How Drones Fly

Session Time: Three, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

UAS contain components that are universal to all category/types, and these components control the flight of the remote aerial platform.

ESSENTIAL QUESTIONS

1. What are the major components shared by all UAS, and how do they work together to achieve controlled flight?

LEARNING GOALS

Students Will Know

- The general components that are shared by all UAS.
- How both fixed-wing and multicopter UAVs achieve lift and thrust.
- How control inputs made on common controllers affect a drone's flight.

Students Will Be Able To

- *Identify* the major components that are common to all UAS. [DOK-L1]
- *Compare* the ways that multicopters achieve thrust and lift with those of airplanes. [DOK-L3]
- *Relate* control inputs made to a multicopter to changes in the platform's thrust. [DOK-L2]

ASSESSMENT EVIDENCE

Warm-up
Students will watch a video to review concepts of lift and thrust and consider their relevance to drone flight.

Formative Assessment
Students will compare and contrast how multicopters and fixed-wing UAS achieve lift and thrust.

Summative Assessment
Students will explain how lift and thrust are manipulated in both fixed-wing and multicopter UAS.

LESSON PREPARATION

MATERIALS/RESOURCES

- How Drones Fly Presentation

- [How Drones Fly Student Activity]
- [How Drones Fly Teacher Notes]

LESSON SUMMARY

Lesson 1: Introduction to UAS
Lesson 2: How Drones Fly

The lesson begins with a warm-up showing a video about how lift and thrust are achieved in airplanes. Students are asked to consider how the principles of lift and thrust are applied to both fixed-wing and multicopter UAS.

The lesson continues focusing on how simple controller movements manipulate the components of both multicopter and fixed-wing UAVs in flight (climb, descent, forward, backward).

Finally, the students will delineate how some components are common to all UAS despite aircraft body type and complexity and how all of the components work together to achieve controlled flight. The lesson concludes with a summative assessment requiring the students to apply how their analysis of how components of the types of UAS function to achieve lift and thrust.

BACKGROUND

Airplanes and drones share physics of operation. An object at rest on the ground has four forces acting on it: gravity (pulls down), normal (pushes up), applied (force in the direction of movement), and friction (opposes movement). In reference to flight, these four forces are identified as weight (pulls down), lift (pushes up), thrust (force in the direction of movement), and drag (opposes movement). Thrust is a force applied to overcome drag—in aircraft, it is often supplied by the engines.

For a fixed-wing aircraft to fly, it must overcome weight and drag to take off, reach cruising speed, and change course in flight. The speed of airflow across the wing's top is greater than that across the bottom of the wing, creating a difference in pressure; this results in lift. Lift works the same in a quadcopter, except on a smaller scale. Each rotor blade is a small airfoil, but instead of moving through the air in a straight line as a wing would, it rotates on a shaft to achieve the lift. While airplanes achieve lift and thrust through different mechanisms (wings and engines), rotors on multicopters provide both forces simultaneously.

Students will recall that fixed-wing aircraft maneuver using control surfaces located on the airplane's wings and stabilizers. A multirotor drone, by contrast, does not have moveable control surfaces. Instead, these aircraft maneuver using differences in thrust between their various rotors. These differences in thrust result in a thrust vector similar to that described in Grade 10 Unit 4 Section A Lesson 3: Vectors of Flight, and cause the drone to move through the air in the direction of the vector.

Drone terminology that was introduced in the introductory lesson will continue to be used, so it is important to keep in mind (and remind students) that UAV refers to an unmanned aerial vehicle, and UAS refers to an unmanned aircraft system: the ground station, aircraft, and anything interfacing with it. An "s" prefix (e.g., sUAS, sUAV) indicates "small," or under 55 lbs.

MISCONCEPTIONS

Students may believe that consumer drones are smaller, simpler versions of large drones, such as those used by the military. Though both types are unmanned and autonomous, they are very different. Fixed-wing and multicopter drones differ in many ways, including sources of lift and control mechanisms. This lesson will explore these differences in greater depth.

Terminology may also be confusing, especially *controller* and *flight controller*; students lacking in drone experience may think these terms are interchangeable. In reality, they are two separate UAS components. The "brain" of a drone is the flight controller, which is physically located on the drone. Its function is to decipher the inputs and sensors from the pilot via the controller. The controller is the interface between the pilot's commands and the response of the drone to those commands.

DIFFERENTIATION

To support student comprehension in the lesson, encourage them to use graphic organizers and/or label components of UAS.

Give students time to do a peer review of **Student Activity** and/or engage in a larger group discussion to discuss the merits of the drone suggestions in the proposal. This will allow students to compare the suggestions and determine which drone is more fitting for the situation.

LEARNING PLAN

ENGAGE

Teacher Material: How Drones Fly Presentation, Small drone for classroom demonstration

Session 1

Slides 1-3: Introduce the topic and learning objectives of the lesson.

Slide 4: Conduct the **Warm-Up**.

Warm-up

The following video is a quick review of how lift and thrust are achieved in airplanes.

- How Do Airplanes Fly? (Length 8:16)
  https://video.link/w/BHry

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/F077WDnB8P8

As students watch, they should consider the following questions, which you may discuss afterward as a class. Students do not need to answer these questions correctly right now; use this exercise as an opportunity to assess students' prior knowledge of how drones fly. If necessary, remind students that the same principles of flight that apply to airplanes or helicopters apply to drones.

How do airplanes achieve lift and thrust?

- *Lift is caused by the pressure difference created by the different speeds of air on the top and bottom of the wing. The higher pressure on the bottom of the wing pushes up on it.*
- *Thrust is forward acceleration (caused by increased engine speed) to overcome drag.*

How do the principles of airplane flight apply to both fixed-wing and multicopter UAS?

- *Both types use pressure difference on the tops and bottoms of wings or wing-like surfaces to create lift.*

- *To generate thrust, multicopters have rotors, or "rotating wings" turned by motors. Thrust can be vertical or at an angle relative to the ground—it depends on the overall tilt of the aircraft. When the thrust vector changes, the multicopter tilts, causing the drone to move in the direction of the vector.*
- *A fixed-wing drone uses an engine to propel the wings through the air. The resulting forward movement of the curved wing creates a pressure difference between the top and bottom of the wing, generating lift.*

EXPLORE

Teacher Materials: [How Drones Fly Presentation]

Slides 5-6: If a small drone is available in the classroom, demonstrate simple control movements that can be made while the UAV is in flight (climb, descent, forward, backward, etc.). If not, the following video (embedded in slide 6) will suffice. (Note that the video shows a particular type of drone called a multicopter, which students will learn about later in the lesson.)

- "Basics of Drone Flight" (Length 3:02)
  https://video.link/w/hVWx

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/watch?v=aSeKzdO_uxo

Based on what they see, students should answer the following questions:

Questions

How do you think these movements are achieved by the drone?

Answers may vary, but students may share the following ideas:

- *Climb: increase motor speed (thrust) of the rotors so that the upward force (lift) is greater than the downward force (weight) of the drone*
- *Descent: decrease the motor speed (thrust) of the rotors so that the upward force (lift) is less than the downward force (weight) of the drone*
- *Forward: increase thrust in rear rotors and decrease it in front rotors*
- *Backward: decrease thrust in rear rotors and increase it in front rotors*

When the controller is manipulated, what is the process that results in the drone making the commanded movement through the air?

- *Changing the motor speed of the appropriate rotors changes the thrust vector, causing it to change attitude, orientation, and direction of movement.*

Don't worry about correcting student responses at this point; the purpose of this exercise is simply to get students thinking about how the principles they've learned about airplanes apply to drones.

EXPLAIN

Teacher Material: How Drones Fly Presentation

Slide 7: Unmanned aircraft systems (UAS), regardless of their complexity or airframe type, possess common components: a flight controller, a controller, a means of communication between them, and power sources (e.g., fuel or electricity). This lesson will explore these universal drone components and explain how they work together to control flight.

Slide 8: UAV and pilot communication relies on the controller. The controller is the instrument used by the remote pilot to fly the drone; it is often referred to as the "interface" and communicates either by Wi-Fi signal (short range) or other radio frequency signal (long range). Radio channels may be selectable on some controllers; this is to allow for compatibility with other models of aircraft or to reduce the interference when operating near other RC equipment or operators.

Slide 9: UAS and RC aircraft have similar receivers. Multiple channels are available to send messages to different UAS components. For example, each component (camera, motor, other instrument, etc.) has an available channel. All of the channels are combined into one signal, which travels from the controller to the UAV. Once the signal reaches the vehicle, each channel is routed to the appropriate component via onboard software.

Slide 10: Multiple styles of drone controller are available. One that uses two primary control sticks for the motor and movement, respectively, is considered the standard configuration. Thrust and yaw (rotation about the vertical axis) are controlled by the left stick. The pitch (rotation about the lateral axis) and roll (rotation about the longitudinal axis) are controlled by the right stick. This default configuration is known as Mode 2. Other modes are shown on this slide. Most controllers are customizable between different modes, but not all.

Teaching Tips

Students may share that they have experience with different controllers with multiple features; however, this lesson focuses on basic controls. More advanced features will be introduced in upcoming lessons.

Slide 11: Communication requires a sender and receiver. An input is sent by the remote pilot, and the drone's flight controller interprets the signal. The flight controller is the "brain" of the UAS, deciphering signals from onboard sensors and controller commands. It is usually located in the UAV.

Slide 12: There are several common UAV sensors that measure data in real time from the UAV and relay this information to the flight controller.

- The Global Positioning System (GPS) helps the UAV determine its location.
- The inertial measurement unit (IMU) helps the UAV determine its orientation in space.
- The altimeter measures the UAV's altitude.
- The magnetometer acts like a compass.
- Engine intake sensors monitor the functioning of the UAV's engine (gas powered engines only).
- The accelerometer measures the UAV's acceleration.

Slide 13: Motors provide thrust for drones. They attach to UAV frames in a variety of arrangements.

- In fixed-wing drones, the motors are arranged horizontally on the front or back of the UAV to push or pull air.
- In multicopters, multiple motors may be arranged in symmetrical patterns, and they are usually oriented vertically.

Slide 14: The speed of a drone's motors is directed by the flight controller based on remote pilot or onboard autopilot commands. Electronic speed controllers (ESCs), located on each motor, are connected to the flight controller. The pilot manipulates the controller (or the autopilot sends a command), which tells the ESCs to change the speed of the individual motors. Each ESC converts onboard direct current (DC) power from the battery to alternating current (AC), which is used by UAS motors. A variation in current provided by the ESC controls the speed of the motor, which eventually translates into a change of the overall aircraft attitude or orientation.

Slide 15: Autopilots, which can be found within complex drones, permit the drone to access pre-programmed GPS coordinates to navigate autonomously. The combination of autopilot and GPS eases the workload of drone pilots and diversifies the UAV's capabilities. Missions that involve beyond visual line-of-sight (BVLOS) tasks leverage these technologies to assist the pilot in extending routes beyond the drone's launch point. In waypoint missions, GPS coordinates are plotted before launch and carried out in flight.

Teaching Tips

BVLOS missions require a waiver from the FAA.

Session 2

Slide 16: From controller input to UAV reception, understanding how the UAV system is powered is crucial to understanding the system. Both electric and internal combustion UAV systems rely on batteries.

- Electric drones use batteries as their primary power source for the flight controller, autopilot, motors, sensors, and servos to move control surfaces.
- Internal combustion engines use liquid fuel to power the engine and batteries for other components, like servos to move control surfaces.

Batteries are complicated components of UAS, and will be discussed in later lessons that take a more in-depth look at drone systems.

Slide 17: Rotors or propellers control thrust on both multicopters and fixed-wing drones. Fixed-wing drones, however, accomplish lift via airflow around stationary wings.

Multicopter rotors serve a dual function, and provide both lift and thrust, wherein the speed of the rotors and resulting overall tilt of the drone can be manipulated for maneuvering. Fixed-wing drones depend on hinged, movable flight controls attached to the wings and tail to maneuver.

Questions

How are the forces of lift and thrust manipulated in fixed-wing and multicopter drones to maneuver the UAV?

Note: Answers may vary but students may mention:

- *Fixed-wing drones manipulate lift and thrust similarly to an airplane*

- *Multicopter drones manipulate lift and thrust by controlling the direction of airflow through the front and rear propellers.*

Slide 18: Fixed-wing drones and airplanes achieve both thrust and lift through similar processes. Both front- and rear-mounted propellers provide thrust for the drone. Front-mounted propellers (“puller props”) pull the UAV through the air. Rear-mounted propellers (“pusher props”) push the UAV through the air.

Teaching Tips

“Pusher props,” usually placed behind the wing, allow for more efficient cruise flight since the air over the wings is “clean” and largely undisturbed. The downside is that they need a longer takeoff run since the relative wind used for wing lift isn't being pushed over the wings directly.

In contrast, “puller props” (usually placed in front of the wings) typically block sensors needed for UAS operation; they are seen more in manned flight, where forward-looking sensors are not used. Airplanes with puller props can fly more slowly since the propeller is providing strong airflow over the wings.

Slide 19: Remember, in fixed wing drones and airplanes, thrust and lift are produced by different components.

- Propellers provide thrust.
- Wings provide lift.

The combination of reduced static air pressure flowing over the top of a wing and increased static air pressure under the wing creates lift. This process is in accordance with Bernoulli’s principle, which states that

an increase in the velocity of a stream of fluid results in a decrease in static pressure. The opposite is also true. (This is also called the Bernoulli effect.)

Teaching Tips

- As the speed of air increases, static pressure drops and dynamic pressure increases.
- As the speed of air decreases, dynamic pressure drops and static pressure increases.
- Static pressure means the air molecules are pushing harder in directions other than the direction of flow: in this case, up into the wing. The air on top is moving faster and has less static pressure. The higher static pressure on the bottom of the wing causes the wing to lift.

Slide 20: Review the lift equation by watching the following video:

- “Lift Formula” (Length 3:16)
  https://video.link/w/7psx

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/2zweEpnT5Fg

The video shows how airspeed (velocity) and angle of attack (coefficient of lift) are able to be manipulated by the pilot when flying a fixed-wing drone. Specifically, the angle of attack is changed by altering the aircraft's flight control surfaces to increase or decrease lift in either or both wings.

Slide 21: Similar to airplanes, fixed-wing UAVs have three types of control surfaces to maneuver in flight.

- Ailerons control roll; they are mounted horizontally on each wing and move opposite relative to each other.
- Elevators control pitch; they are mounted to the tail horizontally.
- The rudder controls yaw; it is mounted vertically to the tail.

These controls are assigned to different channels within the aircraft. The flight controller interprets the signals from the controller and sends them to the appropriate channel to move the flight surfaces.

Slide 22: When a pilot operating a drone remotely manipulates the controller, the flight controller receives the information and the servo amplifier decodes the instructions; the flight controller also controls the servos connected to the proper component. A fixed-wing drone and a manned airplane fly relatively similarly; the difference is simply that on a drone commands are sent remotely as opposed to being input by a pilot on board the aircraft.

Slide 23: In contrast to a fixed-wing system, a multicopter system has motors arranged evenly around the frame of the UAV. Attached to each motor is a propeller, which produces vertical lift and thrust. The propeller is fixed to the motor. Operations are not controlled via the movement of control surfaces (as in an airplane) or by mechanically changing the pitch of the propeller blades (as in a helicopter). Instead, operations are controlled by increasing or decreasing the speed of one or more of the motors; this happens through the electronic speed controllers (ESCs).

Slide 24: Multicopters, by nature, are extremely unstable. These UAS utilize flight controllers and ESCs to independently vary each motor speed and maintain stability. They are also mechanically simple but possess complex electronic systems. These systems include not just the ESCs and flight controller but also the inertial measurement unit (IMU), accelerometers, magnetometers, and more. These systems interface with one another at near-instant speeds to continually maintain the pilot's desired flight characteristics.

Slides 25-29: These four slides show examples of different types of multicopter airframes; there are limitless configurations, but the most common include quadcopters (four motors), hexacopters (six motors), and octocopters (eight motors). Also mentioned is a coaxial motor arrangement; this type of arrangement consists of motors mounted on the top and bottom of the outboard motor mounts, reducing the number of arms required for a set number of motors.

Slide 30: On multicopter drones, half of the motors will spin in one direction, while half will spin in the opposite direction to maintain stability of the craft. This can be attributed to the effects of torque, which is a twisting force that causes rotation. When two motors are mounted to one outboard arm (coaxially), they are set to spin in opposite directions to counter the torque. If the motors were spinning in the same direction on a single outboard arm, it would create a tendency for the aircraft to twist around the axis of that outboard arm. By distributing the rotational forces equally and counteracting them all the way around the aircraft, it helps to eliminate these tendencies and minimizes stability "weak spots."

Teaching Tips

- Bear in mind that regardless of spin direction, all propeller blades are fabricated so that the leading edge is always advancing through the air first.
- A propeller designed for a clockwise-turning motor will not produce lift on a counterclockwise-turning motor.
- The motors do not reverse rotation; there is no "negative throttle."

Slide 31: Complete the **Formative Assessment**.

> **Formative Assessment**
>
> Instruct students to compare and contrast how airplanes and UAVs (both fixed-wing and multicopter) achieve lift and thrust. Allow a few minutes for students to discuss their ideas with a partner; each student should then respond individually to this prompt—for example, by writing a paragraph or creating a simple Venn diagram.
>
> *Student responses will vary, but they should mention:*
>
> - *Airplanes and fixed-wing drones generate thrust along the flight path.*
> - *Multicopters use differential thrust to translate the thrust vector into vertical and lateral components.*
> - *Both types of aircraft use propellers. The orientation of the propeller is the key difference.*
>
> As students discuss in small groups and as a class, walk around and listen to student discussions. Take the opportunity to note and clarify any misconceptions or gaps in knowledge.
>
> [DOK-L2; *compare and contrast*]

EXTEND

Teacher Material: [How Drones Fly Presentation]

Session 3

Slides 32-33: How are maneuvers accomplished with a multicopter?

- Climbing and descent: To climb with the aircraft level, the speed (RPM) of all of the motors must be increased equally at the same time. To descend with the aircraft level, the speed (RPM) of all motors must be decreased equally at the same time.
- Pitch/roll: Pitch and roll occur when the RPM of all motors on one side of the aircraft are increased and the RPM on the opposite side are decreased. Lift increases on the side with the greater RPM and decreases on the side with reduced RPM (think back to the lift equation), causing drone rotation about or around the lateral axis (an imaginary line from left to right) or longitudinal axis (an imaginary line running from front to back).

Slide 34: To yaw, motors spinning in one direction are allowed to spin at a higher RPM than the motors spinning in the opposite direction, which are slowed down. This process is governed by Newton's third law of motion: for every action there is an equal and opposite reaction. The lack of normal torque compensation from the opposite slowed motors allows the aircraft to rotate, or yaw, in place.

- "Quadcopter Yawing on Whiteboard" (Length 0:24)
  https://video.link/w/wZky

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/lNNAw4XgGoM

Slide 35: The following video summarizes how drones fly. Before watching, ask students if they have any remaining questions about the topics covered in the lesson. Record these questions on the board, and then play the video. Afterward, review the questions, referring to the video for answers.

- "How Does a Drone Fly?" (Length 5:56; instruction stops at 3:56, and the remaining video shows drone footage) https://video.link/w/YQ0x

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/GSGesFOUBVQ

EVALUATE

Teacher Materials: How Drones Fly Presentation, How Drones Fly Teacher Notes
Student Material: How Drones Fly Student Activity

Slide 36-41: Remote Pilot Knowledge Test Questions and Answers

Slide 42: Conduct the **Summative Assessment**.

Summative Assessment

Students will create a formal proposal by selecting and defending a type of drone for assisting their local fire department in fighting brush fires. Provide students with **How Drones Fly Student Activity**.

Guidelines to complete the assessment—including useful links, references, and sample responses—are provided in **How Drones Fly Teacher Notes**.

[DOK-L3; *strategizing*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Postings show evidence of one or more of the following:
  - Provides evidence of understanding the functions of the major components that are common to all UAS
  - Provides detailed comparisons of ways that multicopters achieve thrust and lift with those of airplanes.
  - Provides explanation of the relationship between control inputs made to a multicopter to changes in the platform's thrust.
- Contributions show understanding of the concepts covered in the lesson
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

Points **Performance Levels**
9-10 Consistently demonstrates criteria: Knows how control inputs made on common controllers affect a drone's flight; knows how both fixed- wing and multicopter UAVs achieve lift and thrust
7-8 Usually demonstrates criteria; Shows a sufficient understanding of control inputs made on common controllers affect a drone's flight; mostly understands how both fixed- wing and multicopter UAVs achieve lift and thrust.
5-6 Sometimes demonstrates criteria; Shows some understanding of control inputs made on common controllers affect a drone's flight and how both fixed- wing and multicopter UAVs achieve lift

and thrust. There are gaps in understanding.
0-4 Rarely to never demonstrates criteria; does not show an understanding of the lesson objectives.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-Dimensional Learning

- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
    - Science and Engineering Practices
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.B: Developing Possible Solutions
    - Crosscutting Concepts
        - None

COMMON CORE STATE STANDARDS

- **RST.11-12.2** - Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- **RST.11-12.4** - Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.
- **WHST.11-12.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.
- **WHST.11-12.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
- **WHST.11-12.9** - Draw evidence from informational texts to support analysis, reflection, and research

FAA AIRMAN CERTIFICATION STANDARDS

REMOTE PILOT

I. Regulations, Task A. General

- Knowledge The applicant demonstrates understanding of:

- ◦ **UA.I.A.K2** Definitions used in 14 CFR part 107.

I. Regulations, Task B. Operating Rules

- Knowledge The applicant demonstrates understanding of
  - ◦ **UA.I.B.K2** Requirement for the sUAS to be in a condition for safe operation.
  - ◦ **UA.I.B.K20** Preflight familiarization, inspection, and actions for aircraft operations.

REFERENCES

“How do Airplanes fly?” — YouTube: https://video.link/w/5eix (Length 8:16)
“Lift Formula” — YouTube: https://video.link/w/7psx (Length 3:16)
“How Does a Drone Fly?” — YouTube: https://video.link/w/YQ0x (Length 5:56)
“Quadcopter Yawing on Whiteboard” — YouTube: https://youtu.be/GSGesFOUBVQ (Length 0:24)
The Droner’s Manual (Kevin Jenkins) (pp. 5-30)
The Complete Remote Pilot (Bob Gardner and David Ison) (1-4 through 1-9)