Rotorcraft Lift and Stability

Session Time: Two, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

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

Safe and efficient aviation operations require that pilots use math, science, and technology. (EU4)

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. How does a helicopter produce lift?
2. Does the stability of a helicopter depend on its design or on the pilot?

LEARNING GOALS

Students Will Know

- How helicopter lift is different from fixed wing lift
- The aerodynamic challenges that result from the production of lift in different phases of helicopter flight
- The purpose and operations of three different types of rotor systems

Students Will Be Able To

- *Explain* how helicopter flight controls operate and affect the helicopter's movement [DOK-L2]
- *Assess* how helicopter design compensates for issues involving lift and stability. [DOK-L3]
- *Describe* how helicopter rotor systems operate and compensate for aerodynamic effects [DOK-L2]

ASSESSMENT EVIDENCE

Warm-up
As a precursor to learning about the lift and stability of helicopters, show students the picture of the helicopter. Ask students which surfaces of the helicopter produce lift, and how they think these surfaces might be similar to or different from airplane wings.

Formative Assessment

Students will take on the role of aircraft engineers as they analyze a helicopter design that does not use a tail rotor to counter torque. They will apply their understanding of torque, translating tendency, and dissymmetry of lift.

Summative Assessment
Students will create a written briefing for several newly hired engineers who need to be trained on the control operation and aerodynamic challenges posed by helicopter flight. They will explain each challenge, as well as how particular design features solve the problems faced by helicopter engineers.

LESSON PREPARATION

MATERIALS/RESOURCES

- Rotorcraft Lift and Stability Presentation
- Rotorcraft Lift and Stability Student Activity 1
- Rotorcraft Lift and Stability Student Activity 2
- Rotorcraft Lift and Stability Teacher Notes 1
- Rotorcraft Lift and Stability Teacher Notes 2

Flight Controls Explanation

- **Small Model Helicopter (Optional)**

Recommended Student Reading

- **Helicopter Flying Handbook**
  Chapter Three, Helicopter Flight Controls https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/helicopter_flying_handbook/media/hfh_ch03.pdf
- **Helicopter Flying Handbook**
  Chapter Two, Aerodynamics of Flight https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/helicopter_flying_handbook/media/hfh_ch02.pdf

LESSON SUMMARY

Lesson 1 - Stability in Aircraft Design
Lesson 2 - Rotorcraft Lift and Stability

In this lesson, students will learn how helicopters create lift, as well as some of the different aerodynamic forces that impact the aircraft when lift is created. Helicopter stability will be examined as well, including the ways that stability in a hover differs from that in forward flight.

To begin the lesson, students will be asked to recollect how an airplane wing creates lift as it passes through the air. The basic similarities between helicopter rotor blades and a fixed-wing will be discussed, as will the elements that set them apart. Some of the fundamental lift issues that helicopters experience, including dissymmetry of lift and Coriolis Effect, will be examined in this session, and students will learn how the three types of helicopter rotor systems (rigid, semi-rigid, and fully articulated) address these issues.

Next, students will learn about angular momentum and torque as they affect helicopters. To conclude the session, a formative assessment will ask students to take on the role of aircraft engineers as they work to design a helicopter that does not use a tail rotor to counter torque.

The second session looks more closely at the ways that helicopter lift and stability change depending upon whether the aircraft is in a hover or directional flight. Finally, the lesson concludes with a summative assessment requiring students to list the three types of rotor systems, and to explain how each one addresses a different issue involving lift.

BACKGROUND

Students have learned that lift is an aerodynamic force produced by air acting on an airfoil. Helicopters produce lift with airfoils just like airplanes, though they use rotating airfoils instead of a fixed wing. As they rotate, helicopter rotor blades act very much like airplane wings, and lift is generated as they continue to “attack” new air. In a helicopter, thrust and lift are provided through the same mechanism--the rotor system. This is different from airplanes where thrust is provided by the engine and lift is generated by the wings. Also, while airplane wings have a set angle of incidence that cannot be altered, this angle can be varied for each helicopter rotor blade.

Helicopters have unique characteristics that often vary with the phase of flight. Issues involving lift and stability within a hover are not the same as those that are encountered in directional flight. For this reason, each type of flight will be examined separately during this lesson. To understand helicopter lift and stability issues and the way these issues are compensated for in helicopter design, students will need to recall both the lift equation and what they learned about static and dynamic stability in the previous lesson. They will also need to recall Newton’s Third Law, which states that for every action there is an equal and opposite reaction. While similar to rotorcraft, multirotor lift and control will be taught in the “Flight Controls for Unmanned Aircraft” lesson.

MISCONCEPTIONS

People familiar with fixed wing aircraft associate stalls with slower speeds, which may create a misconception about helicopter stalls. Helicopters are more likely to stall at higher speeds (known as a retreating blade stall). This phenomenon is explained in the lesson.

Many people also assume that helicopters always takeoff and land in a purely vertical path, when many helicopters use a horizontal takeoff run and landing path the gain more airspeed that can be used to aid in autorotation in the unlikely event of an engine failure.

Many people assume that airplanes and helicopters fall straight down out of the sky if the engine fails. But in fact, helicopter rotors continue to spin even after the engine stops and they can be used to perform a safe landing by manipulating the blade angles of the rotors in a procedure called autorotation.

DIFFERENTIATION

To support student comprehension of new information throughout the lesson, encourage students to download and read the FAA’s Helicopter Flying Handbook. This free resource will allow students to review and process helicopter concepts at their own pace.

To support student comprehension of new information in the **EXPLORE** and **EXPLAIN** sections, provide a graphic organizer such as a Know/Want-to-Know/Learned (KWL) for students to complete regarding the information on helicopter lift production. This will allow students to better understand the structure of new information and also connect working and long-term memories.

To support student choice in the **EVALUATE** section, allow students flexibility in how they present their summative assessment. Providing students with choice not only increases motivation, but also encourages the use of metacognitive skills in determining the best modality for communicating their messages effectively. Instructors may provide examples of how students can modify their presentations.

LEARNING PLAN

ENGAGE

Teacher Material: [Rotorcraft Lift and Stability Presentation]

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

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

Warm-Up

As a precursor to learning about the lift and stability of helicopters, show students the picture of the helicopter. Ask students which surfaces of the helicopter produce lift, and how they think these surfaces might be similar or different to airplane wings. Teachers may prompt students further by asking them to compare the size of helicopter rotors and airplane wings relative to their respective aircraft size. Considering the smaller size of the helicopter rotor blades, how do students think they are able to create enough lift for flight?

Possible answer:
Most of a helicopter's lift is provided by its rotor system, with a small amount being provided by other surfaces such as horizontal stabilizers. Rotor blades are similar to airplane wings in that they are airfoils, and they produce lift by "attacking" the oncoming air. They are different in that they provide thrust along with lift. Also, unlike an airplane pilot, a helicopter pilot can change the angle of attack of the rotor blade without moving the entire aircraft. Students may recall the crucial role of velocity in the lift equation and hypothesize that since rotor blades have much less surface area than wings, they must move much faster in order to create enough lift for flight.

EXPLORE

Teacher Material: [Rotorcraft Lift and Stability Presentation]

Slide 5: Explain to students that--like airplanes--helicopters use airfoils to produce lift. Unlike airplanes, however, their airfoils take the form of rotating rotor blades instead of wings. Typical helicopters contain airfoils that include both main rotor blades (positioned on top of the helicopter) and tail rotor blades. If a rotor blade is examined in cross section, it resembles an airplane wing. Like a wing, blades have a leading edge and a trailing edge, with a chord line intersecting the leading and trailing edges of the airfoil.

Air is moved past the blades in a helicopter's rotor system through mechanically powered rotation. This powered rotation provides both lift and thrust.

Slide 6: A helicopter's rotor system is comprised of several basic parts. A hub, located on a mast at the top of the helicopter, serves as the center point and attachment point for the root of the blade. The root is the inner end of the blade that attaches to the hub, while the tip is the section of the blade located farthest from the hub.

Slide 7: Students should recall that relative wind is defined as the airflow relative to an airfoil and is created by movement of an airfoil through the air. In a rotary-wing aircraft, this relative wind is created by the rotation of rotor blades as they turn about the mast, and it is termed the rotational relative wind (or tip path plane).

The rotational relative wind flows opposite the airfoil's flightpath and is constantly changing direction as the rotor blades rotate.

Encourage students to recall what they learned about the rotation of airplane propellers in the Unit 4 lesson on thrust. In that lesson they learned that the speed at which the propeller blade moves through the air varies along its length, with the blade moving slowest closest to the propeller hub and fastest at the propeller tip. The same is true of a rotor blade. As a result, the velocity of rotational relative wind is highest at the tips of the rotor blades, and it decreases to zero at the center of the mast.

It is rotational relative wind that is used to generate lift. As the rotor blades spin, air is accelerated over each blade and projected downward. This downward flow of air, which exists any time that the helicopter is producing lift, is called induced flow.

Slide 8: Angle of incidence is term that students will hear often in this lesson. Angle of incidence should not be confused with angle of attack.

Students should be able to recall that the angle of attack is defined as the angle between the airfoil chord and its direction of motion relative to the air. It is an aerodynamic angle.

Angle of incidence is the angle between the blade chord line and the rotor hub. It is a mechanical angle rather than an aerodynamic angle and is sometimes referred to as blade pitch angle.

If a helicopter's blades are positioned at a flat pitch, then no lift will be produced and air will leave the trailing edge in the same direction as it meets the leading edge. As the angle of incidence (blade pitch angle) is increased, however, both induced flow and lift will be created. Rotational relative wind modified by induced flow is called resultant relative wind.

Whenever induced flow or airspeed modifies the relative wind, the angle of attack is different from the angle of incidence.

Slide 9: A device called a swash plate modifies the pitch of a helicopter's rotor blades--either collectively or individually. When the swash plate is used to increase or decrease the pitch angle--and hence the angle of attack--of the rotor system as a whole, the helicopter will either climb or descend. This type of maneuver is accomplished when a pilot raises or lowers the 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 pitch angle of all the rotor blades.

Slide 10: 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.

Have students watch this video that explains the basic operation of the flight controls including the swash plate. It also includes a basic explanation of how helicopters can autorotate to land safely after an engine failure.

- "How Helicopters Fly" (Length 3:44)
  http://video.link/w/730e

Slide 11: Have students recall how a spinning propeller acts like gyroscope. Ask them to to explain the effects that this has on the airplane in flight. Precession occurs when a force is exerted against the side of a gyroscope. The gyroscope reacts as if the force had been exerted 90 degrees in the direction of rotation around the wheel. When a force is applied to the tail of the aircraft to pitch the nose up or down, it's equivalent to a force applied to the propeller. Since the propeller acts like a gyroscope, the force applied to it actually appears 90 degrees off in the direction of rotation. Thus, pitching the nose up is like a force applied forward on the bottom of the propeller, which is rotating clockwise as seen from the cockpit, and the resulting force yaws the aircraft right.

The spinning main rotor of a helicopter also acts similarly to a gyroscope and experiences precession.

When the cyclic control is used to pitch a two-bladed helicopter forward, the angle of incidence on one blade is increased while the angle of incidence on the other is decreased. Assuming a counterclockwise rotor system, the swash plate will decrease the angle of attack on the blade passing the 90 degree position on the left of the helicopter (the advancing blade) while increasing the angle of attack on the blade passing 90 degrees to the right (the retreating blade). These actions will take effect 90 degrees later, which means that the advancing blade will achieve a maximum downward deflection as it passes directly in front of the helicopter while the retreating blade will achieve a maximum upward deflection as it passes to the rear of the helicopter.

EXPLAIN

Teacher Materials: Rotorcraft Lift and Stability Presentation, Rotorcraft Lift and Stability Teacher Notes 1
Student Material: Rotorcraft Lift and Stability Student Activity 1

Slide 12: Ask students how the fact that a helicopter's rotor blades are constantly changing direction might affect the amount of lift that each blade experiences. Students should first consider a helicopter that is hovering in no-wind conditions, suspended in a single location. Then they should consider a helicopter that is in forward flight.

If a helicopter is hovering on a perfectly calm day, then each of its individual rotor blades will produce the same amount of lift as they rotate. This is not the case, however, if the helicopter is moving through the air, or if there is wind. Why not?

To answer this question, it is necessary to consider the lift formula from Unit 4, where $L = C_L \times V^2 \times S\,\rho / 2$. As students will recall, C_L represents the coefficient of lift, ρ represents air density, v represents velocity, and s represents the surface area of the wing. Velocity has the most effect on lift, because its effects are squared.

Slide 13: As a helicopter begins to gain airspeed in any direction, the helicopter will have at least one blade that is advancing and one blade that is retreating. The advancing blade is the blade that is moving in the same direction as the helicopter, while the retreating blade is the blade moving in the opposite direction. Regardless of the direction the helicopter is moving (forward, sideward, or rearward), the velocity of the relative wind will be different for the advancing and retreating blades. The relative wind encountered by the advancing blade will be increased by the speed of the helicopter, while the relative wind encountered by the retreating blade will be decreased by the same amount. As a result, the advancing rotor blade can produce more lift than the retreating blade.

Slide 14: As an example, let's say that a two-bladed helicopter has a blade tip speed of approximately 400 knots, and that it is traveling forward through the air at 100 knots. What would this make the relative wind speed for each blade?

The advancing blade would encounter a relative wind of 500 knots--the speed of the blades plus the helicopter's speed through the air. The retreating blade, however, would meet a relative wind of 300 knots since the helicopter's forward speed would be subtracted. This difference in speed between the advancing and retreating blades causes a dissymmetry of lift.

Slide 15: To compensate for dissymmetry of lift, a helicopter's blades are allowed to flap, or move up and down as they rotate around the mast. Because the advancing blade of a helicopter has more lift than the retreating blade due to its higher velocity, it will flap upward as it travels from the rear of the helicopter to its 3 o'clock position. This upward motion through the air causes the blade to experience a lower angle of attack than the retreating blade, which is flapping downward and hence meeting the relative wind at a greater angle. This flapping motion changes the coefficient of lift as the blade rotates.

Looking again at the lift equation ($L = C_L \times V^2 \times S\,\rho / 2$), we can see that by allowing helicopter blades to flap, C_L increases or decreases to offset changes in V, leaving lift constant.

Have students watch two videos, which explain the theory behind dissymmetry of lift and blade flapping. The second video is a slow-motion visualization of how blade flapping occurs.

- “Compensation for Dissymmetry of Lift in Helicopters” (Length 6:31)
  http://video.link/w/lSxe

- “Helicopter Aerodynamics” (Length 1:20)
  http://video.link/w/rq3e

Slide 16: Flapping is only effective up to a point. If the helicopter gains enough forward airspeed, the angle of attack of the helicopter’s retreating blade will exceed the critical angle of attack, airflow will be disrupted, and the rotor blade will stall in the same way that an aircraft wing stalls when the critical angle of attack is exceeded.

This type of stall is termed “retreating blade stall,” and is a major factor in limiting a helicopter’s never-exceed speed.

Slide 17: As helicopter blades flap they experience changes in velocity, which takes place as they become closer to or farther away from the axis of rotation. This is due to the Coriolis Effect, or the law of conservation of angular momentum.

Angular momentum (L) is the moment of inertia (mass times distance from the center of rotation squared), represented by (I) multiplied by the speed of rotation (ω).

Angular Momentum Equation: $L = I\omega$

The law of conservation of angular momentum states that the value of angular momentum of a rotating body does not change unless an external force is applied. As a helicopter blade flaps up, it becomes closer to the axis of rotation. Because no external force is being applied, angular momentum must remain the same. As a result, angular velocity must increase, causing the blade closer to the axis of rotation (the advancing, upward flapping blade) to want to accelerate. If the motion of one blade is moving faster while the other is slowing down isn’t accommodated for, it causes stress on the blades.

The video uses figure skating to illustrate and explain Coriolis Effect (law of conservation of angular momentum).

- “Angular Momentum” (Length 1:15)
  http://video.link/w/vq3e

Slide 18: There are three types of rotor systems that are used on helicopters: rigid, semi-rigid, and fully articulated. These systems each find different ways to accommodate for the dissymmetry of lift and the Coriolis Effect.

Rigid - The least complex type of rotor system, rigid blades are allowed to feather to change their angle of incidence. Feathering means the changing of the pitch angle of the rotor blades. Dissymmetry of lift and Coriolis Effect both place stresses on this type of rotor system.

Semi-rigid - In addition to having feathering capability, semi-rigid rotor systems include hinges that allow the blades to flap. This counteracts dissymmetry of lift while placing less stress on the rotor blades.

Fully articulated - Fully articulated rotor blades are the most complex, and--in addition to possessing flapping hinges--also have hinges that allow the blades to lead and lag. The advancing blade will lead as the Coriolis Effect brings it closer to the axis of rotation, and the retreating blade will lag. This accommodates Coriolis Effect while placing still less stress on the blades themselves.

Show students a video that describes the three types of rotor systems used on helicopters.

- Types of Rotor Systems in Helicopters (8:41)
  http://video.link/w/wq3e

Slide 19: Explain that as thrust is produced, creating angular momentum in the helicopter’s rotors, torque is produced as well. As Newton’s Third Law states, for every action there is an equal and opposite reaction. As a result, as the helicopter's engine drives its rotors to turn rapidly in a counterclockwise direction, the aircraft's fuselage wants to turn clockwise. To counteract this tendency, most helicopters have a tail rotor, which provides thrust opposite the direction that the aircraft is inclined to turn.

Some of this thrust applies a force to the fuselage that causes the helicopter to drift laterally in the same direction. A helicopter has a tendency to move in the direction of its tail rotor thrust. This is because the tail rotor is acting in the same way as an airplane propeller, and pulling the helicopter to the side.

This sideward movement is called translating tendency.

Slide 20: Complete the **Formative Assessment** on **Rotorcraft Lift and Stability Student Activity 1**. The assessment will complete the first session of this lesson and may be assigned as homework.

Formative Assessment

Working in small groups, ask students to work through the scenario presented in **Rotorcraft Lift and Stability Student Activity 1**. In this activity, students take on the role of aircraft engineers who have designed a helicopter that does not use a tail rotor to counter torque. They will apply their understanding of torque, translating tendency, and dissymmetry of lift to answers the question provided.

Before students begin, you may show them a video that describes the capabilities of this new design.

- "AVX Aircraft Coaxial Compound Helicopter for US Army" (Length 5:00)
  http://video.link/w/4q3e

Answers to the questions can be found in **Rotorcraft Lift and Stability Teacher Notes 1**.

[DOK L3; apply, DOK L2 explain]

EXTEND

Teacher Materials: Rotorcraft Lift and Stability Presentation**, Small Model Helicopter (optional)**

Slide 21: Both helicopter lift and stability change depending upon whether a helicopter is in a hover or directional flight. For this reason, we will look at both phases of flight separately. First, we will examine some of the forces at play while a helicopter is hovering.

The following video looks at the challenge of hovering a helicopter.

- "Hovering a Helicopter is Hilariously Hard" (Length 5:37)
  http://video.link/w/Aq3e

Questions

In the video, hovering a helicopter was likened to solving a Rubik's Cube. Ask students why this is the case and what they feel the video suggests about helicopter stability.

This is due to the delicate balance that a helicopter pilot must maintain between the collective, the cyclic, and the anti torque pedals.

Slide 22: When a helicopter is in a hover, the four opposing forces of flight (lift, thrust, drag, and weight) are in balance. Because thrust and drag are equal to lift and weight, the helicopter remains stationary.

The altitude at which a helicopter hovers can be changed by altering the angle of incidence (and, as a result, the angle of attack) of its blades. For the helicopter to gain altitude, the angle of incidence must be increased using the collective. What happens when this occurs?

1. The higher angle of attack increases the amount of lift, which throws off the balance between lift and weight. The helicopter will climb until the point that this balance has been restored. It is important to note that the increase in lift comes at a cost--an increase in induced drag.

2. This means that the helicopter will require more power to turn the rotor system (to overcome this drag). As power increases, torque increases, which must be countered by additional thrust from the tail rotor. This is accomplished by a pedal input from the pilot.

3. This additional tail rotor thrust will increase the helicopter's translating tendency, which can be countered by a cyclic control movement from the pilot.

Teaching Tips

Use a small model helicopter to walk students through the various control movements and forces that take place when a climb is initiated while in a hover. This is intended to illustrate the interrelatedness of the controls.

Slide 23: Another reason that hovering a helicopter is challenging involves pendular action. Because the fuselage of a helicopter is suspended from a single point, it is free to oscillate in the same way as a pendulum. This is one reason why it is easy to overcontrol a helicopter in a hover, and why any control movements that are made should be minimal and smooth.

The following video shows a student helicopter pilot's first flight, during which pendular action can be observed.

- "Student Pilot First Flight - Pendular Action" (Length 00:30)
  http://video.link/w/Iq3e

Also, when hovering a pilot must keep a helicopter's natural weathercock stability in mind. Weathercock stability refers to a helicopter's tendency to weathervane into the relative wind. If a tailwind is present (blowing from 120 degrees to 240 degrees behind the helicopter), an uncommanded and rapidly accelerating yaw can occur. In order to avoid the onset of this condition, it is vital that a pilot maintain positive control of the yaw rate when in tailwind conditions.

Slide 24: Review the concept of stability with the students. Stability can be classified as either static stability or dynamic stability. Static stability describes the initial tendency of an aircraft to return to equilibrium following a disturbance. If an aircraft is disturbed from its original position and--following the disturbance--returns to this position on its own, it is statically stable. If, however, it continues in the direction of displacement, it is said to be statically unstable.

Dynamic stability describes an aircraft's amplitude over time after it has been disturbed from equilibrium. If the disturbance causes oscillations that diminish over time, the aircraft is dynamically stable. If the oscillations gain amplitude over time, the aircraft is dynamically unstable.

Slide 25: A hovering helicopter is statically stable; if it is disturbed by a gust of wind, it will return to its original position. It will overshoot this position, however, and continue to oscillate with greater amplitude over time (if it is not corrected). This is because helicopters are dynamically unstable in a hover.

Slide 26: What happens to lift and stability when a helicopter accelerates from a hover and begins directional flight? In the last session, we discussed the effects of dissymmetry of lift. Another effect that plays a role in changing lift as a helicopter accelerates is called translational lift. Translational lift refers to the improved rotor efficiency that takes place as a helicopter begins directional flight.

The efficiency of a helicopter's rotor system becomes greater with each knot of additional directional airspeed. Why?

As it moves through the air, the wind it encounters becomes more horizontal and--as a result--induced flow is decreased. Turbulent vortices created by the helicopter's rotor blades are left behind, and both the main rotor and the tail rotor become more aerodynamically efficient. As air moves horizontally through the rotor system, the angle of attack (determined by the angle at which the chord line of each blade is meeting resultant relative wind) becomes greater and--as a result--the angle of incidence or pitch angle of the blades can be reduced.

Slide 27: The stability of a helicopter in forward flight varies from its stability in a hover. As in a hover, a helicopter in forward flight is statically stable, and will return to its original position if disturbed. Also, like in a hover, a helicopter is dynamically unstable in pitch and roll. If oscillations are allowed to begin in either of these axes and not corrected, the amplitude will continue to increase over time.

Yaw, however, is different. In forward flight, a helicopter becomes dynamically stable in yaw because it has a tendency to weathervane into the relative wind. This, along with the streamlining effect that the wind has, causes oscillations in the yaw axis to diminish over time.

EVALUATE

Teacher Materials: Rotorcraft Lift and Stability Presentation, Rotorcraft Lift and Stability Teacher Notes 2
Student Material: Rotorcraft Lift and Stability Student Activity 2

Slide 27: Conduct the **Summative Assessment**.

Summative Assessment

Distribute **Rotorcraft Lift and Stability Student Activity 2**. Working individually, students will prepare a written briefing for newly hired aeronautical engineers at Bell Helicopter company. They will be training the new hires on the operation of a helicopter flight controls and the major aerodynamic challenges and design solutions that occur during flight.

Students should be able to perform the following:

- Explain the operation of each of the helicopter's 3 flight controls
- Explain how a helicopter's design overcomes the aerodynamic challenges of dissymmetry of lift, Coriolis effect, and torque

Teachers can find answers on **Rotorcraft Lift and Stability Teacher Notes 2**.

[DOK L2; explain]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Written explanations show evidence of the following:

    - Accurate description of the helicopter's flight controls and their associated effects on its flight path
    - Accurate explanation of three aerodynamic challenges encountered in helicopter flight: dissymmetry of lift, Coriolis effect, and torque
    - Clear and accurate description of how fully articulated rotor blades correct for the three aerodynamic challenges
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives
- Correct spelling and grammar usage

Points	Performance Levels
9-10	Consistently demonstrates criteria
7-8	Usually demonstrates criteria
5-6	Sometimes demonstrates criteria
0-4	Rarely to never demonstrates criteria

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS2-2 -** Use mathematical representations to support the claim that total momentum of a system of objects is conserved when there is no net force on the system
- Science and Engineering Principles
    - Analyzing and Interpreting Data
    - Using Mathematical and Computational Thinking
    - Obtaining, Evaluating, and Communicating Information
- Disciplinary Core Ideas
    - PS2.A Forces and Motion
    - PS2.B Types of Interactions
- Crosscutting concepts
    - Cause and Effect
    - Structure and Function
- **HS-ETS1-4 -** 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 Principles
    - Asking questions and Defining Problems

- Disciplinary Core Ideas
    - ETS1.B Developing Possible Solutions
- Crosscutting concepts
    - None

COMMON CORE STATE STANDARDS

- **W.9-10.2 -** Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.
- **W.9-10.2E -** Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.
- **W.9-10.4 -** Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **W.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.
- **RST.9-10.1 -** Cite specific textual evidence to support analysis of science and technical texts attending to the precise details of explanations and descriptions
- **RST.9-10.7 -** Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically, (e.g., in an equation) into words.
- **MP.2 -** Reason abstractly and quantitatively
- **MP.4 -** Model with Mathematics

REFERENCES

https://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/media/faa-h-8083-21.pdf
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