Airfoils and Lift Production

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)

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 an airfoil produce lift?
2. Why are there different airfoil shapes?
3. Where are airfoils located on an aircraft?

LEARNING GOALS

Students Will Know

- How to define an airfoil
- The purpose for different airfoil designs
- The five factors affecting airfoil lift production
- Which factors affecting airfoil lift can be controlled by a pilot
- How airfoils other than wings are used to control an aircraft

Students Will Be Able To

- *Identify* airfoil design characteristics. (DOK-L1).
- *Explain* how lift is influenced by airfoil design. (DOK-L2).
- *Discuss* how each of the five factors affect airfoil lift production and which can be controlled by the pilot. (DOK-L3)
- *Explain* the reasons for adjusting the lift of an airfoil. (DOK-L3)

ASSESSMENT EVIDENCE

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Warm-up
As a precursor to learning about airfoil design and lift production, students will predict which surfaces on an airplane besides wings might produce aerodynamic forces.

Formative Assessment
Students will complete a crossword puzzle to help them reconstruct the definitions of terms and concepts covered in this lesson.

Summative Assessment
Students will list the five factors that affect airfoil lift production and explain how changing each of the five factors will affect the lift created by an airfoil. Students will also determine the lift factor(s) that can be adjusted to create increased lift for two different flight scenarios.

LESSON PREPARATION

MATERIALS/RESOURCES

- Airfoils and Lift Production Presentation
- Airfoils and Lift Production Student Activity 1
- Airfoils and Lift Production Student Activity 2
- Airfoils and Lift Production Student Activity 3
- Airfoils and Lift Production Teacher Notes 1
- Airfoils and Lift Production Teacher Notes 2
- Airfoils and Lift Production Teacher Notes 3

LESSON SUMMARY

Lesson 1: Theories of Lift
Lesson 2: Airfoils and Lift Production
Lesson 3: Calculating Lift
Lesson 4: Aerodynamic Stalls

This two-session lesson will begin with asking students to predict which surfaces on an airplane besides wings might produce aerodynamic forces. In a class discussion, students will learn what defines an airfoil and where airfoils are located on various parts of an airplane. In a short activity, students will work in small groups to identify items around the classroom that could be airfoils or converted to airfoils.

Students will learn about the different parts of an airfoil and complete a crossword puzzle to help them reconstruct the definitions of terms and concepts covered in this lesson.

In the second session, students will learn about the purposes and reasons for various airfoil designs.They will also learn about the 5 factors that affect the production of lift for a given airfoil.

As a summative assessment, students will list the five factors that affect airfoil lift production and explain how changing each of the five factors will affect the lift created by an airfoil. Students will also determine the lift factor(s) that can be adjusted to create increased lift for two different flight scenarios.

BACKGROUND

Aircraft need lift to fly. Lift is produced by airfoils which are optimized for the amount and type of lift required. Although conceptually, lift created for an airplane designed to land on short runways in remote areas is the same as the

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lift required for an airliner, that lift is needed in very different amounts and created at widely varying airspeeds. Airfoils must be designed to take these different situations and requirements into account.

There are different wings to accomplish different purposes. No single design can accommodate every need. Each design is a compromise between the desired speed, lift, maneuverability, and stall characteristics.

Five factors affect how much lift an airfoil creates: angle of attack, airspeed, camber, wing area, and air density. Of these five there are two a pilot can easily control, angle of attack and airspeed. Camber can be altered by the employment of devices such as flaps, and wing area can be altered on some, usually high performance aircraft, with the use of certain types of flaps. Air density is not within a pilot's control.

Creating lift is not the only use of airfoils on an aircraft. To provide stability, control, and thrust for the aircraft, designers use other airfoils such as the vertical and horizontal stabilizers and the propeller. Just as wings are optimized for the mission of the aircraft they're paired with, these other airfoils are designed with parameters to accomplish the particular role they must fill.

MISCONCEPTIONS

While the wings contribute most of the lift required for flight, it isn't the only airfoil on an aircraft. There are many surfaces on an aircraft that bend the air to create aerodynamic forces that help maneuver an airplane around its axes (just like the wing bends the air flowing around it downward (action) which results in an "equal and opposite" reaction of the air, pushing the wing upward). Horizontal and vertical stabilizers also produce aerodynamic forces that are used to help control and stabilize the aircraft. The propeller is also an airfoil that produces aerodynamic forces. Even the fuselage produces a negligible amount of lift through the motion of air over the top and bottom surfaces.

DIFFERENTIATION

To support student integration of new information in the **EXPLORE** section, provide a graphic organizer of an aircraft and ask students to label the surfaces that act as airfoils. Encourage students to take notes on how the surface of the aircraft promotes lift, stability, control or thrust.

LEARNING PLAN

ENGAGE

Teacher Material: Airfoils and Lift Production 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 airfoil design and lift production, remind students that wings produce an aerodynamic force (lift). Ask students which other surfaces on an airplane might produce aerodynamic forces.
[DOK L2; predict]

Questions

Possible answer:

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While the wings contribute most of the lift required for flight, it isn't the only airfoil on an aircraft. There are many surfaces on an aircraft that bend the air to create aerodynamic forces that help maneuver an airplane around its axes (just like the wing bends the air flowing around it downward (action) which results in an "equal and opposite" reaction of the air, pushing the wing upward). Horizontal and vertical stabilizers also produce aerodynamic forces that are used to help control and stabilize the aircraft. The propeller is also an airfoil that produces aerodynamic forces. Even the fuselage produces a negligible amount of lift through the motion of air over the top and bottom surfaces.

EXPLORE

Teacher Materials: Airfoils and Lift Production Presentation, Airfoils and Lift Production Teacher Notes 1
Student Material: Airfoils and Lift Production Student Activity 1

Slide 5: Explain to students that an airfoil is any structure specifically designed to produce lift or provide control by interacting with the flow of air around it. The flow of air creates areas of high and low pressure which can be directed to achieve the desired force. The wing, for example, has a high pressure area on the bottom, and a low pressure area on top, resulting in lift. A propeller has the low pressure area on the front side of the blade and the high pressure to the rear, causing thrust. Designers provide lift, thrust, control, and stabilization to aircraft by altering the curve of the airfoil and how it is positioned relative to the flow of air.

Slide 6: Using an airplane model or photo, introduce students to several of the airfoils of an airplane. Point out that the airfoils, regardless of their specific purpose, are designed with a similar, streamlined, curved cross sections in order to produce the necessary aerodynamic forces while causing the least amount of drag.

Show the primary airfoils on most aircraft, including wings, stabilizers, propeller and fuselage.

Slide 7: Stabilizers are used to steady the aircraft about it axes. The vertical stabilizer steadies the airplane about the vertical axis, called yaw. Rising vertically from the tail, or empennage of the aircraft, the vertical stabilizer is designed as an attachment point for the rudder. When the rudder is centered, the symmetrical shape of the vertical stabilizer is not producing a steady force in either direction, left or right. It is simply streamlining with the airflow, keeping the nose from wandering side to side. 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.

As students will learn in a future lesson, the horizontal stabilizer produces a downwards force on the tail, which is counteracting the tendency of the nose to drop due to the location of the center of gravity. Just as with the vertical stabilizer, the horizontal stabilizer is aligning with the airflow, keeping the nose from bobbing up and down. The elevator is attached to the horizontal stabilizer and serves to vary the aerodynamic force produced by the stabilizer, allowing the pilot to control the movement of the aircraft about the lateral axis of the aircraft, more commonly known as the pitch.

Slide 8: Propellers are rotating airfoils operating in the vertical plane. As students will recall from the unit on forces, propellers provide thrust, one of the four fundamental forces acting on an aircraft. Examining a propeller blade will reveal that, like an aircraft wing, the blade is curved on one side. Curvature on the forward side of the blade, along with the twist of the blade, provides thrust just like camber and angle of attack of the wing provide lift. Since the outer portion of the propeller is covering much more distance than the portion of the blade near the hub, the outer portion of the blade has less twist so as to produce a consistent amount of thrust along the length of the blade.

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Slide 9: NASA considers the fuselage to be an airfoil, although its primary purpose is to carry the aircraft's payload and serve as an attachment point for all of the other surfaces necessary for flight. Like other airfoils on the aircraft, the fuselage is streamlined to reduce drag and assist in stabilization, but it does not provide a significant amount of lift.

Slide 10: Wings are the defining feature of an airplane. The size, shape, and mounting of the wings are among the most critical decisions engineers make when designing an aircraft. The airfoil selected for the wing will determine how fast an aircraft will go, how much it will carry, and the basic flight characteristics. There are many tradeoffs involved. For example, a wing optimized for an aircraft to land on very short runways will likely prevent the airplane from being fast.

The following slides will cover important terms related to wing design and the factors contributing to the most important function of wings, generating the lift necessary to overcome weight.

Slide 11: Distribute **Airfoils and Lift Production Student Activity 1** and have students perform the "Discovering Airfoils" activity. This activity reinforces student understanding of airfoil geometry and its role in lift production. Students will work in small groups to identify items around the classroom that could be airfoils or converted to airfoils. Students are asked to label their items and explain why they chose them. Then, students apply their knowledge of airfoils by answering how air vents, fan blades and car spoilers can be used as airfoils. Possible students responses can found in **Airfoils and Lift Production Teacher Notes 1**.

EXPLAIN

Teacher Materials: Airfoils and Lift Production Presentation, Airfoils and Lift Production Teacher Notes 2
Student Materials: Airfoils and Lift Production Student Activity 2

Slides 12-15: Discuss each part of an airfoil:

- Leading edge - the first place air makes contact with the airfoil
- Trailing edge - the last place air makes contact with the airfoil. This is the back edge of the wing.
- Chord - an imaginary straight line connecting the leading and trailing edges of an airfoil
- Relative wind - the direction of airflow relative to the wing when the wing is moving through the air. It always moves directly opposite the direction the aircraft is moving.
- Angle of attack - angle between the chord line and direction of the relative wind.
- Thickness - the point where the airfoil has the greatest height from top to bottom; expressed as a fraction or percentage of the chord
- Camber - the curve of the wing. Camber refers to curvature of the airfoil and may be considered curvature of the mean camber line.
- Mean camber - a line drawn between the leading edge and trailing edge so that the distances between the upper and lower surfaces of the airfoil is equal
- Maximum camber - the point on the airfoil with the greatest distance between the mean camber line and the chord line; the location of the maximum camber helps define the shape of the mean camber line

Teaching Tips

Draw a picture of an airfoil on a board or use a physical model to enable students to appreciate the construction of an airfoil. The picture could be very basic in the beginning, but as the lecture progresses, add more characteristic parts of the airfoil to the picture.

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Slide 16: All airfoils are either symmetrical or asymmetrical (cambered).

A symmetrical airfoil at zero angle of attack has equal upper and lower surfaces. This airfoil will not produce any lift at zero angle of attack because the pressure on the top and bottom of the wing are equal. The camber line and the chord line are the same. The center of pressure does not change when the angle of attack changes.

An asymmetrical airfoil, also referred to as a cambered airfoil, has greater curvature on the top surface. This means there is more cross-sectional area above the chordline than below. The mean camber line and the chord line are different. A cambered airfoil at zero degrees angle of attack will produce some lift. A lesser angle of attack is required to get the same amount of lift for an asymmetrical airfoil, as compared to a symmetrical airfoil.

Slide 17: Aircraft designers have been designing and testing airfoils since the Wright brothers built the first wind tunnel and tested more than 200 airfoil shapes. Since then, literally thousands of different airfoil shapes have been developed and tested.

Each airfoil has its own flight characteristics and there is no single "best" shape for an airfoil. These shapes range from airfoils that operate at low subsonic speeds to those designed for supersonic and hypersonic speeds. The weight, speed and mission of the aircraft determines which airfoil shape is best.

Asymmetrical (cambered) airfoils are the most common and are the most efficient for producing the greatest lift.

Large airliners generally have relatively thick, cambered wings designed to produce maximum lift for heavy loads. These wings also tend to produce more drag.

Fighter jets often use a low camber, thin wing that produces little drag so they can be fast and highly maneuverable. Some fighter jet wings have thin pointed edges which allow for handling shockwaves associated with breaking the sound barrier.

Small training airplanes employ thicker wings with more camber towards the trailing edge which gives the wing favorable stall characteristics.

Wings on aerobatic airplanes are symmetrical. They offer good stability and provide the same lift characteristics whether they are right-side up or upside down. The pilot simply adjusts the angle of attack to create lift.

Slide 18: Complete the **Formative Assessment.** This assessment will conclude the first session.

Formative Assessment

Students will complete a crossword puzzle to help them reconstruct the definitions of terms and concepts covered in this lesson. Provide students with **Airfoils and Lift Production Student Activity 2.** The answers to each clue are terms covered in this lesson or in the previous lesson. Answers can be found in **Airfoils and Lift Production Teacher Notes 2.**

[DOK 3; construct]

EXTEND

Teacher Material: Airfoils and Lift Production Presentation

Slide 19: At the beginning of the second session, explain to students there are five factors the determine the amount of lift an airfoil produces: angle of attack, airspeed, camber, wing area and air density. Each one of these factors will be covered in the following slides. Students will also learn which factors can be controlled by a pilot in flight.

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Slide 20 : Angle of attack is one of the most fundamental and critical concepts related to flying an aircraft. The angle of attack is the angle formed between the chord line and the relative airflow. It is the angle at which the wing is "hitting" the air. Higher angles of attack force more of the airflow downward, one of the primary causes of lift. As the angle of attack increases, lift increases as well up to a certain point, at which, as students will learn in the next lesson, a stall will occur.

The pilot can control the angle of attack, and therefore the amount of lift the wing is producing, using the elevator. In most situations, the pilot is changing the angle of attack to control the flight path and in response to varying airspeeds.

Slide 21: Airspeed is the second factor related to lift production that the pilot has immediate control over. Pilots control the airspeed of the aircraft through a combination of pitch control and power setting.

At higher airspeeds, the airfoil is coming into contact with more molecules of air, producing more lift. While lift is a good and necessary thing, lift in excess of what is required is a limiting factor due to the amount of drag being produced. Up to a point the pilot can compensate for the increased lift that comes with increasing airspeed by reducing the angle of attack. When the angle of attack becomes low, drag and the amount of power available will work together to limit the speed of the aircraft. That's why airfoils intended to operate at high speeds are intentionally designed to produce less lift than a similarly sized airfoil that will be operating at lower speeds.

It's interesting to note that airspeed and angle of attack are judged by the relative wind, meaning that the wind is what is being experienced by the airfoil, not the wind across the ground. In most cases, an aircraft is generating its own wind through the use of thrust. As the following video shows, this doesn't have to be the case. The microburst that hit the aircraft in the video was strong enough to create enough airspeed to generate enough lift to make the aircraft fly, even though they were on the ground and stationary.

- "Microburst Event" (Length 2:30)

  http://video.link/w/xSae

Slide 22: Remind students that camber is the curvature of an airfoil. All other things being equal, the more curved the camber line, the more lift a given surface will generate. That is why airplanes designed for slow flight have fat, flat-bottom wings and flaps. This is also why airplanes with high-speed symmetrical airfoils fly at a higher angle of attack on final, land faster and often have all sorts of lift-enhancing devices (like flaps).

The only way for a pilot to change the camber of a wing during flight is to extend lift-enhancing devices like trailing-edge flaps. As flaps go down, they make the camber line through the center of the wing curve more. This generates more lift.

Remind students how vertical stabilizers are considered airfoils. When deflected, the rudder on a vertical stabilizer changes the camber and causes its lift forces to be exerted left or right. The elevator does the same to the stabilizer, but in an up-and-down direction.

Slide 23: Wing surface area is the total area of the wing when looking down on an aircraft. It is the area of the wing exposed to the airflow. The greater the exposed surface area of the wing to the airflow, the more lift generated by that wing. Generally speaking, a pilot cannot control the surface area of a wing in flight on small aircraft.

Slide 24: Air density is the amount of air particles in a volume of space. As students learned in Unit 3, the density of air varies with altitude, and changes the amount of lift generated by the airfoil. As altitude increases, the density of air decreases. This decrease in air density means there are fewer air particles that "push" on the airfoil to create pressure. If there are fewer particles pushing on the airfoil, then there is going to be less lift.

The pilot cannot change the density of the air at any given altitude.

EVALUATE

Teacher Materials: Airfoils and Lift Production Presentation, Airfoils and Lift Production Teacher Notes 3
Student Material: Airfoils and Lift Production Student Activity 3

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Slide 25: Conduct the **Summative Assessment.**

Summative Assessment

Working individually, students will list the five factors that affect airfoil lift production and explain how changing each of the five factors will affect the lift created by an airfoil. Students will also determine the lift factor(s) that can be
adjusted to create increased lift for two different flight scenarios.

Distribute **Airfoils and Lift Production Student Activity 3.** Answers can be found on **Airfoils and Lift Production Teacher Notes 3.**

[DOK-L4; apply concepts; DOK-L4; predict]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Postings show evidence of one or more of the following:
  - Knowledge of the five factors affecting airfoil lift production
  - An understanding of the factors affecting airfoil lift can be controlled by a pilot
  - Determine factors that needs to be adjusted to generate sufficient lift
  - Explain how adjustmenting the factors will affect the lift of the airfoil
- Contributions show understanding of course of the concepts covered in the lesson
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 The student correctly lists the 5 factors that affect airfoil lift production, correctly explains how changing any the five factors will affect the lift created by an airfoil, and provides a clear and detailed explanation for the airfoil adjustments that need to be made for the two scenarios (full tanker, empty tanker).

7-8 The student lists the 5 factors that affect airfoil lift production with 1-2 incorrect, adequately explains how changing any the five factors will affect the lift created by an airfoil, adequately explains how changing any two of the five factors will affect lift, and provides a sufficient explanation for each of the two scenarios.

5-6 The student lists 5 or fewer factors of which some are incorrect, gives little or no explanation of how changing the five factors will affect lift, provides an insufficient explanation of the airfoil adjustments that need to be made for the two scenarios (empty tanker). Gaps in understanding is evident in student work.

0-4 The student lists few or none of the 5 factors affecting airfoil lift production, and demonstrates major gaps in understanding of airfoils and lift production.

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STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-ETS1-4** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
  - Science and Engineering Practices
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.C: Optimizing the Design Solution
  - Crosscutting Concepts
    - None

COMMON CORE STATE STANDARDS

- **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

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