Vectors of Flight

Session Time: One, 50-minute session

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, which enables a pilot to fly an aircraft to its maximum capabilities in both normal and abnormal situations. (EU5)

ESSENTIAL QUESTIONS

1. Are the forces acting on an airplane really perpendicular to one another?

LEARNING GOALS

Students Will Know

- What a vector is and how it relates to the forces of flight
- That an airplane's flight path may not be the same direction in which its nose is pointed.

Students Will Be Able To

- *Calculate* thrust force vectors for airplanes performing slow flight and climbs. (DOK-L1)
- *Apply the concepts* of thrust analysis to explain how an aerobatic airplane creates lift during a knife-edge pass. (DOK-L4)
- *Summarize* how the vertical component of thrust contributes to lift. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students watch a video of an aerobatic airplane performing a knife-edge pass and will then draw a diagram of the airplane with arrows depicting the four forces of flight.

Formative Assessment
Students will graph flight vectors, then measure the components of the vectors in each direction.

Summative Assessment
Students will write a paragraph that explains to an audience that is not familiar with aviation how the vertical component of thrust contributes to lift.

LESSON PREPARATION

MATERIALS/RESOURCES

- Vectors of Flight Presentation
- Vectors of Flight Student Activity
- Vectors of Flight Teacher Notes

Flight Vector Analysis Activity (per student)

- Protractor

LESSON SUMMARY

Lesson 1: Understanding Motion
Lesson 2: Four Forces
Lesson 3: Vectors of Flight

The lesson opens with a video of an aerobatic airplane performing a knife-edge pass. Students are asked to draw how the four forces of flight are acting on this airplane in an unconventional attitude. It also demonstrates one of the goals of the lesson: for students to understand that an airplane doesn't necessarily move in the direction it's pointed.

Students are introduced to the concept of a vector as a magnitude and direction, shown that the four forces of flight can be represented as vectors and that vectors can be broken down into directional components.

With the idea of vector components in hand, students are shown how thrust can be divided into vertical and horizontal components. They complete an activity, calculating with graphical means the vertical and horizontal components of thrust for an airplane in slow flight and a climb.

Finally, students will write a paragraph that explains to an audience that is not familiar with aviation how the vertical component of thrust contributes to lift.

BACKGROUND

Forces are vectors with direction and magnitude. Most vectors can be broken into components acting in different directions. Doing this with the forces of flight acting on an airplane, we can predict the airplane's flight path and understand where forces are acting on the aircraft.

These forces can act in unusual ways, as when an airplane on the knife-edge is deriving its lift from the engine and not the wing.

Ultimately, understanding the complexities of how these forces act allows us to more precisely engineer the airframe and design more effective and efficient control systems.

DIFFERENTIATION

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

To support verbal reasoning in the **EXTEND** section, organize the class into groups for Think-Pair-Share. Have students pair up and share their drawing comparisons, and then explain to each other the vertical component of lift. This allows learners to think about what they want to say, and discuss their thoughts with a partner before sharing with the larger group. Sharing encourages all students to participate and practice skills, including metacognition.

LEARNING PLAN

ENGAGE

Teacher Material: Vectors of Flight Presentation

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

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

- "Jim Leroy Performs Knife-Edge Pass" (Length 00:23)
  http://video.link/w/PUQd

Warm-Up

Show students a video of an aerobatic airplane performing a knife-edge pass and then ask them to draw a diagram of this airplane with arrows depicting the four forces of flight. This warm-up demonstrates one of the goals of the lesson: for students to understand that an airplane doesn't necessarily move in the direction it's pointed. In this case, the airplane's nose is pointed up, but it is traveling forward at a constant altitude.

Answers:

Students should draw an airplane rolled sideways and pitched up like the one in the video. They may draw the four forces of flight in one of two ways: with thrust/drag horizontal and lift/weight vertical or with the forces at angles aligned to the airplane (e.g. thrust straight from the nose, lift perpendicular to the fuselage, etc.)

Point out that as shown in this extreme example from the video, an airplane does not always travel in the same direction that it is pointing. Vector analysis is a way for us to calculate and visualize how the four forces are acting on an airplane. The students will come back to this exercise as a summative assessment at the end of the lesson and will be able to provide a complete answer.

[DOK-L1; *illustrate*; DOK-L4; *apply concepts*]

EXPLORE

Teacher Material: Vectors of Flight Presentation

Slide 5: Explain to students that a vector is a quantity with both direction and magnitude. Vectors can represent quantities such a lift, thrust, weight and drag.

Slide 6: Ask students if the directions of these forces in the diagram are realistic. Note that each force has a quantity and the airplane is considered to be in balanced flight. In this case, the four forces are measured in pounds which is a common way to quantify the magnitude of the four forces of flight.

The diagram is not very realistic because an airplane's forces rarely all align at ninety-degree angles to each other. This is a fundamental insight of the lesson and will be covered in detail in the following slides.

Slide 7: Most vectors can be broken into components acting in different directions.

While the overall magnitude (size) of the vector on the slide is "5", since it is acting at an angle, its magnitude along the x axis is 3, and its magnitude along the y axis is 4. In other words, the movement of this vector is only 3 units along the x direction and 4 units along the y direction. A two dimensional vector can be broken into components acting in different directions. The x and y axes are perpendicular to one another.

Slide 8: This slide shows a more likely arrangement of the four forces acting on an aircraft in flight. The illustration shows that with the nose-up position of the airplane, some of the thrust is acting upwards instead of all of it pulling forward. This upward component of thrust is acting as lift and is labeled "Vertical Component of Thrust."

Slide 9: The traditional statement that lift equals weight and thrust equals drag, while true, does not give the complete story of the forces acting on an airplane. What it does mean is that the opposing forces are equal to, and thereby cancel each other. As we have seen, vectors such as flight forces can act in multiple directions, such as thrust from the engine providing forward movement as well as a portion of the lift. If you add all of the forces providing lift, and all of the factors contributing to weight, they will cancel each other out in steady flight.

EXPLAIN

Teacher Materials: Vectors of Flight Presentation, Vectors of Flight Teacher Notes
Student Material: Vectors of Flight Student Activity

Slide 10: Show students a video how to break a vector into its component by forming a right triangle on graph paper. In the student activity, students will be graphing thrust vectors as right triangles.

- "Find the Component Form of a Vector From the Graph of a Vector" (Length 1:59)
  http://video.link/w/QUQd

Slide 11: Conduct the **Formative Assessment.**

In this activity, students will graph flight vectors, then measure the components of the vector in each direction. Provide students with copies of **Vectors of Flight Student Activity.**

Before students start the activity, use slide 11 to explain that an aircraft flying level (at a constant altitude) at slow speeds will fly using a vertical component of thrust. The airplane's nose will be pointed in a different direction than it is traveling through the air. In the illustration on the slide, the airplane has a positive (upward) pitch attitude, but is flying at a constant level altitude. This maneuver is called slow flight.

Complete the first step in the student activity with students. Using the thrust magnitude and angle given on the activity, have students complete a vector analysis on graph paper to determine the vertical component of thrust.

Formative Assessment

Students will graph flight vectors, then measure the components of the vectors in each direction.

Complete the first step in the student activity with students. Using the thrust magnitude and given angle, have students complete a vector analysis on graph paper to determine the vertical component of thrust for an airplane in slow flight.

Then, ask students to graph and determine the vertical component of the second maneuver on their own. Several questions will lead students to determine that the airplane in the second maneuver is in a climb.

Completed graphs and answers to the questions are provided in **Vectors of Flight Teacher Notes**.

[DOK-L1; *calculate*; DOK-L2; *interpret*]

Slide 12: Show this slide to students after they have graphed and determined the vertical component of thrust for the second maneuver in the activity.

EXTEND

Teacher Material: Vectors of Flight Presentation

Slide 13: Show students the video of the knife-edge pass again. Using what they have learned about horizontal and vertical components of thrust, ask students to draw a picture of the airplane rolled onto its side with a large positive pitch attitude. They should correctly label the picture with the main thrust vector and a very large vertical component of thrust. Regardless of the orientation of the airplane, the lift vector will always be up, the weight vector will always point towards the earth, and the drag vector will always point behind the airplane.

Have students compare this to the drawing they made during the warm-up. Ask them to explain how learning about the vertical component of lift provides a more complete explanation of the forces during a maneuver like the knife edge pass.

This aerobatic airplane clearly has a very powerful engine capable of creating large amounts of thrust. The airplane is creating the majority of its lift from the vertical component of thrust.

- "Jim Leroy Performs Knife Edge Pass" (Length 00:23)
  http://video.link/w/PUQd

EVALUATE

Teacher Material: Vectors of Flight Presentation

Slide 14: Conduct the **Summative Assessment.**

Summative Assessment

Ask students to write a paragraph that explains to an audience that is not familiar with aviation how the vertical component of thrust contributes to lift. Students should be sure to include an accurate description of both thrust and the vertical component of thrust.

[DOK-L3; *explain*]

Summative Assessment Scoring Rubric

Follows assignment instructions
Written explanation includes:

- Clear and accurate explanation
- Correct description of both thrust and the vertical component of thrust
- Appropriate for an audience that is not familiar with aviation

- Correct spelling and grammar

Contributions show in-depth thinking including analysis or synthesis of lesson objectives

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-PS2-1 Analyze data to support the claim that Newton's Second Law of Motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

- Scientific and Engineering Practices
  - Analyzing and Interpreting Data
  - Obtaining, Evaluating, and Communicating Information
- Disciplinary Core Ideas
  - PS2.A: Forces of Motion
- Crosscutting Concepts
  - Cause and Effect
- Connections to Nature of Science
  - Science Models, Laws, Mechanisms, and Theories, Explain Natural Phenomena

REFERENCES

https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/07_phak_ch5.pdf
http://www.kershnerflightmanuals.com/9115.html