Air Density

Session Time: Three, 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)

ESSENTIAL QUESTIONS

1. How is air affected by variations in pressure, temperature, and humidity?
2. How much air does an aircraft need to fly?

LEARNING GOALS

Students Will Know

1. How air density affects aircraft performance
2. How mass and gravity relate to atmospheric pressure
3. That atmospheric pressure is directly proportional to air density
4. That temperature and humidity are inversely proportional to air density

Students Will Be Able To

1. *Summarize* how pressure, temperature, and humidity affect air density. (DOK-L2)
2. *Explain* how air density affects aircraft performance. (DOK-L2)
3. *Explain* how atmospheric pressure changes with variations in altitude. (DOK-L2)
4. *Hypothesize* how to overcome low air density in order to keep an aircraft in flight. (DOK-L3)

ASSESSMENT EVIDENCE

Warm-up
Students will read the first part of the SpongeGeorge story and answer related questions.

Formative Assessment
Students will test how heating and cooling affect the density of a fluid (in this case, water). They will apply this same concept to air and the effect temperature has on density.

Summative Assessment
Students write a short speech for SpongeGeorge to deliver at a press conference. The speech will include what he learned about air density and its effect on aircraft performance, and how air density is affected by temperature, density, and humidity.

LESSON PREPARATION

MATERIALS/RESOURCES

- Air Density Presentation
- Air Density Student Activity 1
- Air Density Student Activity 2
- Air Density Teaching Aid 1
- Air Density Teaching Aid 2

Visualizing Density Demonstrations (Per Class)

- Balance scale
- Metal counterweights
- Styrofoam cube or slab, at least 4 x 4 x 2 inches
- Large glass or clear plastic jar, at least 8 inches high (e.g. an empty pickle jar)
- Rocks of such a size to be able to fill the jar with 4 or 5 of them
- Small pebbles or river rocks (enough to fill the space between the larger rocks)
- Sand (enough to fill the space between the pebbles)
- Water (to fill the rest of the jar)
- Beaker graduated in liters

Layering Water Activity (Per Group)

- Two identical clear baby food jars
- Hot water (about 50 °C, colored red)
- Cold water (about 5 °C, colored blue)
- Water-resistant card (from a deck of cards or laminated index card)
- Paper towels
- Cookie sheet or something similar to catch drips and spills

LESSON SUMMARY

Lesson 1: Air is a Fluid
Lesson 2: Air Density

This is a guided discovery lesson that follows the adventures of a character, SpongeGeorge, as he tries to reach the moon. Throughout the course of the lesson, students will learn through SpongeGeorge's narrative about the importance of air density and its effect on aircraft performance. This lesson will be completed over 3 sessions.

To begin the lesson, students will read the first part of SpongeGeorge's story and answer questions related to his plan and to what they already know about air and water.

Through a class discussion, students will learn about density and participate in two demonstrations that explore the concepts of mass, volume and density.

As SpongeGeorge's story continues, students will discover how air density affects an aircraft's performance and the factors that affect air density: pressure, temperature, and humidity.

During the formative assessment, students will test how heating and cooling affect the density of a fluid (in this case, water). They will apply this same concept to air and the effect temperature has on density.

The summative assessment asks students to write a short speech for SpongeGeorge to deliver at a press conference. The speech will include what he learned about air density and its effect on aircraft performance and how air density is affected by temperature, density, and humidity.

BACKGROUND

Students have already learned that air is a fluid because, like liquids, it does not maintain its shape, and can flow from place to place. However, unlike water, air is compressible. Pressure applied to air pushes the molecules together, compacting it, and making the air more dense.

Air pushing down from above causes air near the surface of the earth to be under more pressure than air at higher altitudes. Because of compressibility, this lower altitude air is more compact, and thus more dense than the air above. Since airplanes require air to fly, the higher they climb, the more their performance suffers, until the point they are unable to maintain altitude in the thin air.

MISCONCEPTIONS

The primary confusion when talking about density and pressure is over the role pressure plays in aircraft performance. Pressure is important to aircraft performance only because it is related to air density, is easily measured, and can be used as a tool to arrive at density. Aircraft performance is determined by air density, not pressure.

DIFFERENTIATION

To support struggling students, have them create a graphic organizer during the **EXPLAIN** section to keep track of the different properties of air that are studied in this lesson. The graphic organizer should have four columns: temperature, pressure, altitude, and humidity. As they learn about each variable, have them compare its effects on air with the other variables.

Advanced students may know from chemistry that the Ideal Gas Law relates temperature, pressure, and volume. However, we generally do not consider volume when we talk about ambient air pressure. To promote guided inquiry, ask students to consider how volume would relate to pressure and density during the **EXTEND** section. As a hint, help them think about how a volume of air is measured, and how volume and density would change as pressure changes.

LEARNING PLAN

ENGAGE

Teacher Material: Air Density Presentation
Student Material: Air Density Student Activity 1

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

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

Warm-Up

Have students read and complete Part 1 of "The Adventures of SpongeGeorge" in **Air Density Student Activity 1**. Have students write answers to the questions provided. Explain that for this lesson, students should suspend their disbelief for theoretical purposes

- What are some problems with SpongeGeorge's plan?
- You've learned that air is a fluid, what is the main difference between air and water?
- If SpongeGeorge is right and the moon is floating on the top of the atmosphere, could you fly an airplane to the moon?

[DOK 3; *hypothesize*, DOK 2; *explain*]

Questions

What are some problems with SpongeGeorge's plan?

The moon isn't floating on top of the earth's atmosphere. Submarines (like SpongeGeorge's fluid plane) can't fly.

You've learned that air is a fluid, what is the main difference between air and water?

Water is much more dense than air.

Water is heavier than air.If SpongeGeorge is right and the moon is floating on the top of the atmosphere, could you fly an airplane to the moon?

Just as you can't fly most airplanes straight up, you couldn't point an airplane at the moon and fly there unless you had the same amount of power as a rocket. Also, if there was air all the way to the moon, the air pressure on the surface of the earth would be too extreme for the airplanes we have now.

EXPLORE

Teacher Materials: Air Density Presentation, Air Density Teaching Aid 1

Slide 5: He doesn't know it yet, but SpongeGeorge has a density problem. As SpongeGeorge attempts to build a submarine to fly to the moon, students will learn that air density is critical to flight. This will unfold for students as they learn the definition of density and the factors that affect it.

Slide 6: Density is the mass of a substance divided by its volume. It is the measure of how compact a substance is.

If a bag had 25 candies in it, that would be a high density of candies in the space of that bag. If you gave a single candy from the bag to each of your classmates, those same 25 pieces of candy would now fill the space of the classroom, making for a low density.

Slide 7: Perform the two demonstrations included in **Air Density Teaching Aid 1** where students will observe the relationship between mass, volume, and density.

In the first demonstration, students will balance a styrofoam block against counterweights and discover that, while the block and the counterweights contain the same amount of mass, the block has greater volume and is therefore less dense.

In the second demonstration, students will continue to add smaller and smaller pieces of matter to a jar as they measure its increasing density. Students will see that density can increase even if the volume remains constant.

EXPLAIN

Teacher Material: Air Density Presentation
Student Material: Air Density Student Activity 1

Slide 8: Have students read and complete Part 2 of "The Adventures of SpongeGeorge" in **Air Density Student Activity 1**. Have students write answers to the question provided.

Questions

Why was the fluid plane able to travel in the water, but not the air?

The reason is because air is much less dense than water. The fluid plane was less dense than the water, but more dense than the air, so it couldn't stay afloat after it left the water. In the previous lesson, students learned that airhas less viscosity than water, but they haven't yet learned that air is less dense than water. This concept will be taught next.

Teaching Tips

Remind students that the terms mass and weight are not interchangeable. The mass of an object, which is a measure of how much matter it contains, is constant whether that object is on the moon, on Earth, or in outer space. Weight, however, is determined by the pull of gravity on an object. The greater the force of gravity, the more force exerted on an object and the higher the object's s weight. A person who weighs 150 pounds on Earth would only weigh 24.9 pounds on the moon, since the moon has lower gravity than Earth. A substance with mass only has weight if it experiences a force.

Slide 9: Water is much more dense than air. While water weighs 62 pounds per cubic foot, the same volume of air weighs less than a tenth of a pound (at standard temperature and pressure). The fluid plane was able to rise in the water because the plane was less dense than the water. However, it was more dense than the air, and so, after losing momentum, it crashed back into the sea.

Questions

Ask students the following questions leading them to think about what SpongeGeroge should do next to overcome the challenges with air density.

What does SpongeGeorge need to do to get his fluid plane in the air?

He needs to make the fluid plane less dense than the air. Just like his fluid plane was less dense than the water.

What force would SpongeGeorge need more of to stay in the air?

SpongeGeorge would need to create lift.

What can SpongeGeorge do to get it?

He could put larger wings on his fluid plane.

Slide 10: To begin the second session, have students read and complete Part 3 of "The Adventures of SpongeGeorge" in **Air Density Student Activity 1.** Have students write answers to the question provided. Ask students to hypothesize why SpongeGeorge's plane stopped climbing. The answer will be presented on the next slide.

Slide 11: Air density decreases as altitude increases. This is why every airplane has a flight ceiling, an altitude above which it cannot fly. As an airplane ascends, a point is eventually reached where there just isn't enough air to generate enough lift to overcome the airplane's weight, enough air for the engine, or enough air for the propeller to convert engine power into thrust.

SpongeGeorge eventually got to an altitude where there wasn't enough air for his airplane to fly any longer.

Slide 12: Density is mostly determined by the nature of the material. Some materials are naturally packed tighter than others. The more dense something is, the more solid and heavy it feels.

Temperature and pressure also affect density, though much more for a gas than for solids and liquids. Humidity also has an effect on air density.

Slide 13: Liquids and many solids are considered incompressible, meaning applying pressure to them does not make them much more compact. They are already packed as tightly as they can be.

Gases on the other hand, can be compressed into a much smaller volume when pressure is applied. Air, for example, is a gas. When a set amount of air is pressed into a smaller space, it becomes more dense.

In the atmosphere, air near the surface of the Earth is being compressed by the weight of all of the air above it. As you move higher in the atmosphere, there is less weight of air above pressing down, resulting in less pressure and density the higher you go.

Eventually, you reach an altitude where the air is not dense enough for the wings to generate lift, the engine to produce power, or the propeller to convert power to thrust.

Slide 14: Explain that different units are used to measure atmospheric pressure. One measurement uses millibars (mb), where a bar is a unit of pressure. Another measurement uses inches of mercury, which uses the unit Hg. Air pressure can also be measure in psi, or pounds per square inch. A barometer is the scientific instrument that measures atmospheric pressure. If time allows, show students a video about the history of the barometer and how it works.

- "The History of the Barometer (and How it Works)" (Length 4:45)
  http://video.link/w/d7ce

Slide 15: Another factor that affects density is temperature. Heating a substance causes molecules to speed up and spread slightly further apart, so that the same number of molecules occupy a larger volume of space. The result is a decrease in density. Cooling a substance causes molecules to slow down and get slightly closer together, occupying a smaller volume that results in an increase in density. This is an inverse relationship--when one factor goes up, the other one goes down.

Slide 16: When water is a vapor, or gas, it has less mass than air. That means humid air, which contains water vapor, is less dense than dry air. It's a small difference and isn't usually taken into account in aircraft performance calculations.

Students may wonder how humid air could be less dense than dry air, since they know that water is more dense than air. The first thing to understand is that water is the liquid form of H2O, ice is the solid form, and water vapor is the gaseous form. Humidity is water vapor and is a gas rather than a liquid, so although it contains water molecules, they are much farther apart than in liquid water.

Dry atmosphere comprises about 78% nitrogen (N2) and 21% oxygen (O2). The molecular weights of a nitrogen molecule and an oxygen molecule are 28 and 32 respectively. Water vapor has a molecular weight of 18. If you replace oxygen and nitrogen with water vapor, the total mass of a cubic foot of air must go down. Density is mass divided by volume. Thus, a decrease in mass reduces density. Adding water vapor to air (e.g. increasing humidity) decreases mass and therefore also decreases air density.

EXTEND

Teacher Materials: Air Density Presentation, Air Density Teaching Aid 2
Student Material: Air Density Student Activity 2

Slide 17: Conduct the **Formative Assessment.**

This activity will complete the second session.

Formative Assessment

The objective of this activity is to help students explain how heating and cooling affect the density of a fluid (in this case, water). In small groups, students will place one jar filled with colored hot water upside down over another jar filled with cold water of a different color. They will observe that the hot water remains in the top of the jar. Students will then reverse the demonstration by placing a jar of cold water on top of a jar of hot water. Students will apply the concept of temperature and density to explain that hot water is less dense than cold water and vice versa. They will apply this same concept to air and the effect temperature has on its density.

Provide students with **Air Density Student Activity 2**. Refer to **Air Density Teaching Aid 2** for notes about how to set up the activity and for sample answers to questions students will answer in the activity sheet. If time allows, have students share their predictions, observations, and answers with the class.

A video demonstrates how the experiment is performed.

- "Experiment: Effects of Temperature on Density" (Length 1:57) http://video.link/w/n8ce

[DOK 2; *observe, explain*]

Slide 18: At the beginning of the third session, have students read and complete Part 4 of "The Adventures of SpongeGeorge" in **Air Density Student Activity 1.** Have students write answers to the question provided.

Slide 19: Have a discussion with students that leads them to understand how high airplanes can travel in the atmosphere. Students should come to the conclusion that the higher an airplane flies, the more sophisticated equipment is needed to compensate for decreasing air density.

Questions

Why wasn't SpongeGeorge able to make it to the moon with his airship?

An airship would be too heavy to be buoyant in space or else it would be too fragile to last long enough to travel all the way to the moon.

EVALUATE

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

Summative Assessment

Students are to write a short speech (1-2 minutes) for SpongeGeorge to read at a press conference explaining why his adventure did not take him successfully to the moon. Students should include what SpongeGeorge learned about:

- air density and its effect on airplane performance.
- how air density is affected by temperature, pressure, and humidity.

A description of the assessment is included in Air Density Student Activity 1. Use the scoring rubric below.

[DOK 4; *create*, DOK 2; *explain, summarize*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Student work shows evidence of:
    - Understanding how air density affects aircraft performance
    - Understanding how air density changes with temperature, pressure, and humidity
    - Using scientific theories to explain observations from an experiment
- Student makes an oral presentation between 1 and 2 minutes in length
    - Presentation is well-organized and comprehensive

Points	Performance Levels
9-10	The activity is completed thoroughly and in an organized fashion. Student includes all information requested and shows a clear understanding of air density.

7-8	The activity is completed and all questions are answered. Student work shows minor gaps in understanding.
5-6	The activity is completed but student work shows a partial understanding of air density.
0-4	The activity is incomplete. The student shows little or no understanding of air density.

GOING FURTHER

Allow students to investigate the relationship between volume, mass, and density, and to observe buoyancy. They will observe how an egg sinks in tap water until enough salt is added to the water to make the egg float.

1. Fill a tall drinking glass about 3/4 full of water
2. Place a raw egg into the glass and observe the result
3. Fill another tall drinking glass about 3/4 full of water
4. Add 4 tablespoons of salt and stir until combined
5. Place the egg into the glass and observe the result

Ask students why the egg sank in the tap water but floated when sufficient salt was added. The answer is that the salt changes the mass of the water without adding to the volume. The water becomes more dense, exceeding the density of the egg and causing it to float.

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
    - Obtaining, evaluating, and communicating information
    - Constructing explanations and designing solutions
  - Disciplinary Core Ideas
    - PS1.A: Structure and properties of matter
    - PS2.A: Forces and motion
  - Crosscutting Concepts

- Cause and effect
- System and system models
- Structure and function

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.9-12.7** - Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- **WHST.9-12.9** - Draw evidence from informational texts to support analysis,reflection, and research.

REFERENCES

https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/06_phak_ch4.pdf https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/14_phak_ch12.pdf
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