Primary Flight Controls

Session Time: Two, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The intended purpose and use of an aircraft drives aircraft design considerations and construction techniques, materials, and components. (EU1)

The principles of aerodynamics allow an aircraft to fly, yet those same principles limit its ultimate performance and capabilities. (EU2)

A deep understanding of how an aircraft operates enables a pilot to fly the aircraft to its maximum capabilities in both normal and abnormal situations. (EU5)

ESSENTIAL QUESTIONS

1. What surfaces of an aircraft are designated to control the direction of flight?
2. Are all aircraft controlled by the same means?

LEARNING GOALS

Students Will Know

- How an aircraft is controlled in flight by its primary flight controls
- The relationship between the control surfaces of airplanes and helicopters and the movements they command
- Aerodynamic principles behind flight controls

Students Will Be Able To

- *Identify* primary flight control surfaces on fixed-wing airplanes and helicopters. (DOK-L1)
- *Relate* how primary flight control surfaces cause movement about the three axes of rotation. (DOK-L2)
- *Summarize* the meaning of uncoordinated flight and how to correct for it. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students will watch a video that describes the technique first discovered by the Wright brothers to control and maneuver the Wright Flyer. Students will answer questions about wing-warping and describe why it's no longer used as a primary means to maneuver an airplane.

Formative Assessment

Students will work together to enact a short airplane flight, where they play the part of flight crew and control surfaces in order to reinforce their understanding of how movements of the cockpit controls translate to control surface movements.

Summative Assessment
Students will write a paragraph explaining how flight controls manipulate an airplane in relation to the three axes of flight.

LESSON PREPARATION

MATERIALS/RESOURCES

- Primary Flight Controls Presentation
- Primary Flight Controls Student Activity 1
- Primary Flight Controls Student Activity 2
- Primary Flight Controls Teacher Notes 1
- Primary Flight Controls Teacher Notes 2
- Primary Flight Controls Teaching Aid

Flight Simulation Activity

- Flight simulation software
- 3-axes flight simulator joystick (if using a desktop-based simulator)

Recommended Student Reading

- **Pilot's Handbook of Aeronautical Knowledge**
  Chapter Six, Flight Controls
  https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/08_phak_ch6.pdf

- **Helicopter Flying Handbook**
  Chapter Four, Helicopter Components, Systems and Sections
  https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/helicopter_flying_handbook/media/hfh_ch03.pdf

LESSON SUMMARY

Lesson 1: Primary Flight Controls
Lesson 2: Secondary Flight Controls
Lesson 3: Flight Controls for Unmanned Aircraft

In this lesson, students will learn about an aircraft's primary flight controls. The lesson will begin with a video that describes the technique first discovered by the Wright brothers to control and maneuver the Wright Flyer. Students will answer questions about wing-warping and describe why it's no longer used as a primary means to maneuver an airplane.

Students will learn about the three primary control surfaces of both a fixed-wing airplane (elevator, ailerons and rudder) and rotorcraft (collective, cyclic and anti-torque pedals). To conclude the first session, students will complete an activity in which they label the control surfaces for both types of aircraft, identify relevant axes of motion, and explain the type of movement provided by each control.

The second session begins with explaining adverse yaw, coordinated turns and how to remain coordinated in flight. A formative assessment will ask students to work together to enact a short airplane flight, where they play the part of flight crew and control surfaces. The objective of this activity is to reinforce their understanding of how movements of the cockpit controls translate to control surface movements, which maneuver the aircraft around the three axes.

If time allows, students will use a flight simulator to experience the effect of flight controls on an aircraft. As a summative assessment, students will write one paragraph on the relationship between an airplane's primary flight controls (aileron, elevator, and rudder) and the three axes of flight.

BACKGROUND

Airplanes use flight control systems to control the forces of flight and maneuver around three axes—the imaginary lines that pass through an airplane's center of gravity (CG)—while in flight. Three primary flight control surfaces (ailerons, elevators, and rudders) move an airplane around the longitudinal, lateral, and vertical axes.

- The longitudinal axis runs from the nose to the tail of the airplane. Movement about this axis results in a rolling moment, similar to a ship rolling from side to side. Roll is controlled by ailerons, which are usually installed on the outboard trailing edge of each wing of the airplane.
- The lateral axis runs from one wing tip of the airplane to the other. Movement about this axis results in a pitching moment that enables the airplane to climb or descend. Pitch is controlled by the elevator, which is usually attached to the rear of the horizontal stabilizer of the airplane.
- The vertical axis runs from the top of the airplane to the bottom. Movement about this axis results in a yawing moment, as though the airplane were hanging from a thread and being spun around. Yaw is controlled by the rudder, which is usually attached to the vertical stabilizer of the airplane.

There are a number of variants of these primary control surfaces which engineers have created to meet certain objectives. They all share the same operating principle of moving the aircraft by applying an aerodynamic force.

Control surfaces are mounted on the airfoils such as the wings or stabilizers, but are controlled by the pilot in the cockpit. To transfer the motion of the stick or yoke to the control surface, there must be a connection between the two. The most basic connection is a system of cables and pulleys. For larger aircraft where more force must be applied, these mechanical connections are augmented with devices such as hydraulic pistons which can apply more force to the control surface. The newest method of control is called fly-by-wire, which replaces conventional manual flight controls with an electronic interface. The term fly-by-wire implies a purely electrically signaled control system. It is used in the general sense of computer-configured controls, where a computer system is interposed between the operator and the final control actuators or surfaces.

Although an airplane's flight controls can be operated independently of each other, moving one control often requires moving another. Adverse yaw, for example, often occurs when a turn is initiated using only the ailerons. The resulting motion is a yawing of the aircraft away from the direction of the intended turn as the increased drag on the ascending wing pulls the nose. Using the ailerons and rudder together properly results in what is known as a coordinated turn.

The cockpit controls of a helicopter are similar to those of an airplane. A stick controls pitch and roll, and pedals control yaw. Helicopters have an additional cockpit control known as the collective which changes the pitch of the rotor blades, thus affecting vertical motion up and down. While the controls of airplanes and helicopters are similar, the control surfaces are very different. Instead of individual control surfaces attached to the airfoils, helicopters are maneuvered by adjusting blade pitch on the moving rotors.

DIFFERENTIATION

To support a deep understanding of the material presented in the **EXPLORE** section, have students form small groups and participate in reciprocal teaching by using the strategies of predicting, generating questions, clarifying, and summarizing to guide discussion of the two prominent theories on lift as a review.

To support the simulator activity in the **EXTEND** section of the lesson plan, walk through how to set up the simulation and verbalize your actions to demonstrate what learners are expected to do in the assignment.

LEARNING PLAN

ENGAGE

Teacher Material: [Primary Flight Controls Presentation]

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

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

Warm-Up

One of the Wright brothers' major breakthroughs was the ability to control and maneuver their aircraft. They established roll control by developing an idea called wing warping. Wing warping is the twisting, or warping, of airplane wings to control the roll of an airplane left or right. Modern fixed-wing aircraft no longer use wing warping for roll control. As students will learn in this lesson, they typically use either ailerons or spoilers which are small, moveable surfaces on the wing of the aircraft.

Show students the video of "Orville and Wilbur Wright" explaining how wing warping was used to control the Wright Flyer. After the video, ask students to individually write 2-3 sentence responses to the questions on the slide. Have students share their answers in a short class discussion.

- "Wright Brothers Wing Warping" (Length 5:52)
  http://video.link/w/m5Be

[DOK L2; *summarize, infer*]

Questions

Briefly describe how wing warping worked to roll an aircraft.
The Wrights realized that if the wing on one side of the aircraft met the oncoming flow of air at a greater angle than the opposite wing, it would generate more lift on that side. In response, that wing would rise, causing the aircraft to bank. If the pilot could manipulate the wings in this way, he could maintain balance and turn the aircraft as well.

Why doesn't wing warping work for more capable, complex aircraft?
Ailerons replaced wing warping for roll control as aircraft got heavier and faster. Greater forces induced on wings required wings with more structure and stability. Ailerons also had the advantage of not weakening the airplane's wing structure as did the wing warping technique. In addition, as fuel tanks and other accessories were added to the wings, it required them to be rigid.

In engineering, an elegant solution is one in which the maximum desired effect is achieved with the smallest, or simplest effort. How is wing warping an elegant solution?
Wing warping was a very simple solution to one of aviation's most complex problems at the time:

roll control. Only modest mechanical input was needed by the pilot through cables to the wing tips, which weighed very little. Not only could the wings be lightly built, but the rigging provided strength and stiffness that was also needed.

EXPLORE

Teacher Materials: Primary Flight Controls Presentation, Primary Flight Controls Teacher Notes 1
Student Material: Primary Flight Controls Student Activity 1

Slide 5: An airplane moves about three axes of motion: vertical, lateral, and longitudinal.

- The lateral axis of motion extends from one wing tip to the other wing tip. Motion about the lateral axis is called pitch and is controlled by the elevators.
- The longitudinal axis extends from the nose to the tail of the airplane. Movement about this axis is called roll and is controlled by the ailerons.
- The vertical axis of motion extends from the top of the airplane through the bottom of the airplane. Motion about the vertical axis is called yaw and is controlled by the rudder.

All three axes pass through the airplane's center of gravity (CG).

Slide 6: The three primary control surfaces on an airplane are the elevator, ailerons and rudder.

The elevator causes the airplane to pitch up and down and is deflected by moving the control stick or yoke forward and backward. The elevator is attached to the horizontal stabilizer.

The ailerons are used to roll the airplane; they are deflected in opposite directions to each other by moving the control stick or yoke left or right. Ailerons are attached to the trailing edges of the wings.

The rudder causes the airplane to yaw from left to right and is controlled using a set of pedals in the cockpit. The rudder is attached to the vertical stabilizer.

Show students a video that depicts the movement of the airplane's flight control surfaces and the consequent motion they cause on an airplane in flight.

- "3-Axis Flight Control" (Length 00:49)
  http://video.link/w/Bwne

Teaching Tips

This video can be paused intermittently to show the movement of the airplane in relation to the deflection of the pilot's control stick and flight control surface.

Slide 7: Movement of any one of these surfaces, or a combination thereof, changes the attitude of the airplane by deflecting the air in one direction or another or creating different pressures around the control surfaces, thereby affecting the lift and drag caused by the airfoil/control surface combination. This causes the airplane to pitch, roll or yaw.

At slow airspeeds with less relative wind, the flight controls may feel less effective than at high airspeeds with greater relative wind. At higher airspeeds, the flight controls become more responsive and will feel more firm.

Slide 8: The pilot moves the elevator by pushing or pulling the stick or yoke. When a pilot pulls on the yoke, the elevator is deflected upward. This upward deflection of the elevator creates a tail down force which pushes the tail of the airplane down, pivoting the nose of the airplane up and causing it to climb.

The same principle applies to descents; applying forward pressure on the yoke deflects the elevator downward, pushing the tail upward and forcing the nose of the airplane downward.

This up-down motion of the airplane's nose is referred to as pitch.

Teaching Tips

Teachers may wish to go back and show portions of the video, "3-Axis Flight Control" to give students another opportunity to see how controls in the cockpit move elevators, ailerons and rudders.

- "3-Axis Flight Control" (Length 00:49)
  http://video.link/w/Bwne

Slides 9-10: An airplane may use any of several elevator types and locations, based on the airplane's mission and the preferences of its designers.

T-tail - The T-tail configuration features a vertical stabilizer with the horizontal stabilizer mounted on top; the tail thus has the shape of the letter "T." This configuration provides consistent control surface movement throughout the phases of flight because the elevator is above the effects of downwash from the propeller as well as airflow around the fuselage and wings. In some airplanes, such as seaplanes, T-tails are necessary to keep the elevator as far from the water as possible. However, T-tails are disadvantageous in terms of stall recovery. They can go into a deep stall from which it is difficult to recover. This is because in very high angles of attack, the turbulent air flow from wings impinges on the elevators, making it difficult to obtain smooth airflow over the tail and elevator needed for a recovery.

Stabilator - A stabilator is a single-piece control surface that combines the functions of the horizontal stabilizer and elevator into one movable surface, hence the name stabilator (stabilizer and elevator). A stabilator can be considered a one-piece horizontal stabilizer that pivots from a central hinge point, making it very sensitive to control inputs and aerodynamic loads. The widespread Piper Cherokee airplane is an example of an airplane that uses a stabilator.

Canard - Canards are similar to conventional elevators that utilize two lifting surfaces. The difference is that canards are mounted on either side of the nose of the airplane as opposed to the tail. Theoretically, canard configurations are more efficient and lift the nose of the airplane, resulting in less drag for a given amount of lift; this is particularly true for high-speed and long-endurance flights. On the other hand, a canard-fitted airplane is less dynamically stable than conventional airplanes. When a conventional airplane is flying straight and level and encounters a sudden disturbance (e.g., a wind gust), the downforce provided by the horizontal stabilizer quickly gets the airplane back to its original flight attitude.

Elevons - These surfaces combine the functions of the elevator and aileron. These designs are usually found on military airplanes such as the F-117A. Elevons can be moved differently based on the needs of the pilot. If they are moved together, then they result in a pitching moment; in contrast, a differential movement of the same surfaces gives the pilot roll authority over the airplane.

Slide 11: Ailerons are located on the outboard trailing edge on the wings of an airplane. When a pilot turns the yoke to the left or right, the aileron on that side deflects upward while the opposite aileron deflects downward. For instance, if the yoke is turned left, the left aileron goes up, while the right aileron goes down, and the airplane rolls left.

The ailerons work by changing the effective shape of the airfoil of the outer portion of the wing. Changing the angle of deflection at the rear of an airfoil will change the amount of lift generated by the airfoil. With greater downward deflection, the camber of the airfoil is increased, thereby increasing lift.

Slide 12: Like elevators, there are different variants of ailerons.

Flaperons - As the name implies, these are a combination of flaps and ailerons in one surface. Using a device installed in the control system, a pilot can deflect the surfaces in opposite directions, like ailerons, or together, like flaps. For this design to stay effective, the surfaces must be mounted a distance away from the actual wing in order to prevent air flow disturbances at high angles of attack and low airspeed configurations.

Teaching Tips

Flaps will be covered in detail in the next lesson on secondary flight controls. However, students have been introduced to flaps prior to this lesson. As a reminder, flaps are secondary flight controls that are attached to the inboard trailing edges of an airplane's wings (the ailerons are attached to the outboard trailing edges of the wing). Unlike ailerons, which deflect in opposite directions, flaps deflect in the same direction. Flaps are lift-enhancing devices most commonly used on takeoff and landing when the aircraft is slower and additional lift is needed for flight.

Spoilerons - Spoilerons are a combination of spoilers and ailerons in one surface. Spoilerons help direct an airplane's turns by decreasing the lift produced by one wing, but they do not necessarily increase the lift on the other wing. This causes the airplane to roll in the direction of less lift.

Teaching Tips

Spoilers are secondary flight control surfaces that will also be covered in detail in the next lesson. Spoilers are flight control surfaces that are attached to the surface of a wing. When they are activated, they rise up and disrupt the air flow over the top of the wing. This reduces the amount of lift produced by that wing and creates a lot of drag.

Slide 13: The rudder is located on back of the vertical stabilizer. The pilot moves the rudder using a pair of pedals in the cockpit. When a pilot pushes on one pedal, the rudder is deflected in that direction. For instance, if the pilot pushes the left pedal forward, the rudder is deflected to the left. When the pilot depresses a rudder pedal, deflecting the rudder in the direction of the pressed pedal, the deflection of the rudder creates what is, in effect, a vertical wing that produces a horizontal force. That horizontal force will point the nose in the direction desired.

Slide 14: As you will recall from the lesson on rotorcraft lift and stability, rotorcraft also have flight controls, but they are quite different from those of fixed-wing airplanes. Rotorcraft typically have main rotor blades that rotate over the fuselage, providing lift, pitch and roll control. They also have a smaller rotor located on the tail used to counteract torque and yaw the aircraft.

Collective - The collective is a control located to the left of the pilot's seat and is operated by the pilot's left hand. When the collective is raised, there is a simultaneous and equal increase in the pitch angle of all the main rotor blades. When the collective is lowered, there is a simultaneous and equal decrease in the pitch angle of all the rotor blades.

Cyclic - A control called a cyclic can be used to manipulate the swash plate in a way that will alter the pitch of individual rotor blades. Cyclic maneuvers tilt the arc of the main rotor, which in turn tilts the lift vector and allows the pilot to control the aircraft in pitch and roll. In other words, the cyclic allows the pilot to fly the helicopter in any direction: forward, rearward, left and right. The cyclic is usually located between the pilot's legs and is manipulated with the right hand.

Anti-torque pedals or tail rotor pedals - The tail rotor pedals are located at the pilot's feet and are used to adjust the pitch of the tail rotor blades, which serve to yaw the helicopter.

Slide 15: A pilot's inputs —for example, by moving the control yoke in the cockpit— are transferred to the control surfaces to deflect them to the desired position and maneuver the airplane accordingly. A flight control system consists of flight control surfaces, the respective cockpit controls, connecting linkages, and the necessary operating mechanisms to control an aircraft's direction in flight.

The original flight control systems, and those still used on small airplanes today, use a system of cables and pulleys to transfer the motions of the pilot's controls to the control surfaces.

As airplanes got larger, the amount of force necessary to move the control surfaces became too great for cable and pulley systems. To compensate, control systems were developed that inserted hydraulics into the control path so that the pilot's movement of cockpit controls could be boosted by hydraulic pistons powered by pumps.

Mechanical and hydraulic flight control systems are relatively heavy and require careful routing of flight control cables through the aircraft by systems of pulleys, cranks, tension cables and hydraulic pipes. Both systems often require redundant backup to deal with failures, which increases weight. Fly-by-wire is a system that replaces the conventional manual flight controls of an aircraft with an electronic interface. The term "fly-by-wire" implies a purely electrically signaled control system. It is used in the general sense of computer-configured controls, where a computer system is interposed between the operator and the final control actuators or surfaces. The computers send commands to the flight controls through electrical wires attached to either electrical or hydraulic actuators which move the control surfaces. The fly-by-wire computers continually act to stabilize the aircraft and prevent the pilot from operating outside the aircraft's safe performance envelope.

Slide 16: Provide students with **Primary Flight Controls Student Activity 1.**

In the first part, students are shown an incomplete diagram of an airplane. Working independently, students should label the control surfaces shown in the diagram and identify the relevant axes of motion and the type of movement provided by each surface.

In the second part, students are shown an incomplete diagram of a rotorcraft cockpit. Working independently, students should label the flight controls shown in the diagram and identify each control's function in maneuvering the helicopter.

Answers can be found in **Primary Flight Controls Teacher Notes 1.** This activity will conclude the first session of this lesson.

EXPLAIN

Teacher Materials: [Primary Flight Controls Presentation](), [Primary Flight Controls Teaching Aid]()

Slide 17: Begin the second session of the lesson by explaining that adverse yaw is a phenomenon associated with turning an airplane. It is the natural and undesirable tendency for an aircraft to yaw in the opposite direction of a roll. Whenever the pilot moves the control yoke left or right in an airplane, the aileron corresponding to the direction of movement deflects upward while the opposite aileron is deflected downwards. For instance, moving the control yoke left moves the left aileron up and the right aileron down.

The upward deflection of the left aileron reduces the lift produced by the left wing. The opposite happens with the right aileron; the downward deflection increases camber and increases lift on the right wing. The airplane rolls into a left turn. However, the increased lift on the right wing also increases the drag on the wing, slowing down that wing in relation to the opposite (left) wing. This causes the nose of the airplane to yaw toward the wing with increased lift and drag (right). The nose initially moves opposite the direction of the intended turn. This is termed adverse yaw.

Adverse yaw is countered by using the rudder (in almost all cases, stepping on the rudder *into* the turn). By adding rudder input, the pilot is creating a side force on the vertical tail that opposes adverse yaw. This creates a yawing moment that helps turn the airplane in the correct direction.

Slide 18: A coordinated turn is one in which the relative wind is aligned with the aircraft's fuselage. If the wind is coming from one side or the other, then the airplane would be in either a slip or a skid.

In a slipping turn, the rate of turn is too slow for the angle of bank. The nose is pointing too much to the outside of the turn (and the tail is inside the turn).

In a skidding turn, the rate of turn is too great for the angle of bank. The nose is pointing too much to the inside of the turn (and the tail is outside of the turn).

Another way to think of coordinated flight is flight in which the movement of the airplane is such that tail tracks the nose.

To coordinate the turn, rudder is applied to yaw the airplane so that it is neither slipping nor skidding (to counteract adverse yaw). A pilot monitors this by watching the turn coordinator, which contains an inclinometer (the instrument with a glass tube and a ball).

A simple way to see if a turn is coordinated is with a yaw string, which is a piece of yarn taped to the nose of the airplane on the centerline. When the string is pointed straight toward the tail of the airplane, the airplane is in coordinated flight. Yaw strings are often seen on gliders.

Slide 19: The turn coordinator (or slip/skid indicator) is an instrument used in the cockpit to tell the pilot the quality of the turn. A ball contained in a curved glass tube (also called an inclinometer) shows when a turn is coordinated or in a slip or a skid. When the ball is in the same direction as the turn, the airplane is said to be in a slip. Conversely, when the ball is to the opposite side of the turn, the airplane is skidding. A pilot can correct a slip or a skid using rudder input while turning an airplane using the ailerons. The pilot deflects the rudder pedal corresponding to the deflection of the ball. If the ball is to the left in the tube, the pilot deflects the left rudder and vice versa. In aviation parlance, this is called "stepping on the ball."

Show students this video which describes coordinated flight, slips and skids, and how to keep an airplane coordinated during a turn.

- "One Minute Ground School - Coordinated Flight" (Length 2:21)
  http://video.link/w/UjDe

Slide 20: Complete the **Formative Assessment**.

Formative Assessment

In this activity, students will work together to enact a short airplane flight, where students play the part of flight crew and control surfaces. The objective of this activity is to reinforce their understanding of how movements of the cockpit controls translate to control surface movements, which maneuver the aircraft around the three axes.

Space should be cleared in the room to allow students to approximate the layout of an airplane. If there is additional time, students can construct and act out their own script or scenario.

Refer to **Primary Flight Controls Teaching Aid** for guidance. Dividing into two groups, students will take various roles to simulate the flight of an aircraft with the necessary control inputs and control surface movements.

Students should be assigned the roles of:

1. Flight Director
2. Pilot
3. Flight Engineer
4. Right Aileron
5. Left Aileron
6. Rudder
7. Elevator

Students not assigned roles will act as judges to decide which group gave the most accurate and engaging performance. Print three copies of the scenario/script found in **Primary Flight Controls Teaching Aid** and provide to the flight director, pilot and flight engineer.

[DOK 4; create, DOK 2; *relate*]

EXTEND

Teacher Materials: Primary Flight Controls Presentation, Primary Flight Controls Teacher Notes 2
Student Material: Primary Flight Controls Student Activity 2

Slide 21: If time allows, students will use a flight simulator to complete the flight simulator activity found in **Primary Flight Controls Student Activity 2**.

Simulator Extension Powered by Redbird

In this activity, students will use a flight simulator to experience the effect of flight controls on an aircraft. Working in pairs, one student will begin by flying the aircraft; the other student will record answers to the following questions. Students will then switch roles.

Provide students with **Primary Flight Controls Student Activity 2**. They will record their observations and answer comprehension questions on their activity sheets. Further details on this activity, as well as possible answers to the questions, can be found in **Primary Flight Controls Teacher Notes 2**.

EVALUATE

Teacher Material: Primary Flight Controls Presentation

Slide 22: Conduct the **Summative Assessment.**

Summative Assessment

As a summative assessment, students will write one paragraph on the relationship between an airplane's primary flight controls (aileron, elevator, and rudder) and the three axes of flight. In their writing, students must explain how each flight control manipulates an airplane in relationship to a particular axis.

Sample student response: The aileron, elevator, and rudder are controlled by the pilot to manipulate the airplane in a particular direction or position. The aileron changes the roll of the airplane which is a rotation, left or right, about the longitudinal axis of the airplane. The elevator of an airplane changes the pitch of the airplane which is a rotation, up or down, about the lateral axis of the airplane. The rudder changes the yaw of an airplane which is a rotation, directly left or right, about the vertical axis of the airplane.

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Written explanation includes:
    - Clear and accurate explanation
    - Correct description of all three primary flight controls and how they control the aircraft around the three axes of flight
    - Correct spelling and grammar
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 Student writing shows a clear understanding of an airplane's flight controls, and how each flight control manipulates an airplane to rotate about its respective rotational axis.

7-8 Student writing shows a sufficient understanding of an airplane's flight controls, and how each flight control manipulates an airplane about the three axes of flight. Minor gaps in understanding are evident.

5-6 Student writing shows a partial understanding of an airplane's flight controls, as well as the three axes of flight, but does not sufficiently connect each flight control with its respective rotational axis.

0-4 Student writing shows little or no understanding of an airplane's flight controls and the three axes of flight. Student work is incomplete with many gaps in understanding.

[DOK 2; *summarize, cause/effect, relate*]

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS2-4** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects
    - Science and Engineering Practices
        - Analyzing and Interpreting Data
        - Obtaining, Evaluating, and Communicating Information
    - Disciplinary Core Ideas
        - PS2.A Forces and Motion
        - PS2.B Types of Interactions
    - Crosscutting Concepts
        - Cause and Effect
- **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.9-10.2 - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- RST.9-10.4 - 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 9-10 texts and topics.
- WHST.9-10.6 - Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- WHST.9-10.8 - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- WHST.9-10.9 - Draw evidence from informational texts to support analysis, reflection, and research.

REFERENCES

https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/08_phak_ch6.pdf
https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/helicopter_flying_handbook/media/hfh_ch03.

pdf
https://www.youtube.com/watch?v=UV8xcm5xsuo