# Four Forces

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

### ESSENTIAL QUESTIONS

1. Does a pilot need to know aerodynamics to fly an airplane?
2. What happens when an airplane's forces become unbalanced?

### LEARNING GOALS

**Students Will Know**

- The definitions of the four forces of flight
- How the four forces balance each other to result in steady state flight

**Students Will Be Able To**

- *Describe* how four key forces (lift, weight, thrust, drag) act on airplanes during flight. (DOK-L2)
- *Analyze* which forces make an airplane climb or descend, and which forces make an airplane speed up or slow down. (DOK-L4)

## ASSESSMENT EVIDENCE

**Warm-up**
Students will brainstorm answers about balloons, parachutes and airplanes. In a class discussion, they will be guided to the conclusion that forces makes things move.

**Formative Assessment**
Students will sketch airplanes and use arrows to illustrate the magnitude of each of the four forces of flight for different flight scenarios. They will explain which factor is affected, which force is being overcome and how the airplane will react as a result of the action taken in the scenario.

**Summative Assessment**
At the conclusion of an activity about the effects of lift and drag, students will answer questions about how their results relate to the forces of flight.

## LESSON PREPARATION

### MATERIALS/RESOURCES

- Four Forces Presentation
- Four Forces Student Activity 1
- Four Forces Student Activity 2
- Four Forces Teacher Notes 1
- Four Forces Teacher Notes 2

**Dart Paper Airplane Test (per team)**

- Sheet of 8 ” x 11” paper
- Paperclips
- Measuring tape
- Scissors

### LESSON SUMMARY

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

In this lesson, students will learn about the four forces of flight. They will learn that more than one force acts on objects that fly, and they will learn that forces work against one another to create balanced flight.

Students will begin this lesson with questions about balloons, parachutes and airplanes. In a class discussion, they will be guided to the conclusion that forces makes things move.

Students will then learn about each of the four forces of flight and about which two forces promote flight and which two forces impede flight. They will refer back to what they learned in the last lesson about Newton’s laws of motion in order to understand how an airplane achieves balanced flight. At the end of the session, students will sketch airplanes and use arrows to illustrate the magnitude of each of the four forces of flight for different flight scenarios. They will explain which factor is affected, which force is being overcome and how the airplane will react as a result of the action taken in the scenario.

The second session of this lesson will engage students in an activity demonstrating the effects of lift and drag. At the conclusion of the activity, students will answer questions about how their results relate to the forces of flight.

### BACKGROUND

Airplanes fly on the principles of physics. The competent pilot needs to understand what those principles are. First among the principles to grasp are the four forces acting on an aircraft in flight. Every climb, descent, turn, or any other maneuver is about pilots subtly bending the forces of nature to their will.

The four forces are law, but they aren’t absolute. Lift, weight, thrust, and drag act independently, but a change in one results in a change in the others. Knowing how each works can help the pilot anticipate how the airplane will react.

Lift is what pulls an airplane into the sky. Created by the shape of the wings on an airplane, or the blades of a helicopter or drone, it, by definition, acts perpendicular to the relative wind or the line of flight.

Weight is the force of two masses being attracted to each other. It is the force that pulls us towards the center of the earth, and makes things fall down.

Thrust is created by the jet engines or propellers of an airplane. Birds create thrust (and lift!) with their wings. Thrust is the push that makes things fly.

Drag is the resistance (or friction) to things moving through the air. It is caused by air particles bumping into the object. An object that is going faster bumps into more air particles, and so experiences more drag. Similarly, an object with a large surface area bumps into more particles, and experiences more drag.

## DIFFERENTIATION

To support student comprehension of new information 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 and also connect working and long-term memories.

# LEARNING PLAN

## ENGAGE

**Teacher Material:** Four Forces Presentation

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

**Slide 4:** Conduct the **Warm-up.** In this lesson, students will learn about the four forces of flight. They will learn that more than one force acts on things that fly, and they will learn that forces work against one another to create balanced flight.

**Warm-Up**

During this warm-up, lead students to the conclusion that forces make things move. The answer to all the questions on slide four is forces. Forces can make things speed up, slow down, climb or descend. Balanced forces can make objects stay still or move at a constant speed.

[DOK-L2; *predict*]

## EXPLORE

**Teacher Material:** Four Forces Presentation

**Slide 5:** Flight is founded on four basic forces—lift, weight, thrust and drag. As a class, work with the students to fill in the blanks, labeling the forces.

Lift is the force caused by airflow around the wings, supporting the aircraft in flight.

Thrust is the force caused by the engine, propelling the airplane forward.

Weight is the force pulling the airplane towards the center of the earth.

Drag is the force trying to slow the airplane down.

**Slide 6:** By definition, the lift force acts perpendicular to the relative wind or the line of flight. Lift is what pulls an airplane into the sky. Created by the shape of the wings on an airplane, or the blades of a helicopter, it by definition, acts perpendicular to the relative wind or the line of flight.

**Slide 7:** Weight is the force of two masses being attracted to each other. It is the force that pulls us towards the center of the earth, and makes things fall down.

**Slide 8:** Thrust is created by the jet engines or propellers of an airplane. Birds create thrust (and lift!) with their wings. Thrust is the push that makes things fly.

**Slide 9:** Drag is the resistance (or friction) to things moving through the air. It is caused by air particles bumping into the object. An object that is going faster bumps into more air particles, and so experiences more drag. Similarly, an object with a large surface area bumps into more particles, and experiences more drag.

**Slide 10:** Two of the four forces promote flight, and two impede it. Ask the students which two promote and which two impede.

Lift and thrust promote flight, weight and drag impede flight.

Practically, a pilot has control only over the two forces which promote flight. At any given moment, the weight of an aircraft is a fixed constant. The same is true of drag. Unless an airplane has special equipment to cause drag, such as flaps or speed brakes, the drag of an airplane is a part of its design and cannot be changed. A pilot thus controls the flight path of their aircraft by changing the forces they have control over, the thrust and the lift.

Thrust is controlled by the throttle. Lift is controlled by moving the elevator, which changes the pitch of the aircraft.

## EXPLAIN

**Teacher Materials:** Four Forces Presentation, Four Forces Teacher Notes 1
**Student Material:** Four Forces Student Activity 1

**Slide 11:** It's important to understand that when an aircraft is in balanced flight, meaning that neither altitude nor airspeed is changing, the four forces are in equilibrium - the force of lift is equal to its counterforce, the force of weight; and the force of thrust is equal to its counterforce, the force of drag. The object won't accelerate. This is directly related to Newton's First Law: An object at rest stays at rest and an object in motion stays in motion unless acted on by an outside force.

**Slide 12:** If an airplane was in balanced flight (lift equals weight and thrust equals drag) and then one of the forces were to change value, the aircraft would obey Newton's First Law and move in the direction of the unbalanced force.

Ask students which of Newton's Law would dictate the speed at which the airplane would move in the direction of the unbalanced force and ask them to explain why? The answer is Newton's Second Law.

**Slide 13:** The speed at which the plane would move in that direction would follow Newton's Second Law, (F=ma), meaning that the greater the applied force, the more rapidly the aircraft would move.

Ask the students to indicate by show of hands what would happen if the force of lift were to increase. The possible choices are: Go faster, go slower, go up, go down. The correct answer is that the aircraft will go up, or climb.

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

**Formative Assessment**

Provide students with copies of **Four Forces Student Activity 1**. Each question on the activity sheets describes an action which will affect one of the four forces of flight. Students should assume that each question will begin with an airplane in balanced flight.

For each scenario, students will draw a picture of an airplane and use arrows to illustrate the magnitude of each of the four forces of flight. They should explain which factor is affected, which force is being overcome and how the airplane will react as a result of the action (e.g. climb, slow down, etc.).

Answers to this assessment are found in **Four Forces Teacher Notes 1**.

[DOK-L2; *cause/effect*; DOK-L1; *illustrate*; DOK-L4; *apply concepts*]

**Simulator Extension Powered by Redbird**

See each of the four forces of flight in action! Here are 4 different in-simulator exercises you can try to see how thrust, drag, lift, and gravity independently affect an airplane in flight.

LIFT - Line up on the runway, set trim to take off, and add full throttle. Steer with your feet, but don't touch the yoke. When the air is passing over the wings fast enough, lift overcomes gravity and the airplane takes off.

DRAG - While trimmed and flying straight and level below 85 knots (C172), put down 30° of flaps and notice that airspeed decreases even though the throttle hasn't been touched. Use pitch to maintain straight and level flight.

THRUST - While trimmed and flying straight and level at about 2100 RPM (C172), add full throttle but don't touch the yoke. Notice that altitude increases. Try it again, but push the yoke forward to maintain altitude, and watch airspeed increase.

GRAVITY - While trimmed and flying straight and level at about 2300 RPM (C172), reduce throttle so that engine is at around 1800 RPM. The airplane will try to maintain the airspeed for which it is trimmed by allowing gravity to speed it up, resulting in a loss of altitude.

## EXTEND

**Teacher Material:** Four Forces Presentation
**Student Material:** Four Forces Student Activity 2

The second session of this lesson will engage students in a demonstration of the effects of lift and drag.

**Slide 15:** In this activity students working in small groups will use **Four Forces Student Activity 2** to construct a paper airplane. Once the airplane is completed, students will perform a series of tests by throwing the airplane three times, recording the distance of each throw, then averaging the results. This result is the control, by which other configurations of the airplane will be measured.

With the control results in place, students will then predict the performance of the airplane for each of the variations of weight (paperclips) and lift (elevator position). Flight tests will be performed, against which their predictions will be measured.

**Teaching Tips**

If time allows, have students design their own paper airplanes. After recording the data from the first airplane, based on their observations, they can design and construct a new plane with the goal of beating their best average distance from the first plane. They should record their results.

## EVALUATE

**Teacher Materials:** Four Forces Presentation, Four Forces Teacher Notes 2
**Student Material:** Four Forces Student Activity 2

**Slides 16-21:** Quiz the students on questions related to aerodynamic forces for the Private Pilot Knowledge Test.

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

**Summative Assessment**

Ask students to complete the evaluation section of Four Forces Student Activity 2 as a summative assessment.

To conclude the experiment, students will answer questions about how their results relate to both their expectations and the forces of flight. Students should find that the airplane will fly farther with conditions of less weight (fewer paperclips) and more lift (elevators deflected up).

The final question asks where a glider gets its thrust. Gliders don't actually develop thrust—they get their forward motion by using the force of gravity to convert the potential energy of altitude into the kinetic energy of speed. Students learned this concept in the second unit of the ninth-grade curriculum.

Answers to this assessment are found in **Four Forces Teacher Notes 2**.

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

**Summative Assessment Scoring Rubric**

Follows assignment instructions
Written explanation includes:

- Each of the four forces (thrust, drag, lift, weight)
- A clear and accurate explanation of how each of the four forces acted on the glider during the flight test
- Correct grammar and spelling
- Organized explanation

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 described the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

- Science and Engineering Practices
  - Analyzing and Interpreting Data
  - Constructing Explanations and Designing Solutions
  - Obtaining, Evaluating, and Communicating Information
- Disciplinary Core Ideas
  - PS2.A Forces and Motion
  - PS2.B1 Types of Interactions
- Crosscutting Concepts
  - Cause and Effect

### COMMON CORE STATE STANDARDS

- **RST.11-12.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
- **WHST.11-12.2** - Write informative/explanatory texts, including the narration of historical events, scientific procedures /experiments, or technical processes.

## REFERENCES

https://www.aopa.org/training-and-safety/students/presolo/topics/the-four-forces

https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/07_phak_ch5.pdf