Lesson 4: Heavier than Air–Planes and Newton's Third Law

Students have now been introduced to the role that weight and material choice play in the flight of aircraft. This lesson teaches how such heavy objects as planes become airborne and stay in flight. Students will gain understanding of the multiple forces that act on an object during flight and how engineers construct planes around those forces.

Learning Objectives

Students will

- Be able to explain and define the differences between lift, thrust, gravity, and drag
- Be able to explain Newton's Third Law through giving an example

Materials

These will vary depending on which experiments you elect to conduct. Think about how your students like to learn and choose the activities accordingly. You want to capitalize on how students engage and retain information while also challenging them to be comfortable learning outside of their comfort zone.

Time

2 hours

WELCOME AND CHECK-IN (5 MINUTES)

Welcome students to the classroom and ask a check-in question. This lesson builds upon what students learned about flight from the last lesson. Students will learn more about the physics involved in plane flight and the differences between propeller and jet engines. Some example check-in questions are

- What is Bernoulli's principle?
- If you were to build an airplane, what materials would you use and why?
- Why does a paper airplane stay in flight?
- How do you think a jet engine works?
- What is drag? Can you give an example?

PART I: THRUST (5 MINUTES)

We have two opposing forces left to understand. Let's look at thrust. Thrust is the force that causes an airplane to move forward because of the movement of air or gas. Thrust pushes the airplane forward, which also enables the wings to create lift.

Showing pictures of a jet, propeller, and rocket engine will be helpful.

> Engines are responsible for giving airplanes thrust. Several different types of airplane engines are propeller, jet, and rocket engines. Basically, all three types of engines "throw" air one direction in order to move the plane in the opposite direction. All airplane engines push air backward.

PART II: NEWTON'S THIRD LAW OF MOTION (20 MINUTES)

Ask the class if they have heard of Isaac Newton or Newtonian physics. Some students may already be familiar with Newtonian physics, while others may not be. We are providing enough information to foster an elementary understanding that will be built upon through hands-on activities.

Giving students a chance to showcase what they have learned will help them build confidence and be more comfortable speaking in front of the class. It is important to note that individual students will learn at their own pace.

Isaac Newton learned that for every action there is an equal but opposite reaction. For example, as an engine forces air backward, the airplane will move with an equal but opposite force forward. Each engine is throwing air out one way so the plane can move the opposite way. This reaction force is known as thrust.

Newton's third law of motion: Every action has an equal but opposite reaction.

PART III: NEWTON'S THIRD LAW EXPERIMENT 1 (20 MINUTES)

We are going to explore Newton's third law of motion.

Instruct students to create illustrations for each of the activities. Stick figures are fine. What is important is that students understand and correctly label the forces in action during each activity. Make sure the students draw the equal and opposite forces being applied.

- Draw and label an arrow indicating the action force.
- Draw and label an arrow indicating the reaction force.

Still Standing

Materials: an unobstructed wall, one piece of paper per student, and one pencil per student

Instructions

1. Students should form pairs. One student will complete the activity while the other observes and takes notes. Then students will switch roles.
2. Instruct students to have one member of their pair stand in front of the wall and push on it as hard as they can.
3. Ask the observer what they noticed. Did their partner brace themselves before pushing on the wall? Why do they think the wall didn't move?
4. Have students switch roles and repeat.
5. Once all students have had a chance to push on the wall, explain to them that this was an example of a slow collision: Neither the wall nor the student moved. The wall exerted an equal force back on to the student pushing against it.
6. Now tell students to stand flat-footed as close to the wall as possible and to push as hard as they can.

7. Students should switch roles and record their findings.
8. Students should find that they are pushed backward from the wall.

Transition students to their seats and give them a few minutes to finish their drawings. Then ask the group what differences they noticed between the two activities.

PART IV: NEWTON'S THIRD LAW EXPERIMENT 2 (OPTIONAL, 20–30 MINUTES)

Balloon acceleration

Materials: one balloon per student (not inflated)

Instructions

1. Instruct students to blow up the balloon to the size of a fist.
2. Students should then hold the balloon between their thumb and index fingers with the palm of their other hand facing the opening of the balloon.
3. Tell students to slowly release the air from the balloon but not to let go of it.
4. What sensations do they notice with their hand that isn't holding the balloon?
5. Now tell students to blow the balloon up as big as their head.
6. Tell them to repeat steps 2 and 3.
7. Give students 2–3 minutes to finish their drawings. Then ask the group what differences they noticed between the two activities. How did the balloons behave similarly? How did they behave differently?

Make sure the students record the following:

- Where were the equal and opposite forces being applied?
- Draw and label an arrow indicating the action force.
- Draw and label an arrow indicating the reaction force.

After students have completed their illustrations, show them a drawing or picture of the forces working during the experiment and have them correct their drawings. Don't forget to ask if students need clarification or want you to restate the concept.

> What would happen if you let go of a balloon while letting the air out of it? Why?
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> It would fly all over the place, changing direction. Remember, equal but opposite. The escape route, or the direction the air is leaving, would no longer be held in place, so as direction changes the force in the opposite direction also changes.
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> When the balloon is inflated, compressed air presses equally against all sides of the inside of the balloon. If the balloon is not sealed shut the air will rush out from it. The air being pushed in one direction is the action. What do you think the reaction is?

The reaction is the balloon flying in the opposite direction. The balloon is propelled by the force from the air escaping the balloon.

This process of releasing air from the balloon illustrates the operating principles of a rocket engine's propelling force acting on the region opposite the exhaust port.

Now you will move into introducing students to engine power and the different forces that drive engines.

PART V: ENGINES (40 MINUTES)

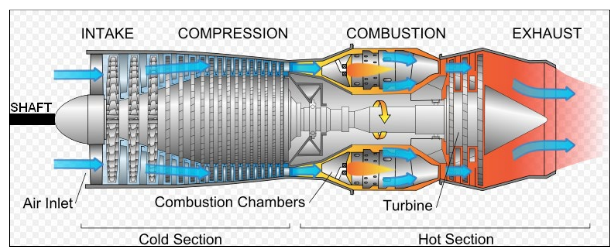
Propeller Engines

A visual aid will help the students identify a propeller engine. Consider incorporating a video clip, image, or small model to pass around the room if you think students will not be distracted during your lecture.

> Propellers are made up of multiple, individual blades (of various sizes, depending on the overall size of the propeller), each shaped like small wings. Lift is created on one side of the propeller blade as it rotates through the air. This lift also pulls the propeller forward, because it is oriented vertically, not horizontally like the wings. The propeller then pulls on the engine and the rest of the airplane. What principle does this remind you of?

Students should identify Bernoulli's principle.

Prepare an introductory explanation of a jet engine with pictures of component chambers. Reiterate to students that engines are complex. Many of us benefit from engines without giving much thought to all of the necessary processes behind what makes them work.



Jet Engines

> Jet engines are much more complex than propeller engines. They are masters of Newton's third law as well as other principles of physics. Jet engines suck air directly into the engine. For a jet going slower than the speed of sound, the engine is moving through the air at about 1,000 kmph (600 mph).
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> 1. Air is pulled into the engine.
> 2. A fan at the front sucks the cold air into the engine and forces it through the inlet. This slows the air down by about 60 percent, and the air's speed is now about 400 kmph (240 mph).

A companion diagram with components labeled or blanks for students to fill in should be used to help students follow along. You may paraphrase or give them a moment to read the diagram on their own before you continue.

> 3. A second fan called a compressor squeezes the air (which increases the pressure).
> 4. Kerosene (liquid fuel) is then squirted into the engine from a fuel tank in the plane's wing.

The compressor pushes the air into a combustion chamber. This increases the pressure by about eight times, which dramatically increases the air temperature.

Then, liquid fuel is continually sprayed into the combustion chamber and burned.

5. In the combustion chamber, just behind the compressor the kerosene mixes with the compressed air and burns fiercely, giving off hot exhaust gases and producing a huge increase in temperature.
6. The exhaust gases rush past a set of turbine blades, spinning them like a windmill. This creates exhaust gas, which is heated to an extremely high temperature and pressure. This high-pressure gas exits the engine through a turbine and nozzle.
7. The turbine blades are connected to a long axle that runs the length of the engine.
8. The hot exhaust gas exits the engine through a tapering exhaust nozzle.

Visual aids showing each part of the engine will help students imagine how air moves through the engine while keeping them engaged.

The compressor and the fan are also connected to this axle. So, as the turbine blades spin, they also turn the compressor and the fan.

Just as water squeezed through a narrow pipe accelerates dramatically into a fast jet (think of what happens in a water pistol), the tapering design of the exhaust nozzle helps to accelerate the gases to a speed of more than 2,100 kmph (1,300 mph). The hot air leaving the engine at the back is traveling more than twice the speed of the cold air entering it at the front—and that's what powers the plane. The backward-moving exhaust gases power the jet forward. Because the plane is much bigger and heavier than the exhaust gases it produces, the exhaust gases have to zoom backward much more quickly than the plane's own speed of about 900 kmph (575 mph).

Drag

Drag is a force that works in the opposite direction from which you are moving.

If you stick your hand out of a car window while moving, you'll experience a very simple demonstration of drag at work. The amount of drag that your hand creates depends on a few factors, such as the size of your hand, the speed of the car, and the density of the air. If you were to slow down, you would notice that the drag on your hand would decrease.

When an airplane flies through the air, it runs into air molecules, which cause it to slow down. The challenge for engineers is to find creative ways to reduce drag so that airplanes can go faster and fly more efficiently. The less drag an airplane experiences, the less fuel it needs to fly at the same speed. Engineers reduce form and friction drag by making the body of the plane more streamlined, the wings more narrow, or by using new materials and manufacturing processes to make the skin of the plane smoother.

Engineers reduce induced drag by making the ends of the wings oval shaped or by adding wing tips that stick up from the end of the wing.

Ask students if they can think of another example of drag. If they need prompting, ask if they have seen Olympic skiers get into a tuck. Why do students think they do this? Students should be able to guess that tucking lessens skiers' drag, which gives them more speed.

This is a good opportunity to show different wing designs and ask students how they think wing shape may affect how a plane flies.

Through the efforts of engineers, airplanes are continually changing shape to improve efficiency and performance, with the goal of becoming more aerodynamic. If you have time, show students different plane designs to illustrate aerodynamic design in practice and prove that there are many different interpretations regarding how to reduce drag.

Guiding Discussion Questions

- How do engineers try to decrease drag on airplanes?
- What is the difference between a propeller and a jet engine?
- How are propeller engines and jet engines the same?
- What is Newton's third law?