Calculating Lift

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 is a pilot balancing forces when they control lift?
2. What factors determine how much lift an airfoil generates?

LEARNING GOALS

Students Will Know

- The mathematical relationships among the factors that affect lift
- How to calculate lift using the lift equation

Students Will Be Able To

- *Calculate* the aerodynamic force produced by an airfoil in various phases of flight by using the lift equation. (DOK-L2)
- *Explain* how pilots compensate for varying lift in changing conditions. (DOK-L2)
- *Explain* the interdependent nature of the lift factors for an aircraft in flight. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students discuss what pilots do to create enough lift for takeoff.

Formative Assessment
Using the lift equation, students will determine what speed an F-22 fighter jet needs in order to takeoff at a given weight, air density and angle of attack.

Summative Assessment

Students will apply the lift equation to three different scenarios which involve various aircraft, configurations and environmental conditions.

LESSON PREPARATION

MATERIALS/RESOURCES

- Calculating Lift Presentation
- Calculating Lift Student Activity 1
- Calculating Lift Student Activity 2
- Calculating Lift Student Activity 3
- Calculating Lift Student Activity 4
- Calculating Lift Teacher Notes 1
- Calculating Lift Teacher Notes 2
- Calculating Lift Teacher Notes 3
- Calculating Lift Teacher Notes 4

Lift Equation Scenarios (each student)

- Calculator

Airfoil Simulation Activity (each group)

- iPads with “Wind Tunnel” application downloaded ($4.99)

  https://itunes.apple.com/us/app/wind-tunnel-for-ipad/id450980034?mt=8

LESSON SUMMARY

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

The lesson will help students understand the factors that affect lift, including velocity, wing surface area, angle of attack (AOA), and air density. It will also present the equation used for calculating lift.

The lesson will begin by having students discuss what they think pilots can do to create enough lift for takeoff. Students will be prompted to think back to the lesson on “Airfoils and Lift Production” where they learned about the factors that affect the lift of an airfoil.

During the next part of the lesson students will learn the lift equation and its factors, the relationship among the factors that affect lift, and why it is important for pilots to understand the lift equation. During this time students will complete an activity in which they fill in a matrix of the variables that determine how much lift an airfoil is producing.

Using the lift equation, students will determine what speed an F-22 fighter jet needs in order to take off at a given weight, air density and angle of attack. They will then use an iPad airfoil simulation application to draw different airfoil shapes and vary the factors that affect their lift.

Finally, students will apply the lift equation to three different scenarios which involve various aircraft, configurations and environmental conditions.

BACKGROUND

Understanding the lift equation and knowing the variables that affect lift helps pilots fly safely. In order to keep the airplane aloft, as one factor is changed another must compensate for the change in order to stabilize how much lift is generated.

The lift equation is as follows: $L = (C_L \times \rho \times V^2 \times S) / 2.$

- C_L stands for coefficient of lift and is a relative measure of an airfoil's lifting capacity. It is based on the shape of the airfoil (a cross-section of the aircraft's wing) and determined through experimentation, as in a wind tunnel. Coefficient of lift is a dimensionless number in that it is not measured in units like pounds or square feet. Engineers have compiled charts that list coefficients of lift for different wing shapes. Changing the design of a wing will change the wing's coefficient of lift at given angles of attack. Generally, pilots can't change the shape of an airfoil in flight (except for using flaps on takeoff or landing), but they can change the angle of attack (AOA).
- stands for air density. It is not a factor controllable by pilots unless they change the aircraft's position or altitude. Changes in air temperature and elevation can affect air density.
- V stands for velocity of the air flow over the wing; it is the factor that most significantly affects lift. Because velocity in the equation is squared, faster-moving aircraft generate exponentially more lift.
- S stands for surface area of the wing(s). For smaller aircraft, the surface area of the wing remains relatively constant. On more advanced aircraft, the wing's surface area can be in increased with special lift devices like flaps on the trailing edge and slats on the leading edge.

Throughout the lesson, students will evaluate the interrelationship among these factors. Students will also evaluate which factors typically change the most, and which generally stay constant.

MISCONCEPTIONS

Some students may think that lift is a constant for a given aircraft; however, the lift equation shows it is greatly affected by several important factors. Some of those factors can be controlled by the pilot and some cannot. The coefficient of lift is constant for each individual wing shape, but only at a constant angle of attack.

Contrary to what some students may think, weight does not affect lift. Rather, lift must overcome the weight of the aircraft for it to fly.

DIFFERENTIATION

To help students during the **EXPLORE** section, allow them to complete **Calculating Lift Student Activity 1** in small groups. Permitting students to come to conclusions in small groups reduces the risk of students getting lost in a full-class discussion.

LEARNING PLAN

ENGAGE

Teacher Material: [Calculating Lift Presentation]

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

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

Warm-Up

Have students imagine they are in a Cessna 172 for their first flight lesson. As a class, ask students to discuss what they can do as a pilot to create enough lift for takeoff. Prompt students to think back to the lesson on “Airfoils and Lift Production” when they learned about the factors that affect lift of an airfoil.

Possible answers:

Even though students haven’t learned the lift equation, they should remember that angle of attack, airspeed and camber are all factors a pilot can control. So a pilot could advance the throttle to increase engine power to create airspeed, pull back on the elevator to increase the wing’s angle of attack, and extend flaps to increase the camber of the wing. Students may share factors that they erroneously think contribute to lift, including the weight of the aircraft and drag on the aircraft.

[DOK 2; *Explain, Show relationships*]

Slide 5: Remind students of the definition of lift. Lift is a force that, by definition, acts perpendicular to the relative wind or the line of flight. Lift is what pulls an airplane into the sky. Lift is created by the shape of the wings on an airplane or the blades of a helicopter.

In a previous lesson, students learned the five factors that affect lift created by an airfoil. Ask students to name the five factors and identify which of the factors can be controlled by the pilot.

- Angle of Attack - yes, by adjusting the pitch of the aircraft
- Airspeed - yes, by adjusting thrust or by climbing or descending
- Camber - yes, by adjusting flap setting
- Air Density - no
- Wing Area - no

Let students know that in this lesson they will learn how to calculate lift using the lift equation.

EXPLORE

Teacher Materials: Calculating Lift Presentation, Calculating Lift Teacher Notes 1
Student Material: Calculating Lift Student Activity 1

Slide 6: Ask students why they think it is important for pilots to understand the lift equation. Explain that pilots must understand all the factors that affect the performance of the aircraft they are flying in order to know its safe operating limits. Thus, it is important that students also know which lift factors can be controlled by the pilot and which cannot be controlled. This is essential to safe flight; the knowledge allows a pilot to compensate for a change in one factor of lift by changing one of the other factors of lift.

Slide 7: Introduce the lift equation to students.

- CL stands for coefficient of lift. It is determined by the shape of the airfoil (a cross-section of the aircraft’s wing) and the angle of attack. Differently shaped wings have different coefficients of lift for a given angle of attack.
- stands for air density, which is determined by air temperature and elevation.
- V stands for velocity of the airflow over the wing. Faster-moving airflow generates more lift.
- S stands for surface area of the wing(s). For smaller aircraft, the surface area of a wing remains relatively constant. On more advanced aircraft, the wing’s surface area can be in increased with special lift devices like flaps on the trailing edge and slats on the leading edge.

In particular, emphasize that the coefficient of lift is a factor that remains constant unless the angle of attack (AOA) is changed. Coefficient of lift is determined through rigorous aerodynamic testing and is unique to each different shape of wing.

Ask students to examine the lift equation and determine which of the factors has the greatest effect on lift. They should recognize that because velocity is squared, it has the greatest effect on lift. As an aircraft's airspeed increases, lift increases by the square of the speed. Every other factor in the lift equation is a linear factor.

Slide 8: The coefficient of lift is determined by the shape of the airfoil, which generates a set amount of lift for a given AOA. Prior to a stall, as AOA increases, the coefficient of lift increases. Coefficient of lift is a dimensionless number that is not measured in units, like pounds or square feet. The coefficient of lift for a given airfoil shape is determined through rigorous aerodynamic testing in wind tunnels; computer simulations are used as well.

Slide 9: The shape of the airfoil is a determining factor in the amount of lift a wing creates. In grade nine, students built a wind tunnel and two airfoils of varying shapes - one symmetrical and one asymmetrical. Their testing should have showed that the asymmetrical airfoil generated more lift. Remind students that if an airfoil is shaped so that its upper and lower surfaces are identical, it is a symmetrical airfoil. Asymmetrical airfoils are curved differently on the top and bottom.

Generally speaking, a thick airfoil will generate more lift than a thin airfoil. If two wings have a similar shape but different thickness, the thicker wing will generate more lift; therefore, it will have a greater overall coefficient of lift.

On the graphs on the slide, students can see that the thick, asymmetrical (or cambered) airfoil creates much more lift than the thin, symmetrical airfoil.

Slide 10: As students have learned, airfoils with different shapes have different coefficients of lift. Similarly, the same wing at varying angles of attack will have different coefficients of lift. Coefficient of lift increases as AOA increases, until the aircraft experiences a stall. Students will learn in the next lesson that a stall occurs when the AOA is too great to maintain a laminar flow of air over the wing; the air above the wings becomes too turbulent to support flight, and lift diminishes.

The bottom left of the graph on the slide is where the airfoil has a lower AOA and therefore a lower coefficient of lift. Moving from left to right along the X-axis, AOA increases; follow the line of the graph to see that coefficient of lift increases steadily as AOA increases, until AOA increases too much and the airfoil stalls. In the diagram, point out the bottom airfoil, which is in a stalled condition where the coefficient of lift drops off rapidly. The top airfoil has a smaller coefficient of lift because its AOA is lower; it represents a point along the line on the graph prior to a stall.

Slide 11: Present students with two different perspectives on coefficient of lift. Pilots cannot readily alter the shape of the wing in flight. The only exception to this would be to deploy flaps, which changes the overall shape of the wing, and thus changes the coefficient of lift. The most practical way pilots can alter the coefficient of lift is to change the angle of attack. Note that while an increase in the AOA does increase lift, it also increases drag—the force that acts opposite the direction of thrustbecause an airplane with a greater AOA is less aerodynamic; more of its surface area is being impacted by air molecules and more of the lift force is directed rearward. Students will learn more about drag later in the unit.

Conversely, from an engineering perspective, coefficient of lift can easily be changed while designing the airfoil. However, engineers must consider the needs of the aircraft being designed, such as the amount of lift needed to achieve flight: does the amount of lift and drag of a given shape of wing meet the speed requirements for an aircraft?

Slide 12: This slide aims to help students think about the effect of coefficient of lift during the design process. Students imagine they are engineers tasked with designing an aircraft to go very fast (above Mach 0.8). Is it a good strategy to design a wing with a great amount of camber? Will the camber generate significant lift without prohibitive tradeoffs?

The answer is no; the tradeoffs will prevent the aircraft from operating efficiently at high speeds. It is true that a wing with a great amount of camber will generate a lot of lift; however, it will also generate a lot of drag. If velocity is the goal, the wing would be generating more lift—and thus, more drag—than desired. As lift exceeds what is needed, it becomes difficult to keep the aircraft in a level condition.

What's more likely to happen is that all of the lift the wing is producing would be creating so much drag that a pilot couldn't get the aircraft going fast in the first place.

Teaching Tips

As students consider the questions in this scenario, have them demonstrate on the board what a wing with more or less camber looks like. Given a wing with more camber, have multiple volunteers discuss their answers to the questions listed on the slide. This will help them to formulate answers to the questions, hopefully guiding them to the correct solution: an aircraft designed to go fast must have enough lift to achieve flight, but not so much lift that the resulting drag prevents it from being efficient.

Slide 13: Air density is a factor that can be considered a constant, unless there is a change in an aircraft's position or altitude. The pilot has no control over air density, other than to place the aircraft in a different environment. As students may recall from Unit 3, air density decreases as altitude increases and as temperature increases.

As altitude increases, an aircraft must fly faster to achieve the same amount of lift. This is because the air density is lower at higher altitudes.

Slide 14: Present a scenario to students where they must consider the effect of lower air density on lift. Split students into small groups and have them answer the questions related to the scenario. Students should be prepared to share their answers with the class.

Questions

You and a friend are in Leadville, Colorado over summer break for a hiking trip. The airport in Leadville is at 9,934 feet in elevation. How will the high elevation affect the amount of lift your airplane can produce? Why?

It will decrease the lift the airplane can produce. In order for an aircraft to have the required lift for takeoff, an aircraft departing at a high elevation airport (where the air density is low) must take off at a higher airspeed in order to make up for the lower density. This is one of the reasons why a longer takeoff run is required at airports at higher elevations.

You are taking off in the middle of the day and it's 80 degrees outside. How will the high temperature affect the airplane's ability to generate lift? Why? What will the pilot need to adjust to take off under these conditions? Explain.

As students learned in Unit 3, higher altitudes and higher temperatures create higher density altitudes. Higher density altitudes mean lower air density. Aircraft engines produce less power when the air is less dense. In the scenario in Leadville where the elevation and temperature are high, not only does the aircraft need to have more velocity to takeoff, but the pilot must also consider that the aircraft engines will produce less power. This is the second reason why it will take more runway length to produce the true airspeed required for takeoff.

Slide 15: Velocity is the factor that most affects lift. Because velocity in the equation is squared, faster-moving aircraft generate exponentially more lift. A pilot can affect velocity by changing airspeed. This can be accomplished by adding or decreasing engine power, or by initiating a climb or descent. Because velocity is an exponential function of lift, doubling the velocity of an aircraft quadruples the amount of lift created, and the reverse is true for decreases in velocity.

Slide 16: For smaller aircraft, the surface area of a wing remains relatively constant. More advanced aircraft have extendable flaps on the trailing edge of each wing and slats on the leading edge that increase the wing's overall surface area when needed, particularly during takeoff and landing. Because of these flight control devices, larger and more complex aircraft can increase or decrease lift by changing the surface area of their wings.

Slide 17: Hand out **Calculating Lift Student Activity 1** and have students complete the matrix on the effects of changing lift factors. For each factor given, students should mark whether it will increase or decrease lift produced by the wing. After students complete the activity, review the answers using **Calculating Lift Teacher Notes 1**. Have students discuss their answers in class.

This activity may be assigned as homework and the answers covered in class at the beginning of the second session.

EXPLAIN

Teacher Materials: Calculating Lift Presentation, Calculating Lift Teacher Notes 2
Student Material: Calculating Lift Student Activity 2

Slide 18: Complete the **Formative Assessment** at the beginning of the second session of this lesson.

Formative Assessment

Using the lift equation, students will determine what speed an F-22 fighter jet needs in order to take off at a given weight, air density and angle of attack. They will also determine whether or not the same jet can take off given a scenario where the air density has decreased as the pilot prepares for a second sortie late in the hot afternoon in Las Vegas.

Provide students with **Calculating Lift Student Activity 2** and have them complete the scenario. Ensure students work alone on this activity and show their mathematical work, step-by-step.

After students complete the activity, write the given factors of lift on the board. Then have a volunteer show how they determined the velocity necessary to achieve enough lift for takeoff. Have another volunteer demonstrate the second phase of the activity, determining whether the aircraft can take off with a change in air density. Facilitate a class discussion about what the pilot could do to compensate for the change in air density.

Answers to this assessment are found in **Calculating Lift Teacher Notes 2**.
[DOK 2, Compute; DOK 2, Extrapolate]

EXTEND

Teacher Materials: Calculating Lift Presentation, Calculating Lift Teacher Notes 3
Student Material: Calculating Lift Student Activity 3

Slide 19: Students will use an iPad-based airfoil simulation application to isolate and adjust factors of lift for various airfoils.

Download the iPad application called "Wind Tunnel" (https://itunes.apple.com/us/app/wind-tunnel-for-ipad/id450980034?mt=8) on as many iPads as available. Be sure to download the paid version ($4.99) in order to have access to the full suite of options to measure lift and adjust the factors of lift.

Form small groups of students and provide each group with an iPad with the "Wind Tunnel" app downloaded. Have the students draw airfoils with the characteristics described in Calculating Lift Student Activity 3. Students should record the lift produced under each scenario and describe why the lift produced is higher or lower as compared to other airfoils they draw or load during the activity.

If there are limited iPads available, some students can be working on the summative assessment while others are working on this airfoil simulation activity.

At the end of the activity, have representatives of each group share their answers and observations. Possible answers to this activity are found in **Calculating Lift Teacher Notes 3**.

> **Teaching Tips**
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> If you do not have iPads available, this website can serve as a free alternative: https://www.grc.nasa.gov/www/k-12/airplane/foilsime.html

EVALUATE

Teacher Materials: Calculating Lift Presentation, Calculating Lift Teacher Notes 4
Student Material: Calculating Lift Student Activity 4

Slide 20: Conduct the **Summative Assessment**.

Summative Assessment

Students will apply the lift equation to three different scenarios that involve various aircraft, configurations and environmental conditions. Provide students with copies of **Calculating Lift Student Activity 4**. Students will demonstrate use of the lift equation, and then apply the equation a second time, either changing one of the variables or thinking about how a pilot could change the lift equation by manipulating one of the factors of lift.

[DOK 2, Show; DOK 3, Explain how]

Summative Assessment Scoring Rubric

- Student follows instructions
- Student comes to correct answers as provided in **Calculating Lift Teachers Notes 4**
    - Demonstrates proper steps in mathematical equations
    - Answers all questions with a value and/or explains why or why not the answer is correct

- Uses their knowledge of the lift equation to achieve desired result or explain how various factors affect lift.

- Answers show understanding of the concepts covered in the lesson
- Answers show in-depth thinking including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 Correctly and accurately uses the lift equation in each of the 3 scenarios and provides a clear answer to the question posed in each scenario. There are no gaps in understanding.

7-8 Uses the lift equation in each of the 3 scenarios with minor computation errors; provides answers to the questions posed in each scenario with some gaps in understanding.

5-6 Uses the lift equation in each of the 3 scenarios with computation errors; gives vague answers to the questions posed in each scenario with many gaps in understanding.

0-4 Uses the lift equation in some or all scenarios with many computation errors; provides vague to the questions posed in some or all of the scenarios; demonstrates little or no understanding.

GOING FURTHER

Challenge interested students to research famous wind tunnels and to understand the testing involved to determine coefficient of lift. If there is a wind tunnel in your local area, consider taking a trip to a local university or scientific institution that may be able to demonstrate the use of a wind tunnel in action.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-ETS1-2** - 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
    - Asking Questions and Defining Problems
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.A: Defining and Delimiting Engineering Problems
  - Crosscutting Concepts
    - None
- **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.youtube.com/watch?v=1NWI0RkNBBs
https://www.grc.nasa.gov/www/K-12/airplane/lifteq.html
https://www.grc.nasa.gov/www/K-12/airplane/size.html
https://www.grc.nasa.gov/WWW/K-12/airplane/foil3.htm