4.1.7 Flight

OBJECTIVES

Students will be able to
- apply Bernoulli's principle to flight.
- describe how thrust, drag, lift, and weight work in flight.
- explain how a plane accelerates.

VOCABULARY

- **drag** the frictional force of air molecules exerted on a flying aircraft
- **lift** the force that pushes an aircraft up
- **pneumatic device** a device that uses compressed gas to transfer pressure from one point to another
- **thrust** the force that pushes an aircraft forward

MATERIALS

- Blow dryer, table tennis ball (*Introduction, Option 1*)
- Glass of water, straw, scissors (*Introduction, Option 2*)
- Copy paper, heavy paper, paper clips, tape, metersticks (*A*)
- BLM 4.1.7A Airplane Instructions
- TM 4.1.7A Flight Forces

PREPARATION

- Cut a slit perpendicular to the length of a straw about 5 cm from the end. Do not cut all the way through. (*Introduction, Option 2*)
- Gather materials for *Lab 4.1.7A Paper Airplanes*.
- Familiarize yourself with flight simulation software. Download it, if necessary. (*B*)
- Plan a field trip to a local flight or space museum. Have students prepare a list of questions to ask the docent during the tour. Guide students in writing questions focused on the topic of flight. (*E*)

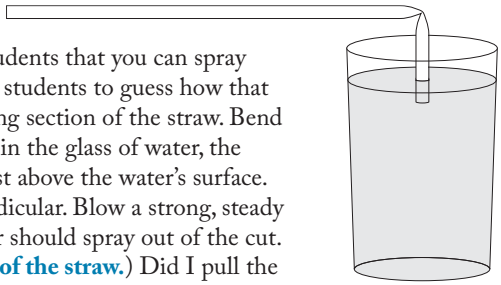
Introduction

Choose one of the following options to demonstrate Bernoulli's principle:

Option 1

Direct students' attention to the blow dryer and the table tennis ball. Ask students what would happen if you turned on the blow dryer and placed the ball in front of it. (**Possible answers: The ball will fall down. The ball will fly forward.**) What would happen if I hold the dryer straight up in the air, turn it on, and then place the ball in the airstream? (**The ball will fly up in the air.**) Turn on the dryer, aim it toward the ceiling, and place the ball in the airstream. Let the ball sit in the airstream for a few moments. Ask students what they think happened and why. (**Answers will vary.**) Explain that the fast moving air actually creates an area of low pressure. The higher pressure outside the stream keeps the ball in the airflow. If the ball moved slightly outside of the airflow, it would experience slower, higher-pressure air that would force it back into the air stream. Share that this demonstration shows Bernoulli's principle, which states that as the speed of a fluid increases, the pressure within the fluid decreases.

Option 2



Place the glass of water on the table. Convey to students that you can spray water out of the glass without using a sprayer. Ask students to guess how that could be done. (**Answers will vary.**) Flatten the long section of the straw. Bend the straw to a 90˚ angle at the cut. Place the straw in the glass of water, the short end immersed in the water with the bend just above the water's surface. Hold the straw so that the two lengths are perpendicular. Blow a strong, steady airstream through the long end of the straw. Water should spray out of the cut. Ask students what happened. (**Water sprayed out of the straw.**) Did I pull the water out of the cup? (**Answers will vary.**) Explain that as you blew air through the long part of the straw, the fast moving air was creating an area of low pressure. The water below had much higher pressure so it was lifted up into the stream of air. This demonstrate's Bernoulli's principle, which states that as the speed of a fluid increases, the pressure within the fluid decreases.

Discussion

- Display **TM 4.1.7A Flight Forces** on a whiteboard and discuss the forces involved in flight, describing how they work in opposition to each other. Ask a volunteer to label the forces on the image projected on the board and to explain how lift occurs. Discuss acceleration in relation to balanced and unbalanced forces. Ask how a plane maintains constant velocity. (**All four forces of thrust, drag, lift, and weight are balanced.**) What is acceleration? (**It is a change in speed or direction.**) What has to happen to the net force for the plane to accelerate? (**It has to be unbalanced.**) What does a pilot have to do to land a plane? (**Answers will vary but should include reduce the lift by changing the position of the flaps, and change the pitch by moving the elevators.**)

- Ask the following questions:
  1. What is a fluid? (**A fluid is any substance that flows and takes the shape of its container. Both liquids and gases are fluids.**)
  2. Which option would create an increase in velocity in water flow: large pipes to small pipes, or small pipes to large pipes? Why? (**large pipes to small pipes because a fluid's velocity increases when the flow is restricted**)
  3. Why is a plane narrower at the front than the rest of the body? (**The shape of the plane reduces drag and helps increase wind speed. This creates the low pressure needed for greater lift.**)
  4. Why do rockets not have wings? (**Wings create lift for travel that is parallel to the ground. Rockets do not travel parallel to the ground. Instead, they create huge amounts of thrust so they can travel vertically through the atmosphere.**)

5. Which would move faster through the water, a square raft or a canoe? Why? Use Bernoulli's principle to explain. (**Answers will vary but should include a canoe would move faster because the shape of the canoe would force the water to move faster around the canoe and propel it through the water.**)
6. Explain how a hose-end sprayer works. (**The bottle of chemical solution is attached to the end of a hose. The fast moving water from the hose travels above the solution. As the water flows, it creates an area of low pressure. Because the solution below has a higher pressure, it is lifted up a tube and joins the fast-streaming water above. Both water and chemicals come out of the container.**)
7. What is a pneumatic device? (**It is a device that uses compressed air to transfer pressure from one point to another.**)

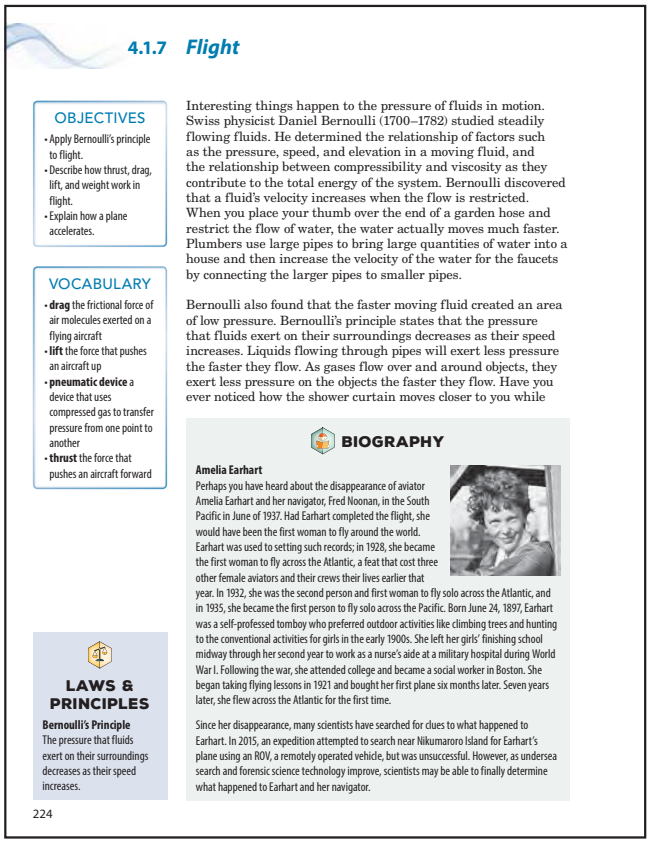
NOTES

Activities

Lab 4.1.7A Paper Airplanes

- copy paper or slightly heavier paper, several sheets per group
- metersticks, 1 per group
- masking tape
- small paper clips, several per group
- scissors, 1 pair per group
- cellophane tape

Print **BLM 4.1.7A Airplane Instructions** for students to use during the lab.



4.1.7 *Flight*

OBJECTIVES
- Apply Bernoulli's principle to flight.
- Describe how thrust, drag, lift, and weight work in flight.
- Explain how a plane accelerates.

VOCABULARY
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LAWS & PRINCIPLES
Bernoulli's Principle
The pressure that fluids exert on their surroundings decreases as their speed increases.

Interesting things happen to the pressure of fluids in motion. Swiss physicist Daniel Bernoulli (1700–1782) studied steadily flowing fluids. He determined the relationship of factors such as the pressure, speed, and elevation in a moving fluid, and the relationship between compressibility and viscosity as they contribute to the total energy of the system. Bernoulli discovered that a fluid's velocity increases when the flow is restricted. When you place your thumb over the end of a garden hose and restrict the flow of water, the water actually moves much faster. Plumbers use large pipes to bring large quantities of water into a house and then increase the velocity of the water for the faucets by connecting the larger pipes to smaller pipes.

Bernoulli also found that the faster moving fluid created an area of low pressure. Bernoulli's principle states that the pressure that fluids exert on their surroundings decreases as their speed increases. Liquids flowing through pipes will exert less pressure the faster they flow. As gases flow over and around objects, they exert less pressure on the objects the faster they flow. Have you ever noticed how the shower curtain moves closer to you while

BIOGRAPHY

Amelia Earhart

Perhaps you have heard about the disappearance of aviator Amelia Earhart and her navigator, Fred Noonan, in the South Pacific in June of 1937. Had Earhart completed the flight, she would have been the first woman to fly around the world. Earhart was used to setting such records; in 1928, she became the first woman to fly across the Atlantic, a feat that cost three other female aviators and their crews their lives earlier that year. In 1932, she was the second person and first woman to fly solo across the Atlantic, and in 1935, she became the first person to fly solo across the Pacific. Born June 24, 1897, Earhart was a self-professed tomboy who preferred outdoor activities like climbing trees and hunting to the conventional activities for girls in the early 1900s. She left her girls' finishing school midway through her second year to work as a nurse's aide at a military hospital during World War I. Following the war, she attended college and became a social worker in Boston. She began taking flying lessons in 1921 and bought her first plane six months later. Seven years later, she flew across the Atlantic for the first time.

Since her disappearance, many scientists have searched for clues to what happened to Earhart. In 2015, an expedition attempted to search near Nikumaroro Island for Earhart's plane using an ROV, a remotely operated vehicle, but was unsuccessful. However, as undersea search and forensic science technology improve, scientists may be able to finally determine what happened to Earhart and her navigator.

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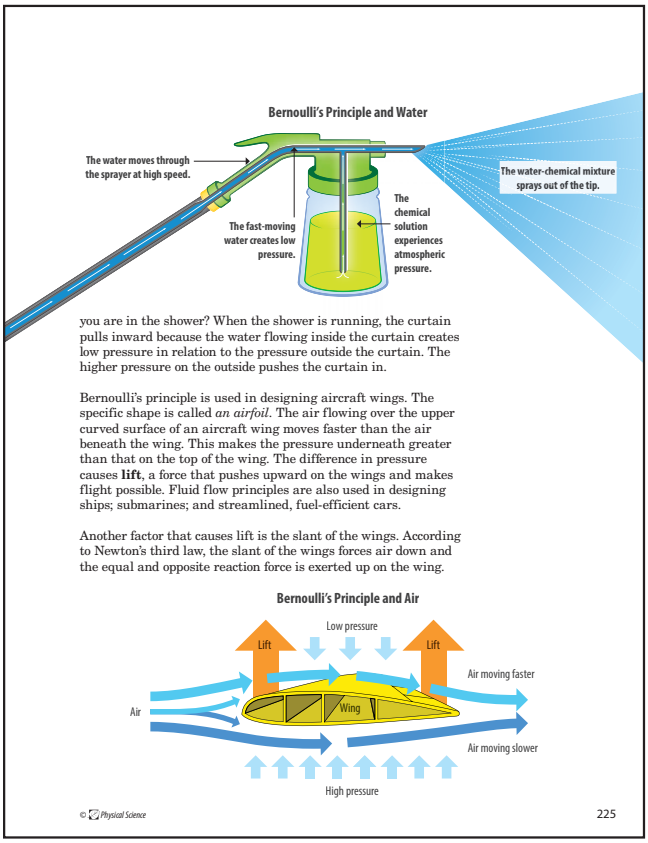

Bernoulli's Principle and Water

you are in the shower? When the shower is running, the curtain pulls inward because the water flowing inside the curtain creates low pressure in relation to the pressure outside the curtain. The higher pressure on the outside pushes the curtain in.

Bernoulli's principle is used in designing aircraft wings. The specific shape is called *an airfoil*. The air flowing over the upper curved surface of an aircraft wing moves faster than the air beneath the wing. This makes the pressure underneath greater than that on the top of the wing. The difference in pressure causes **lift**, a force that pushes upward on the wings and makes flight possible. Fluid flow principles are also used in designing ships; submarines; and streamlined, fuel-efficient cars.

Another factor that causes lift is the slant of the wings. According to Newton's third law, the slant of the wings forces air down and the equal and opposite reaction force is exerted up on the wing.

Bernoulli's Principle and Air

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NOTES

A. Divide the class into groups to design the best paper airplane. Direct students to document supplies used, results of test trials, and final design. Hold a competition and commend students for the fastest, farthest, and longest flights.

B. Using computer simulation software, have students simulate flights of different plane designs.

C. Assign students to research a specific plane design or specific aviator. Guide students in narrowing their topic. Have students make a visual display and present their findings to the class.

D. Challenge students to research helicopters and how they differ from airplanes. Direct students to compare methods of flight and uses for each.

E. Take students on a field trip to a local flight or space museum.

Lesson Review

1. What is Bernoulli's principle? (**The pressure that fluids exert on their surroundings decreases as their speed increases.**)
2. How does Bernoulli's principle apply to flight? (**The air moves faster over the top of the wing than below the wing. The air above the wing exerts very little pressure compared to the air underneath the wing. The unbalanced pressure creates lift.**)
3. Explain how lift, weight, thrust, and drag exert force on an airplane. (**Lift pushes up on the plane and weight pushes down. Thrust moves the plane forward and drag is the friction that works in opposition to thrust.**)

SCIENCE IN ACTION

Physics of Sailing

Sailboats also depend on Bernoulli's principle. Boats of all kinds are subject to it while traveling through the water, but the sail on a sailboat acts just like a wing, creating lift. If a sailor only wanted to go in the direction of the wind, he or she would not need lift. The wind would just push the boat along. But, how is sailing into the wind possible? The boom, or pole, at the bottom of the sail is maneuvered to "catch" the wind so it will actually pull the boat. It is important for the sailor to maintain the curve in the sail. Remember, the wind moves faster over the rounded part of the sail, creating low pressure. What does that do on the other side? It creates higher pressure that pushes the sail and moves the boat. Since there is almost always a sideways force, the keel keeps the boat from moving sideways. This fin provides drag to resist sideways motion and keep the boat sailing forward and into the wind.

In addition to lift, three other forces are working during flight: gravity, or weight; thrust; and drag. Weight works in opposition to lift. If it is greater than the lift, the plane will descend. If the plane begins its flight with too much weight, it will not be able to create enough lift to take off. How does the plane create enough lift to take off? Consider Bernoulli's principle. The speed of the air over the top of the wing has to create extremely low pressure. To increase the speed of air over the wing, the plane has to reach a certain velocity. This is why an airplane speeds down a runway. It continues to accelerate until it creates enough lift to get off the ground.

Thrust is generated by the engines and is the force that pushes the plane forward. **Drag** works in opposition to thrust and is the friction created by air molecules. Imagine how much drag would be generated if the front of the airplane were a flat square. Too much drag on the plane would prevent its ability to create lift. That plane would never take off. When thrust and drag are equal, the plane is moving at a constant rate. For the plane to speed up, thrust has to be greater than drag.

The motion of an airplane relies on the relationship of these four forces. When all are balanced, the plane cruises at a constant speed. Suppose the pilot wants to maneuver the plane while it is in the air. When driving on the ground, a car can move side to side by turning the wheel, or front to back by placing the car

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HISTORY

History of Flight

Louis Bleriot's first flight across the English Channel, 1909

The thought of flying is exhilarating, and the desire to fly has probably existed since the beginning of time. Watching the path of a soaring bird delights the heart and inspires the mind. Many have dabbled in the possibilities and contemplated what it would take to make human flight a reality. Leonardo da Vinci drew plans for a flying machine as far back as 1490. For centuries, man attempted to fly by emulating the flapping wings of a bird, but the attempts were futile. Finally, in the late 19th century and early 20th century the dream of human flight became a reality.

But those who hope in the LORD will renew their strength. They will soar on wings like eagles; they will run and not grow weary. Is. 40:31a

1884 Horatio Phillips of England designs the airfoil.

1896 Samuel P. Langley launches a steam-powered model aircraft over the Potomac River, with flights reaching 0.75 of a mile.

1901 In a speech Wilbur Wright makes to a group of Chicago engineers, he notes three general difficulties in sustaining flight:
1. The construction of sustaining wings
2. The generation and application of power to drive the machine through the air
3. The balancing and steering of the machine after it is actually in flight

The Wright brothers have much of what they need to be successful, building on over four centuries of research from Leonardo da Vinci and Galileo Galilei of Italy, Christiaan Huygens from the Netherlands, Sir Isaac Newton in England, Daniel Bernoulli and Leonhard Euler from Switzerland, John Smeaton from England, and many others.

Wilbur and Orville Wright make their famous flight on December 17, 1903, at Kitty Hawk, North Carolina. They actually make four flights that day and only consider the last one a true flight. They fly for 59 seconds and travel 260 meters.

Their accomplishment ushers in the age of flight.

1906 A patent is issued for the brothers' flying machine.

1908 Madame Therese Peltier is the first woman to fly solo.

1908 US War Department purchases a flying machine from the Wright brothers.

1918 The US post office inaugurates airmail service.

1924 US Army Service planes avert a flood in Nebraska by dropping bombs to clear an ice jam.

1932 Amelia Earheart flies solo across the Atlantic.

1947 The US Air Force is established as an equal element of the US armed forces, no longer a division of the US Army.

1950s The Space Race begins.

1954 The first Air Force One, private plane for the president of the United States, is inaugurated for service.

1964 Geraldine Mock becomes the first woman to fly around the world.

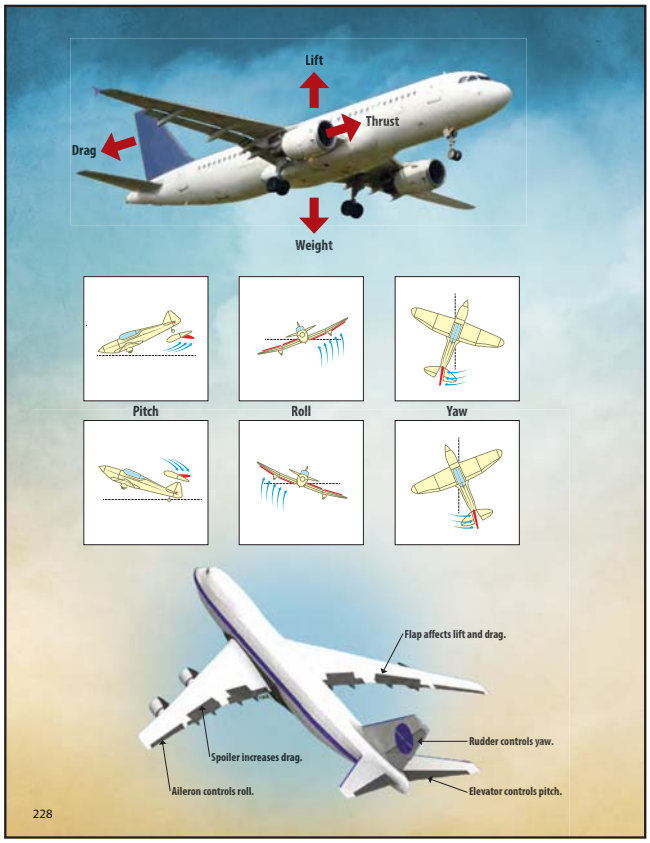
1994 Test flight of Boeing 777 occurs, the first aircraft to be designed entirely on a computer.

2010 Bertrand Piccard and Solar impulse team fly more than 24 consecutive hours nonstop in a solar airplane.

2016 FAA predicts that 7 million UAVs (unmanned aircraft vehicles) will swarm the skies by the year 2020.

4. What creates acceleration, or a change in velocity? (**an unbalanced force**)
5. Describe how a plane changes direction using the terms *yaw*, *pitch*, and *roll*. (**To change the yaw, the left and right movement, the pilot moves a rudder on the tail. To change the pitch, the up-and-down movement, the pilot adjusts the elevators on the back of the plane. To roll the plane, the pilot adjust the ailerons—one up and one down.**)

NOTES



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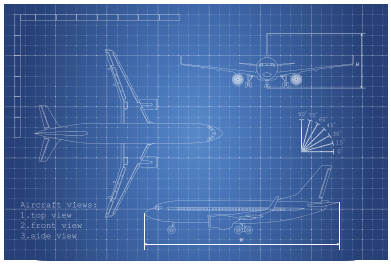

in drive or reverse. A plane has different methods to create an unbalanced force and to accelerate. To change the yaw, or left- and right-movement, the pilot moves a rudder on the tail. To change the pitch, the up-and-down movement, the pilot adjusts the elevators on the tail of the plane. To roll the plane, the pilot moves a part of one wing up and a part of the other wing down. These parts are called *ailerons*.

Pneumatic devices also make use of Pascal's principle and Bernoulli's principle. Pneumatic devices are devices that use compressed gas to transfer pressure from one point to another. Pneumatic tools are connected with hoses to compressed air tanks. When a valve is opened at the end of the hose, the force of the compressed air moving from high pressure to low pressure provides the energy needed to make the tools work. Examples include rock drills, pavement breakers, and blast cleaners.

LESSON REVIEW

1. What is Bernoulli's principle?
2. How does Bernoulli's principle apply to flight?
3. Explain how lift, weight, thrust, and drag exert force on an airplane.
4. What creates acceleration, or a change in velocity?
5. Describe how a plane changes direction using the terms *yaw*, *pitch*, and *roll*.

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Name: _____ Date: _____

Lab 4.1.7A Paper Airplanes

QUESTION: How does added drag affect the flight of a plane?

HYPOTHESIS: Possible answer: Adding drag will slow down the flight of a plane.

EXPERIMENT:

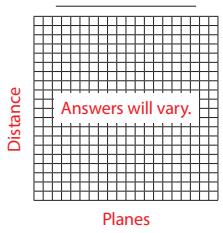
You will need:		
• copy paper or slightly heavier paper	• masking tape	• scissors
• meterstick	• small paper clips	• cellophane tape

Steps:

1. Label the plane below to show the direction of the four forces that are exerted on a plane during flight—thrust, drag, lift, weight.

2. Build three identical paper airplanes, using **BLM 4.1.7A Airplane Instructions.**
3. Place a piece of masking tape on the floor to mark the launch line. Make note of where you are holding the plane when you launch it. Answers will vary.
4. Launch the first plane. Measure the distance it flew and record. Add any important notes about the flight path and pattern. For example: *It flew upside down*; *it rolled as it flew*; *it went straight up and came back down*; *the nose was damaged so I had to straighten it*.
5. Launch the plane four more times and record the results.
6. After five flights with Plane 1, calculate the average distance.
7. Change the plane to increase its drag. Use scissors to cut slits 2.5 cm long where the wings meet at the middle.
8. Fold up the 2.5 cm cut section on both wings so these sections are at a 90° angle to the rest of the wing.
9. Launch Plane 1 with the added drag. Record the distance it flew and make note of its flight path and pattern.
10. Launch Plane 1 with the added drag four more times. Record the distances.
11. Repeat Steps 4–10 for Plane 2 and Plane 3.
12. Create a bar graph comparing the average distance for each plane with and without drag.
13. What will the *x*-axis label be? Planes
14. What will the *y*-axis label be? Distance

Lab 4.1.7A Paper Airplanes



ANALYZE AND CONCLUDE:

1. Which plane averaged the shortest flight? Why? Answers will vary but should include discussions about lift, weight, drag, and thrust.
2. Which plane averaged the longest flight? Why? Answers will vary but should include discussions about lift, weight, drag, and thrust.
3. What other variables could be tested? Possible answers: weight, shape, design
4. Write an experiment to test one variable. Note that the experiment should include a hypothesis; a step by step procedure; methods for avoiding experimental error; a method for recording data; and an analysis that includes the terms thrust, drag, lift, weight.

Name: _____ Date: _____

Lab 4.1.7A Paper Airplanes continued

Paper Plane	Flight 1	Flight 2	Flight 3	Flight 4	Flight 5	Average	Notes
Plane 1	Answers will vary.						
Plane 1 with added drag							
Plane 2							
Plane 2 with added drag							
Plane 3							
Plane 3 with added drag							