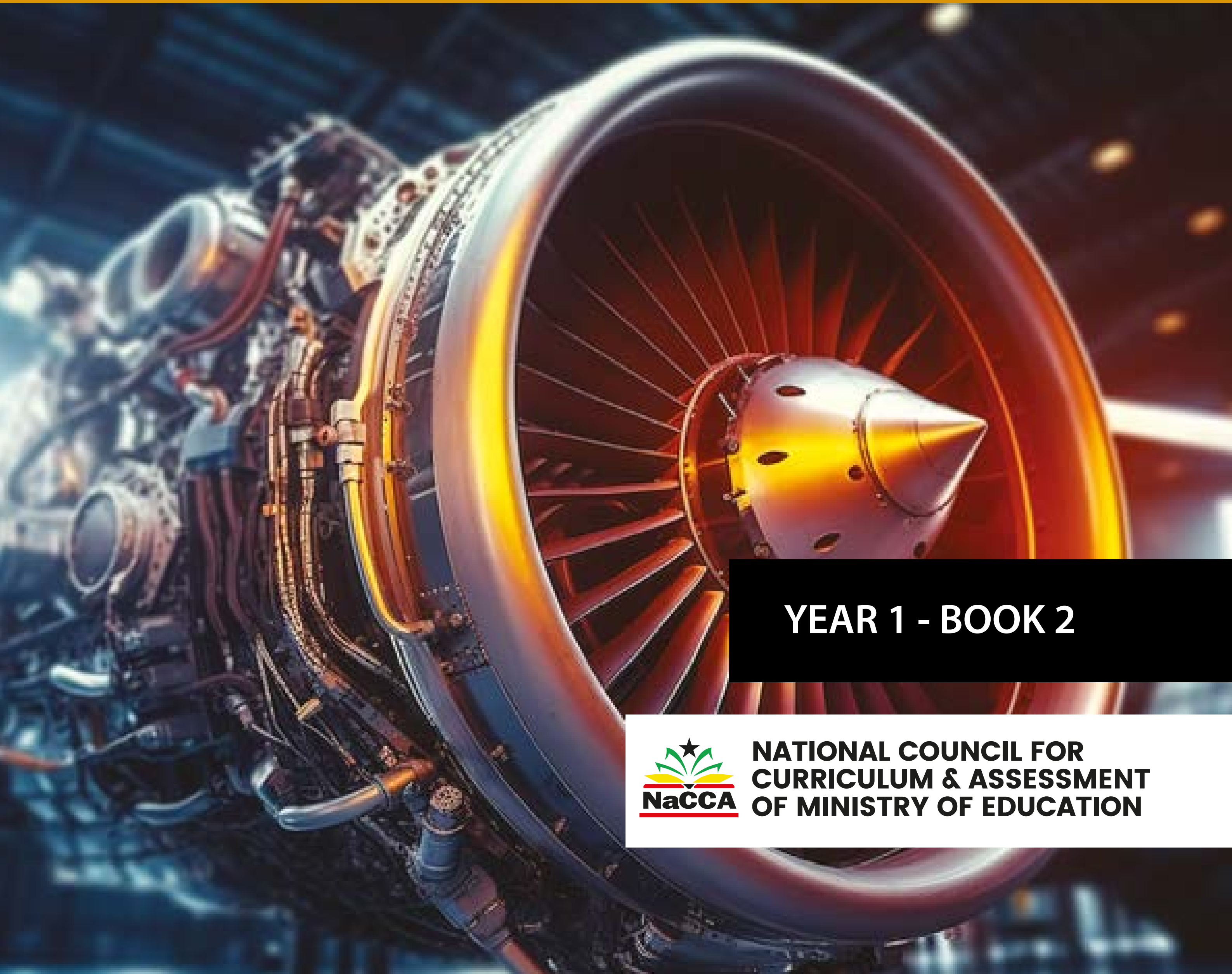
MINISTRY OF EDUCATION

Aviation & Aerospace Engineering

For Senior High Schools

TEACHER MANUAL



YEAR 1 - BOOK 2

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MINISTRY OF EDUCATION

REPUBLIC OF GHANA

Aviation and Aerospace Engineering

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Teacher Manual

Year One - Book Two

NATIONAL COUNCIL FOR
CURRICULUM & ASSESSMENT
OF MINISTRY OF EDUCATION

AVIATION AND AEROSPACE ENGINEERING TEACHER MANUAL

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INTRODUCTION

The National Council for Curriculum and Assessment (NaCCA) has developed a new Senior High School (SHS), Senior High Technical School (SHTS) and Science, Technology, Engineering and Mathematics (STEM) Curriculum. It aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, competencies, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, further their education and enter the world of work.

This is the first time that Ghana has developed an SHS Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

This Book Two of the Teacher Manual for Aviation and Aerospace Engineering covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively teach Year One of the new curriculum. It contains information for the second 11 weeks of Year One. Teachers are therefore to use this Teacher Manual to develop their weekly Learning Plans as required by Ghana Education Service.

Some of the key features of the new curriculum are set out below.

Learner-Centred Curriculum

The SHS, SHTS, and STEM curriculum places the learner at the center of teaching and learning by building on their existing life experiences, knowledge and understanding. Learners are actively involved in the knowledge-creation process, with the teacher acting as a facilitator. This involves using interactive and practical teaching and learning methods, as well as the learner's environment to make learning exciting and relatable. As an example, the new curriculum focuses on Ghanaian culture, Ghanaian history, and Ghanaian geography so that learners first understand their home and surroundings before extending their knowledge globally.

Promoting Ghanaian Values

Shared Ghanaian values have been integrated into the curriculum to ensure that all young people understand what it means to be a responsible Ghanaian citizen. These values include truth, integrity, diversity, equity, self-directed learning, self-confidence, adaptability and resourcefulness, leadership and responsible citizenship.

Integrating 21st Century Skills and Competencies

The SHS, SHTS, and STEM curriculum integrates 21st Century skills and competencies. These are:

- **Foundational Knowledge:** Literacy, Numeracy, Scientific Literacy, Information Communication and Digital Literacy, Financial Literacy and Entrepreneurship, Cultural Identity, Civic Literacy and Global Citizenship
- **Competencies:** Critical Thinking and Problem Solving, Innovation and Creativity, Collaboration and Communication
- **Character Qualities:** Discipline and Integrity, Self-Directed Learning, Self-Confidence, Adaptability and Resourcefulness, Leadership and Responsible Citizenship

Balanced Approach to Assessment - not just Final External Examinations

The SHS, SHTS, and STEM curriculum promotes a balanced approach to assessment. It encourages varied and differentiated assessments such as project work, practical demonstration, performance assessment, skills-based assessment, class exercises, portfolios as well as end-of-term examinations and final external assessment examinations. Two levels of assessment are used. These are:

- Internal Assessment (30%) – Comprises formative (portfolios, performance and project work) and summative (end-of-term examinations) which will be recorded in a school-based transcript.
- External Assessment (70%) – Comprehensive summative assessment will be conducted by the West African Examinations Council (WAEC) through the WASSCE. The questions posed by WAEC will test critical thinking, communication and problem solving as well as knowledge, understanding and factual recall.

The split of external and internal assessment will remain at 70/30 as is currently the case. However, there will be far greater transparency and quality assurance of the 30% of marks which are school-based. This will be achieved through the introduction of a school-based transcript, setting out all marks which learners achieve from SHS 1 to SHS 3. This transcript will be presented to universities alongside the WASSCE certificate for tertiary admissions.

An Inclusive and Responsive Curriculum

The SHS, SHTS, and STEM curriculum ensures no learner is left behind, and this is achieved through the following:

- Addressing the needs of all learners, including those requiring additional support or with special needs. The SHS, SHTS, and STEM curriculum includes learners with disabilities by adapting teaching and learning materials into accessible formats through technology and other measures to meet the needs of learners with disabilities.
- Incorporating strategies and measures, such as differentiation and adaptative pedagogies ensuring equitable access to resources and opportunities for all learners.
- Challenging traditional gender, cultural, or social stereotypes and encouraging all learners to achieve their true potential.
- Making provision for the needs of gifted and talented learners in schools.

Social and Emotional Learning

Social and emotional learning skills have also been integrated into the curriculum to help learners to develop and acquire skills, attitudes, and knowledge essential for understanding and managing their emotions, building healthy relationships and making responsible decisions.

Philosophy and vision for each subject

Each subject now has its own philosophy and vision, which sets out why the subject is being taught and how it will contribute to national development. The Philosophy and Vision for Aviation and Aerospace Engineering is:

Philosophy: Every learner can be trained in aviation and aerospace engineering given the right environment and qualified, skilled facilitators/teachers.

Vision: A trained learner grounded in fundamental knowledge and hands-on aviation and aerospace engineering skill sets required to solve the industry's developmental challenges beyond 21st century needs.

SUMMARY SCOPE AND SEQUENCE

S/N	STRAND	SUB-STRAND	YEAR 1			YEAR 2			YEAR 3		
			CS	LO	LI	CS	LO	LI	CS	LO	LI
1.	Core Concepts In Aerospace Engineering	Fundamentals of Flight	3	3	6	-	-	-	-	-	-
		Aerodynamics and Propulsion	-	-	-	3	3	7	-	-	-
		Aircraft Structures and Control	-	-	-	-	-	-	3	3	8
2.	Avionics	Fundamentals of Avionics	2	2	6	-	-	-	-	-	-
		Aircraft Instrumentation	-	-	-	2	2	4	-	-	-
		Communication, Navigation and Surveillance System	-	-	-	-	-	-	3	3	6
3.	Aviation Industry	The Aviation Profession and Operations	2	2	4	-	-	-	-	-	-
		Aviation Organisations	-	-	-	2	2	4	-	-	-
		Aircraft Maintenance	-	-	-	-	-	-	2	2	4
4.	Unmanned Aerial Vehicles (UAVS)	UAV Applications	2	2	4	-	-	-	-	-	-
		Safety And Deregulations	-	-	-	1	1	3	-	-	-
		Design And Fabrications Of UAVS	-	-	-	-	-	-	3	3	5
Total			**9**	**9**	**20**	**8**	**8**	**18**	**11**	**11**	**23**

Overall Totals (SHS 1 – 3)

Content Standards	**28**
Learning Outcomes	**28**
Learning Indicators	**61**

SECTION 5: **UAV CLASSES AND SUBSYSTEMS**

Strand: **Unmanned Aerial Vehicles (UAVs)**

Sub-Strand: UAV Applications

Learning Outcome: *Distinguish between the classes of UAVs (fixed wing, multi-copters, rotary wing, missiles, etc.).*

Content Standard: Demonstrate knowledge and understanding of the types of UAVs.

INTRODUCTION AND SECTION SUMMARY

This section is dedicated to the discussion of aeronautical principles used in developing unmanned aerial vehicles. Much attention is given to the classification of UAVs, concepts of operation, system components, safety and regulation, engineering design, as well as civilian and military uses of UAVs. The section covers the following weeks;

Week 14: UAV Classes/Concept of Operation

Week 15: UAV Classes/Concept of Operation

Week 16: UAV System Components

Week 17: UAV System Components

Week 18: UAV System Components

SUMMARY OF PEDAGOGICAL EXEMPLARS

This section employs experiential learning, group work, collaborative learning and talk-for-learning to help learners appreciate the basic understanding of the operation of UAVs. The teacher should pay particular attention to the application of scientific and physical principles in developing UAVs. Advanced and adequate preparation is needed on the part of the teacher in acquiring all that is needed to bring the lesson home to learners.

ASSESSMENT SUMMARY

All the levels of depth of knowledge are applied to measure learners' ability to recall and apply knowledge in unmanned aerial vehicles. This includes assessments from Levels 1, 2, 3, and 4 of Webb's hierarchy.

WEEK 14-15: Classification of UAVS

Theme or Focal Area: UAV Classes/Concept of Operation

Unmanned Aerial Vehicles (UAVs) are aircraft that do not have a pilot on board. They are either controlled remotely or operate autonomously based on a series of pre-set instructions or artificial intelligence. This week explores common UAV types.

There are two main types of UAVs. They are:

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

Rotary-wing UAVs

Rotary wings, as their name implies, have rotors with blades or propellers attached to them that spin to generate lift. There could be a single rotor, as on a helicopter or more than one rotor. UAVs with more than one rotor are called multi-rotor UAVs. Multi-rotor UAVs are probably the most common type of drone used by professionals and hobbyists. They provide a very cheap solution to problems that lend themselves naturally to UAV solutions. Multi-rotors derive their name from the fact that they use more than a single rotor. When two rotors are employed, they are called bicopters. If three rotors, they are called tri-copters; four – quadcopters; six – hexa-copters; eight – octocopters. They have very good lifting capability and the amount of payload (cargo) they carry increases with the number of rotors. Multi-rotors have limited flight time compared with other UAVs. The same rotors are used for generating lift and providing control capabilities. Since their flight depends entirely on the rotors, they provide better stability and control of the aircraft during flight. They are easier to fly, have higher manoeuvrability and can fly closer to structures when they are used for inspections. However, they require a lot of energy to remain airborne and are, therefore, not suited to large-scale aerial mapping, long-endurance monitoring and long-distance inspections.

Figure 1: *Multi-rotor UAV*

Concept of Operation

Multi-rotors use more than one rotor where the lift is wholly generated by the rotors. The rotors also provide a means for control of the UAV. Most of these UAVs are powered by electricity. Thus, they make use of batteries. The rotors, therefore, consist of electric motors and propellers. The propellers are usually standard elements that are used in other situations, for example on fixed-wings. Control of the multi-rotor UAV is achieved by varying the rotational speed of the rotor. There are usually four controls: collective, pitch, roll and yaw. Collective control applies the same rotational speed to all rotors whereas pitch, roll and yaw controls apply differential speeds to the rotors. By varying the rotational speed, and thus lift generated by each rotor, the attitude of the UAV is changed, altering its flight path.

Fixed-wing UAVs

These UAVs are built similar to regular aeroplanes. Compared with rotary-wing UAVs, they do not require a lot of energy to stay in the air because they make use of the aerodynamic lift provided by their wings. As a result, they can fly for longer periods between fuelling. These UAVs require space or the use of special equipment such as catapult launchers and parachutes for take-off and landing. They cannot also hover and are considered to be more difficult to fly, usually requiring a lot of training. On the other hand, fixed-wing UAVs possess a lot of desirable characteristics. Most can glide, enabling them to fly for longer. They typically consume less fuel and fly much faster than rotary-wing UAVs, reaching up to high altitudes carrying considerable payloads.

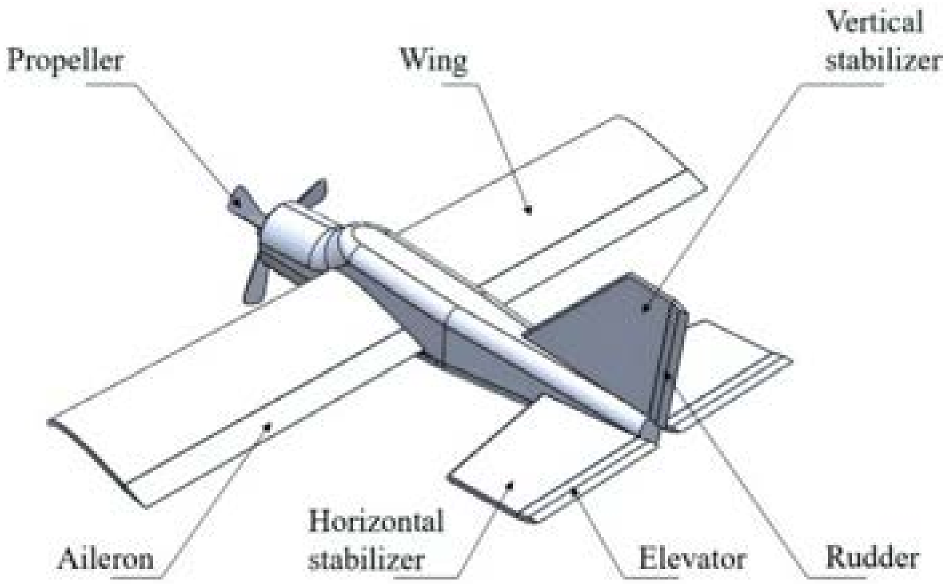

Figure 2: *Fixed-wing UAV*

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 there must be relative velocity between the aircraft and the surrounding air. Some configurations use a pusher propeller, while others use a tractor configuration. Roll control is provided by ailerons, pitch control by the elevator and yaw control by the rudder.

Single-rotor UAVs

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 turbine engines and can, therefore, fly for a longer time compared with multi-rotor UAVs. They cost more than fixed-wing UAVs, but come with heavier payload capability and can hover in place for extended periods. They can take off and land in small spaces, as they do not require a runway. On the downside, these UAVs have many moving parts and travel at lower speed than fixed-wing UAVs. In addition, they generate a lot of noise and present operational hazards because of their large rotor. Like fixed-wing UAVs, they are harder to fly and require significant training.

Figure 3: *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 attached to the tail boom provides yaw control for the coordination of turns.

Hybrid VTOL UAVs

VTOL stands for Vertical Take-Off and Landing. Hybrid VTOL UAVs combine the abilities of fixed-wing and multi-rotor UAVs. There are generally two configurations. One group has rotors that tilt to transition from vertical to horizontal flight. With the other group, there is typically four upward-facing rotors attached rigidly to the airframe. These rotors are responsible for liftoff and landing and for transitioning from vertical to horizontal flight. For prolonged periods of horizontal flight, another propeller at the front (tractor) or rear (pusher) of the fuselage is used. Hybrid UAVs have a long flight time 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.

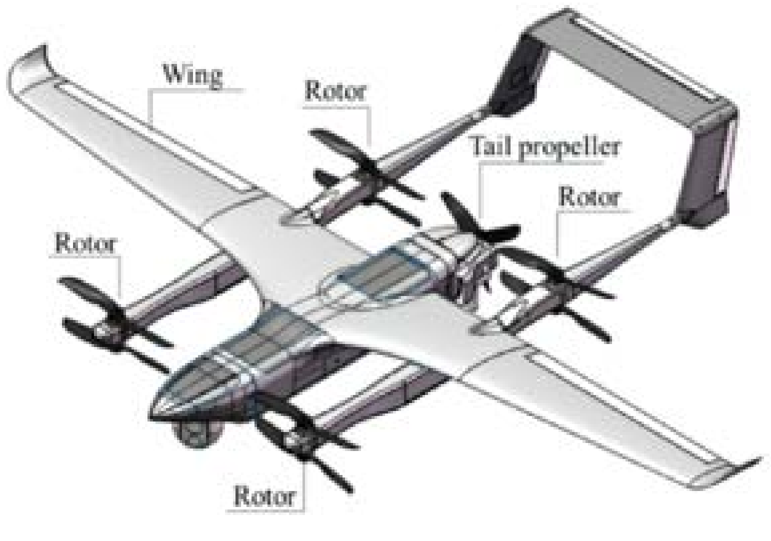

Figure 4: *Hybrid VTOL UAV*

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

Rockets move by ejecting high-velocity gases. This, according to Newton's third law, generates an opposite force on the rocket, causing it to move forward. This principle is also used in missiles and jet- propelled UAVs. Fins on the body of the rocket are used to provide control.

Learning Tasks

1. Write about the principles of operation of at least one UAV type.
2. Draw and label any UAV of choice.
3. Describe fixed-wing and rotary-wing UAVs.

Pedagogical Exemplars

Talk for learning: With the aid of audio-visuals or pictures, learners identify various features of UAVs. Use webbing or concept maps to organise the thoughts of learners on the functions of the various features after they think-pair-share. Encourage learners to confer and share ideas with peers cordially and respectfully. Guide them to do a freehand sketch of UAVs for peers to review one another's sketches.

Experiential learning: Organise field trips or demonstrations to observe UAVs in action. Visit a local UAV testing facility, research institution or industry partner to witness UAVs being operated, maintained or tested in real-world settings. This firsthand experience provides students with insights into the practical applications and challenges of UAV technology.

Project-based learning: In mixed-ability groups, learners design UAVs with cards and examine the functions of the various parts. In pairs, learners discuss principles of operation of UAVs and share with the class. Encourage the participation of females in a free and cordial manner. Guide learners in using Newton's 3rd law of motion to demonstrate the principles of operation of spacecraft, e.g. rockets.

Key Assessments

1. Identify at least two features of each of the four different UAV types.
2. Comment on at least two features of each of the different UAV types.
3. Analyse the features of UAVs.
4. Explain the principles of operation of at least one UAV type.

WEEK 16: UAV System Components

Theme or Focal Area: UAV System Components

The broad UAV system can be split into two main parts. The air system and the ground system. The air system consists of the UAV airframe, propulsion systems, flight controls, navigation and payload. The ground system is made up of the ground control station, which is comprised of hardware and software components.

Airframe

The airframe is the body of the UAV. In a fixed-wing UAV, the airframe consists of the wings, fuselage, control surfaces and tail. The airframe of multi-copters is generally much simpler. They usually have arms on which brushless DC motors are mounted with on-board electronics housed in a shell or composite plates. 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. 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 stress when in operation like the landing gears, wings and propellers. Aluminium is also used in UAVs due to its lightweight.

Figure 5: *UAV Airframe parts*

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. Each option has its advantages and disadvantages.

Electrical propulsion

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

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 be 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 indicates 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 1 hour before being depleted. Now, if the battery is required to supply more current, say 16A of current, (two times 8A), then it will be depleted in half the 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;

$$2 \times 3.7\ Volts = 7.4\ Volts$$

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 the parallel connection is done to increase the battery capacity and current output.

Figure 6: *Lithium- Polymer battery*

Figure 7: *Lithium-ion cell*

Electronic Speed Controller

The Electronic Speed Controller **(ESC)** takes power from the battery and gives it to the motor depending on the instantaneous power requirement as dictated 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, hence it is 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 8: *Electronic Speed Controller*

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 DC. They may be brushed DC motors or brushless DC motors. Brushed DC motors are simpler and usually cheaper, however, they are seldom used in UAVs because their brushes wear off after prolonged high RPMs as usually required to produce adequate thrust in UAVs. Brushless DC motors on the other hand can 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. The KV rating refers to the RPM that the motor spins at for each unit of voltage applied to it. So a 1000KV supplied with 1V will spin at 1000rpm. If it is supplied with

1.5V, it will spin at 1500rpm. It is usually the case that motors of high RPM are used with propellers of small diameters.

Figure 9: *Brushless motor*

Propellers

Propellers 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 plastic or carbon fibre. Propellers for small 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 10: *A propeller mounted on a brushless motor*

Generally, electrical propulsion systems are less complicated, quick and cheaper to implement when compared to internal combustion engines. They, however, lack endurance due to their lower energy densities when compared with fuel-based propulsion systems. It is very important to also note that the overall performance of the propulsion system is dependent on the combination of the motor, battery, electronic speed controller and propeller. The overall performance of the propulsion system does not depend solely on one component.

WEEK 17: Engine-Based Propulsion Systems

Theme or Focal Area: UAV System Components

These are propulsion systems that use petroleum fuels as a power source. The fuel may be petrol (gasoline) or Jet-A. 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 and the rest of the gases are expelled from the exhaust of the gas turbine engine at high speed to produce thrust.

Figure 11: *A gas engine kit for radio-controlled aircraft*

Figure 12: *A UAV with a 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 the autonomous decisions of the drone. 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. 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 amount of G's 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 sensor fusion of accelerometer and gyroscope data, the IMU can provide the UAV with attitude readings. So for instance, 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 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 13: *A Radiolink flight controller 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 14: *An MQ-9 Reaper drone with camera and missiles*

WEEK 18: UAV Communications Components

Theme or Focal Area: UAV System Components

It is very important to maintain a communication link constantly between the UAV and the operator on the ground. This is to ensure that the operator is always aware of the status of the UAV while in flight. Information such as 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 most common and easiest way to send commands to a drone. The 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 15: *Radio transmitter and receiver*

A telemetry module allows for two-way communication between the drone and the operator. The information 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 UAVs received by the telemetry module on the ground is displayed on a screen for the UAV pilot to see and take appropriate action.

Figure 16: *Air and ground Telemetry modules*

UAV Ground System Components

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 consist usually 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 are 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 it 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 is capable of flying autonomously when given a flight route, certain drone operations such as surveillance and military reconnaissance 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 does not know the path that will be taken by the suspect, he or she cannot plan the flight. In this case, the UAV pilot will have to take control of the drone and fly it manually. The joystick is used in this situation. The pilot can control all manoeuvres (roll, yaw and pitch) and speed of the UAV using the joystick.

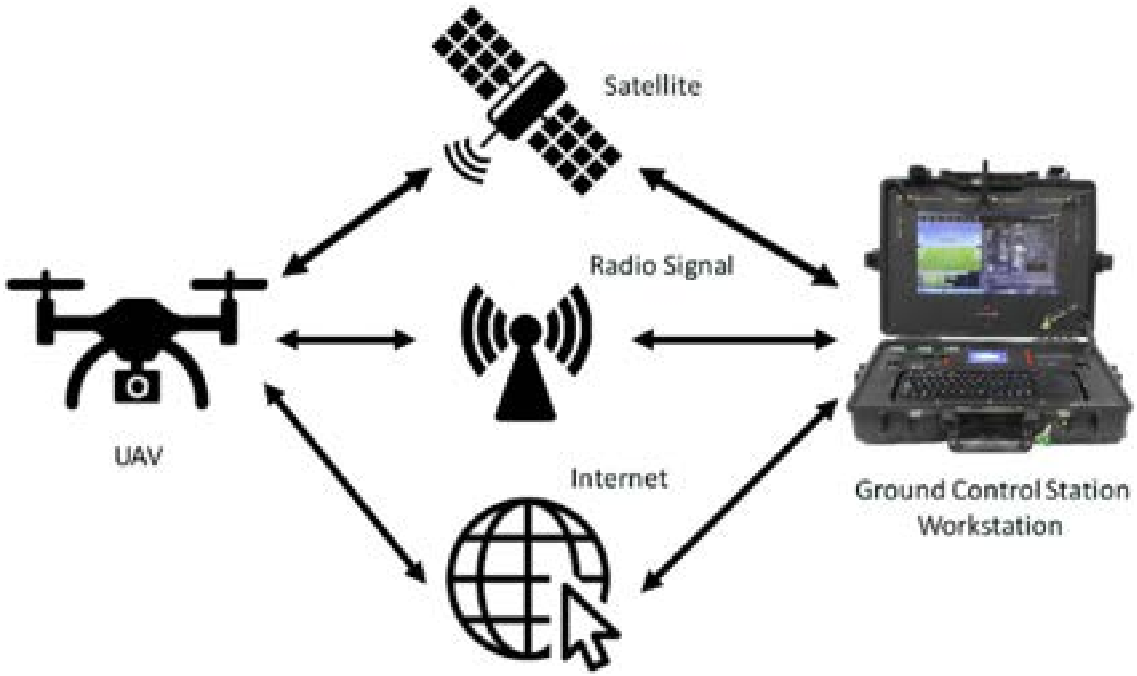

Figure 17: *UAV communication system with ground control*

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.

Rolling take-off is used for fixed-wing drones with landing gear wheels. The drone taxis to take off position on a runway and then accelerates on the runway to gain speed. Once the drone reaches rotation speed, the pilot then 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.

Vertical take-off 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. They are called vertical take-off and landing (VTOL) aircraft.

Hand-launch, as the name implies, is where the 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 either land on their bellies or deploy a parachute for landing.

Figure 18: *UAV pneumatic catapult- launch*

Learning Tasks

1. Identify components of a UAV system
2. Describe the interdependence between UAV ground and airborne systems
3. Select a suitable combination of UAV electronic components for a given mission
4. Using knowledge of various UAV platforms, design a system to improve upon an existing design

Pedagogical exemplars

Talk-for-learning: Lead learners to discuss the features of a UAV system. Use varying conversational approaches to engage learners to share knowledge on UAV components.

Think-Pair-Share: Create a comparison sheet for the advantages and disadvantages of each type of power and propulsion for UAVs. Present findings to the whole group.

Building on What Others Say: Guide learners to build on their previous knowledge of UAVs to enhance their understanding of the intricate linkage between the airborne and ground systems. Use additional resources to make the lesson practical.

Key assessment

1. List four major components of a UAV system
2. Using appropriate examples, describe how ground and airborne systems on a UAV interact
3. Select a suitable combination of UAV electronic components for a given mission
4. Suggest additional features or enhancements that can be used to optimise the following UAV designs
   i. Quadcopter
   ii. Fixed-wing UAV
   iii. Hybrid UAV

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   - Drone Components: Everything You Need to Know (extremefliers.com)
   - Introduction to UAV Systems (Chapter 1) - UAV Networks and Communications (cambridge.org)

Section Review

This has been an exciting journey into the various classifications of UAVs and the system components used in their operations. Also discussed were the various launch and recovery systems.

SECTION 6: **UAV APPLICATIONS**

Strand: **Unmanned Aerial Vehicles (UAVs)**

Sub-Strand: UAV Applications

Learning Outcomes: *Explain the uses of UAVs.*

Content Standard: Demonstrate knowledge of the various uses of UAVs.

INTRODUCTION AND SECTION SUMMARY

Unmanned aerial vehicles have become the order of the day in the modern society. This section discusses the various civil and military applications of UAVs. The list discussed here is not exhaustive, as there are new uses developed each day and new drones for these new uses. The proliferation of UAVs, especially in civilian space poses a significant threat to personal and infrastructural safety. This section also discusses the regulations imposed by authorities on the use of UAVs to ensure safety. The weeks considered are:

Week 19-20: Civilian Applications of UAVs

Week 21: Military Applications of UAVs

SUMMARY OF PEDAGOGICAL EXEMPLARS

This is an interactive section and should be treated as such. The teacher must promote collaboration among students to explore the numerous uses of UAVs in civilian and military environments. Through experiential learning, teachers must engage learners to think critically about the possible applications of UAVs. Additional audio-visual resources could be sought to enhance learners' understanding.

ASSESSMENT SUMMARY

Learners' ability to show extended thinking is emphasised here. Depending on the make-up of your class, develop appropriate assessments for learners at all levels.

WEEK 19-20: Civilian Applications of UAVS

Theme or Focal Area: Civilian Applications of UAVs

The modern proliferation of unmanned aerial systems has created a host of application opportunities in everyday life.

Disaster Management

Drones can be deployed in regions that are dangerous for humans to intervene when a man-made or environmental catastrophe such as terrorist strikes, tsunamis and flooding occur. Power, telecommunications infrastructure, water utilities and transportation can all be affected when tragedy strikes. Drones are employed in the collection of data, need for quick answers and navigation of debris. UAVs equipped with sensors, radars and high-resolution cameras can help rescue teams to identify damages, launch urgent recovery efforts and dispatch supplies including first-aid manned helicopters and medical kits. Sometimes, lots of drones can swarm to an emergency zone without human intervention. They can be used to find people and animals in danger for rescue.

Figure 19: *Disaster management drone*

Remote Sensing

Drones are increasingly being applied by people to collect high-resolution imaging data of isolated places including mountaintops, coastlines and islands. Drones serve as a link between aerial, ground-based and space-borne remotely sensed data. Because of their small size, drones can achieve quality aerial data in a short time. Disease diagnosis, water quality inspection, famine monitoring, gas and oil yield estimations, conservation of natural resources, geological calamity survey, topographical survey, woodland mapping, hydrological modelling and crop management are all applications of drones. Moreover, this technique is also being utilised in archaeological and cartography for crowd-sourced mapping and the generation of 3D atmospheric maps. Drones may deliver current data at a low cost, allowing land planners to avoid depending on old mapping sources.

Search and Rescue (SAR)

Drones are used to follow lost mountaineers on any trip or to defend humans in any isolated forest or desert. Drones may, therefore, aid in the tracking of unlucky victims, as well as any difficult terrain or harsh weather conditions. Drones can deliver critical medical equipment during an emergency before physicians arrive. Drones containing food supplies and medical supplies such as vaccines, medical kits and life-saving jackets can be sent to disaster-stricken communities and isolated areas. Drones can deliver clothing, water and other essentials to stranded people in difficult regions before rescue workers arrive. This can help in avalanches, forest fires and deadly gas penetration.

Infrastructure and Construction Inspection

Drones have made project monitoring and surveys more efficient, simple and quick. Tracking the development of the building project from start to finish ensures that the work on the site is of high quality. It may deliver reports to prospective stakeholders that include pictures, video and 3D mapping. UAVs are gaining high popularity for evaluating the global system for mobile communication towers, keeping an eye on gas pipelines, inspecting power cables and keeping an eye on building projects.

Figure 20: *Drone for inspection*

Precision Agriculture

Drones are deployed to gather agricultural data using ground sensors to assess the quality of water, soil composition, humidity etc. They are also configured to spray pesticides, diagnose illness, schedule irrigation, detect weeds, and monitor and manage crops. Drones are cost-effective and time-saving and thus improve agricultural systems' revenue, performance and agricultural production. Drones that are fitted with the necessary cameras and sensors can analyse crop health status, including leaf area, foreign pollutants, chlorophyll content and temperatures.

Figure 21: *Agric spraying drone*

Real-Time Monitoring of Road Traffic

The introduction of drones into road traffic monitoring has had a major impact on road safety. Reliable and intelligent drones have emerged as a new viable instrument for gathering data on highway traffic situations. As compared with traditional monitoring systems e.g. surveillance cameras, ultrasonic sensors and circuit analysers, low-cost drones can inspect large sections of roads. Local police can use drones to gain a clear picture of road accidents or to conduct a large security crackdown on illegal activities along the highway, including car theft. Other implications include vehicle recognition; raids on suspect cars; pursuing hijackers and armed robbers or anybody who breaches traffic regulations. It may also be used to monitor driving and incidents in vehicles and prevent traffic congestion and overcrowding. Drones are also used to inspect and track the state of roads for appropriate reparation.

Automated Forest Restoration

One more developing study area is the use of UAVs for controlled forest restoration. UAVs could be used to aid in the accomplishment of re-vegetation activities e.g., site infrastructure, site inspection, restoration plan, seedling supply, site maintenance (germinating and weeding, for example) and bio-diversity survey after restoration interventions. Existing technology such as GPS and image sensors assist UAVs in performing specific tasks, such as fundamental pre-restoration site inspections and monitoring various aspects of biodiversity revival. UAVs could evaluate any alterations in temperature, forest functions and ecological composition, hence assisting in the surveillance of replanting. High-resolution cameras mounted on UAVs can give useful data on natural forests to aid in forest restoration initiatives. Because of their simplicity of data acquisition and mobility, UAV cameras with suitable resolution can aid in the characterisation and study of forest landscapes. Likewise, optical sensors mounted on UAVs are being used to obtain geometric properties of forests such as vegetation cover, diameter and length. UAVs can also be used for remote sensing, which is a reliable and effective way to monitor forests.

Space Exploration

There is an emerging trend to utilise UAVs for planetary exploration. UAVs offer tremendous potential to carry out space missions such as studying the moon's surface and atmosphere. Although several planetary exploration techniques are available to perform these missions including rovers, landers, orbiters, flying balloons, flying spacecraft, probes and telescopes, these techniques are restricted by resolution, limited information and versatility. Therefore, UAVs have recently been in focus due to several benefits of such missions. In particular, UAVs offer a wide coverage area as compared with existing orbiters and rovers.

This list is not exhaustive and more could be added from further research.

Learning Task

Discuss civilian applications of UAVs

Pedagogical Exemplars

Experiential learning: With the aid of audio-visuals, discuss civilian uses of UAVs. Invite operators of UAVs to make a presentation on their activities. Let learners work in small mixed-ability groups to summarise the uses of UAVs to society health, education, business, agriculture, research etc. Encourage participation, respect and tolerance of views and opinions.

Key Assessment

Level 2: Describe two applications of UAVs in civilian logistics or agriculture.

Level 3: Identify and explain three factors that could hinder UAV operations in urban areas.

Level 4: Formulate at least one new application of UAVs in logistics, agriculture, health, education etc.

WEEK 21: Military Applications of UAVS

Theme or Focal Area: Military Applications of UAVs

Search and Rescue

Drones are increasingly being used for search and rescue operations. They can be used to locate and rescue personnel in hazardous or inaccessible areas. Drones can also be used to drop supplies to troops on the field.

Logistics and Supply

Drones are also used for logistics and supply operations. They can be used to transport supplies, equipment and personnel to remote locations. Drones can also be used to resupply troops in the field, reducing the need for ground convoys.

Anti-Drone Operations

As drones become more prevalent in military operations, anti-drone operations have become more important. Drones can be used to detect and neutralise enemy drones, reducing the risk of aerial attacks.

Training and Simulation

Drones are also used for training and simulation purposes. They can be used to simulate enemy positions and scenarios, allowing troops to practice tactics and strategies in a safe environment.

Unmanned Cargo and Transport UAVs

Unmanned cargo and transport drones are designed for logistical support such as delivering supplies, medical evacuation and personnel transport. While still in the early stages of development, these drones have the potential to revolutionise military logistics by providing quick and efficient transportation of goods and personnel on the battlefield.

Communication Relay and Jamming

Tactical drones can be used to establish communication networks on the battlefield, relaying signals between ground forces and command centres. They can also be employed to disrupt enemy communications by jamming radio frequencies, impairing their ability to coordinate and execute operations effectively.

Electronic Warfare

Electronic warfare is a critical aspect of modern military operations, and tactical drones have emerged as valuable assets in this domain. They can be equipped with electronic warfare systems to detect, identify and disrupt enemy radar and communication systems, rendering them ineffective and vulnerable to attack.

This list is not exhaustive and more could be added from further research.

Learning Task

Discuss military applications of UAVs

Pedagogical Exemplars

Experiential learning: With the aid of audio-visuals, discuss military uses of UAVs.

Experiential learning: Invite a resource person or a video recording from the military to make a presentation on the military application of UAVs.

Group work/Collaborative learning: Let learners work in small mixed groups to summarise uses etc. Encourage all to participate, respect and tolerate one another's views.

Key Assessment

Level 2: Describe two applications of UAVs in the military.

Level 3: Explain two potential problems with the use of military UAVs that must be overcome to ensure safety of use.

Level 4: Formulate at least one new way UAVs can be used for military purposes.

SECTION 7: **BASIC UAV DESIGN**

Strand: **Unmanned Aerial Vehicles (UAVs)**

Sub-Strand: UAV Applications

Learning Outcomes: *Distinguish between the classes of UAVs (fixed wing, multicopters, rotary wing, missiles, etc.)*

Content Standard: Demonstrate knowledge and understanding of the types of UAVs

INTRODUCTION AND SECTION SUMMARY

This section is dedicated to the practical application of knowledge of UAVs to conceptualise, design and build an actual UAV. It exposes learners to the rigours of a hands-on building of UAVs. It discusses the processes an engineer would pass through to design and build a model. It covers the following weeks;

Week 22: Engineering Design Process

Week 23: Introduction to UAV Design

Week 24: Introduction to UAV Design

SUMMARY OF PEDAGOGICAL EXEMPLARS

Since this is a practical session, the teacher should make preparations for the building activity and engage all the learners to share their knowledge from previous discussions so that each learner is adequately prepared for the activity. Encourage collaboration and mutual support until the activity is done.

ASSESSMENT SUMMARY

Learners' ability to use previous knowledge for strategic and extended thinking will be tested.

WEEK 22: Engineering Design Process

Theme or Focal Area: Engineering Design Process

What is Engineering Design?

Engineering design is a systematic approach to problem-solving that combines engineering expertise, knowledge (mathematics, science, technology, environmental and social sciences etc.) and innovation to develop and optimise products. It involves several stages from problem identification to the final product. It is an iterative process in that the prototype usually undergoes a phase of testing and a series of optimisations to improve it.

There are many factors to constrain the design. Some of these factors are cost, ease of manufacture, time, aesthetics, resources availability, required skills, robustness and safety.

The purpose of design is basically to draw on knowledge and innovation to produce an optimum.

The Design Process

The design process is a series of steps followed by engineers to design and test new products. They are meant to guide engineers find solutions to problems. The process involves the following steps: Define the problem and identify the constraints.

i. **Define the problem and identify the constraints:** This is the beginning of the design process. It involves identifying and clearly stating the problem to know exactly the challenge that needs to be addressed. It is important to also identify the constraints that may be associated with the problem. For example, a farmer has a vast land that is being encroached upon. The farmer wants a means to periodically survey the entire land to spot areas of encroachment. The problem has hence been defined. The UAV designer must now consider the possible constraints like: Is there a prepared runway? And where on the farm will the UAV be stored as that will affect the sizing of the UAV? Also questions like, will the UAV be stationed to launch and land at the same point or will it be moved around and launched from different spots on the farm? This is important because this will determine if the UAV needs to be modular.

ii. **Research the problem**: In most cases, the problem you are solving is not unique. Others may have attempted to solve that problem or they may have solved a similar problem. It is wise to draw on their ideas and lessons learned so as not to make the same mistakes. The internet is a very useful resource in this exercise. Talking to experts can also be very useful.

iii. **Brainstorming and concept generation**: At this step, the engineer(s) think about the information they have gathered about the problem and generate concepts of how the solution will operate and what it will look like. This is usually accompanied by a technical drawing of the concept. It is advisable to generate numerous concepts at this stage.

iv. **Concept evaluation and prototyping:** This is the stage where the pros and cons of the concepts generated are weighed in an evaluation matrix and the best is selected. The evaluation matrix is a table that contains the concepts generated and some factors such as cost, ease of manufacture, durability, skills required, aesthetics, functionality etc. Each concept is evaluated based on the factors. Below is an example of an evaluation matrix table comparing 3 design concepts A, B and C. Each factor is weighted between 0 and 1. The more favourable the factor, the higher the weighting.

Table 22.1: An example comparison of 3 designs in an evaluation matrix

	Concept A	Concept B	Concept C
Functionality	0.7	1.0	0.4
Cost	0.5	0.1	0.9
Time consumption	0.7	0.7	0.8
Robustness	0.6	0.8	0.3
Ease of manufacturing	0.4	0.2	0.9
Aesthetic	0.6	0.8	0.2
Skill required	0.7	0.3	0.7
	4.2	3.9	4.0

So based on this evaluation matrix, concept A is chosen for prototyping and development.

v. **Testing design and optimisation:** This section is usually a series of testing and optimisation. This is a very important step where the design is tested against real-world conditions and tuned to perform optimally.

vi. **Redesign and testing:** In this stage, the product is redesigned to account for test results.

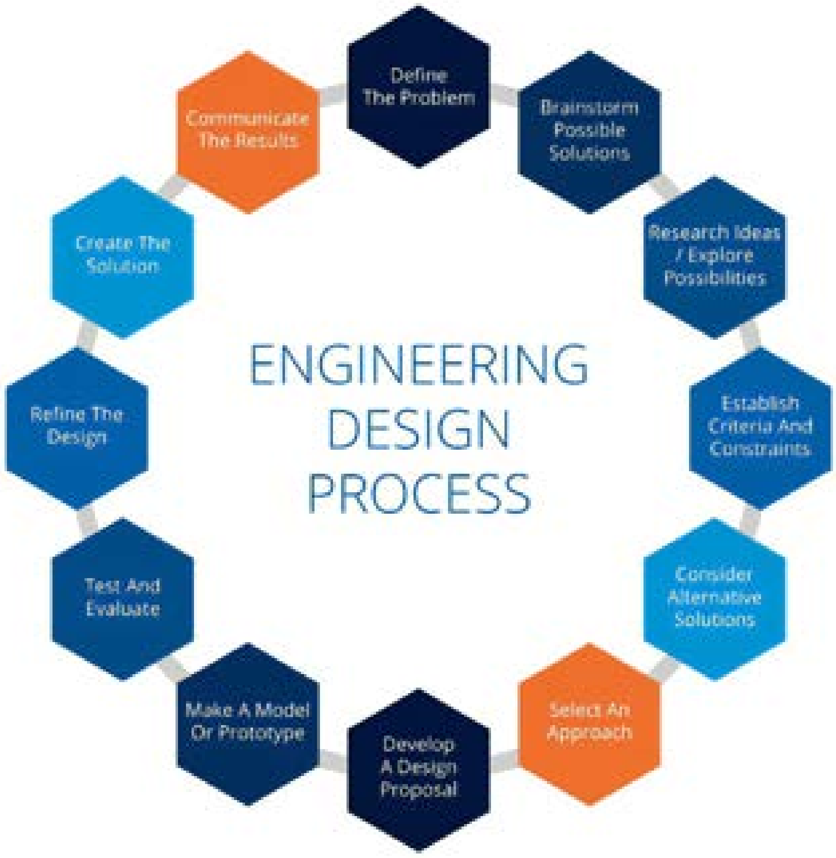

Figure 17

Learning Tasks

1. List the steps in the engineering design process.
2. Identify real-world problems by engineering design.
3. Highlight the difference between design and haphazard fabrication.

Pedagogical Exemplars

Collaborative learning: Learners in mixed-ability groups identify a problem in society, share ideas to come up with three concepts and use an evaluation matrix to choose one design and make a paper model of it. The group then presents their design to the whole class.

Key Assessments

Assessment Level 1: What is Design?

Assessment Level 2: Explain why it is important to use scientific and mathematical approaches when designing as opposed to haphazard fabrication.

Assessment Level 4: Given a problem statement, design and sketch three prototypes to solve the problem and use an evaluation matrix to select the best option based on stated customer preference.

WEEK 23-24: Introduction to UAV Design

Theme or Focal Area: UAV Build

In these two weeks, learners design and build a model UAV under the guidance and supervision of the teacher. The learners use cheap, locally sourced materials to model their UAVs. The build process should be simple enough but functional. Students should be able to hotwire polystyrene (Styrofoam) boards or fold paper-laminated foam boards to create their wings. Integration of the electronics and battery should be done under the strict supervision of the teacher to not damage electronic components and to guard against electrical fires. Please beware that the Lithium-based batteries used to power UAVs usually have high discharge current ratings and any short-circuit could cause a fire.

Below are some important measures the teacher should take to ensure a safe and all-inclusive involvement.

1. Assign learners to mixed groupings
2. Make sure there is enough material for each group
3. Assign team leaders to coordinate the work of the group.
4. Review and stress the importance of adhering to safety precautions for learners.
5. As much as possible, engage each learner with specific tasks.
6. Discuss the results of each group's activity with the whole class and invite views for optimisation.

Learning tasks

1. Identify materials that can be locally sourced for UAV modelling.
2. Perform UAV flight simulation on software.
3. Identify and source necessary tools and Personal Protective Equipment (PPE) for UAV modelling.
4. Design and build a model UAV.
5. UAV performance testing and optimisation.

Pedagogical Exemplars

1. **Experiential Learning:** Learners build UAV prototypes based on their designs. They assemble the components and wire the electronics under the supervision of the teacher.

   Learners practice how to fly UAVs using simulators with the aid of animation videos on how basic flight manoeuvres work. Learners conduct flight tests in controlled environments to evaluate the performance of the UAV prototypes. Learners observe how their designs behave in real-world conditions and make adjustments accordingly.

2. **Group Work**: Learners in mixed-ability groups build their own UAV models under the guidance of the teacher.

Key Assessments

Assessment Level 1: List 5 items required to build your UAV model.

Assessment Level 2: Build an unpowered hand-launched glider capable of covering a distance of 12 metres.

Assessment Level 3: Build a powered UAV and fly it.

Assessment Level 4: The teacher should observe learners' activities and contributions in their respective groups and grade them accordingly.

Section Review

This section immerses learners into the practicality of all the theoretical concepts they learnt in previous sections. They learn about the importance of engineering design based on scientific and engineering principles as opposed to haphazard fabrication. They also learn to adhere to safety in engineering practice during their practical lessons.

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