Hydraulics and Landing Gear

Session Time: Three, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The intended purpose and use of an aircraft drives aircraft design considerations and construction techniques, materials, and components. (EU1)

A deep understanding of how an aircraft operates enables a pilot to fly the aircraft to its maximum capabilities in both normal and abnormal situations. (EU5)

ESSENTIAL QUESTIONS

1. What aircraft systems use hydraulics for operation?
2. Why are hydraulics required to operate these systems?
3. What are the different types of landing gear and what purpose does each serve?

LEARNING GOALS

Students Will Know

- The key parts of a hydraulic system
- The basic operation of a hydraulic system
- The various types of landing gear

Students Will Be Able To

- *Analyze* the mechanical advantage for a given simple hydraulic system. (DOK-L4)
- *Create* a simple hydraulic system model. (DOK-L4)
- *Compare* the advantages of different types of landing gear systems. (DOK-L3)

ASSESSMENT EVIDENCE

Warm-up
Students will use the example of a squirt gun to describe how a fluid travels when pressure is applied.

Formative Assessment
Students will be shown a variety of aircraft landing gear and will be expected to accurately identify each type as well as the advantages and disadvantages of each type.

Summative Assessment
Students will build a simple hydraulic system (scissor lift) to model retractable landing gear and answer questions about hydraulic systems.

LESSON PREPARATION

MATERIALS/RESOURCES

- Hydraulics and Landing Gear Presentation
- Hydraulics and Landing Gear Student Activity 1
- Hydraulics and Landing Gear Student Activity 2
- Hydraulics and Landing Gear Student Activity 3
- Hydraulics and Landing Gear Teacher Notes 1
- Hydraulics and Landing Gear Teacher Notes 2
- Hydraulics and Landing Gear Teacher Notes 3

Syringe Hydraulics Activity (per group)

- 2 plastic syringes
- Plastic tubing of a size to fit snugly on the syringe nozzle
- Colored water

Build a Hydraulic System Activity (per group)

- 2 plastic syringes
- Plastic tubing of a size to fit snugly on the syringe nozzle
- Colored water
- Cardboard
- 8 thick popsicle sticks
- 8 small dowel rods
- 16 beads that fit on the dowel rods
- 8 plastic straws, cut down to fit
- Needle or drill
- Hot glue gun and glue sticks
- Scissors

Hydraulic Car Jack Demonstration (Optional)

- Hydraulic car jack
- Something heavy to lift (cinder blocks or a box of books)

Recommended Student Reading

- **Pilot's Handbook of Aeronautical Knowledge**
  Chapter Seven, Sections on Hydraulic Systems and Landing Gear https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/09_phak_ch7.pdf

LESSON SUMMARY

Lesson 1: Fuel Systems
Lesson 2: Heating and Electrical Systems
Lesson 3: Hydraulics and Landing Gear

In a warm-up activity, students will use the example of a squirt gun to describe how a fluid travels when pressure is applied. The lesson proceeds with a discussion of what hydraulics are and how hydraulic systems operate. In small groups, students will research and describe the mechanical advantage of a simple hydraulic system.

To finish the first session of the lesson, students will use syringes to model a hydraulic system.

The lesson then presents the main components of a hydraulic system, their function(s), and how hydraulics are used in aircraft systems. Students will have an opportunity to draw and label a simple hydraulic system using the components they just learned about. At the end of the first session, students will explore how a hydraulic car jack operates and is able to allow a person to lift a car.

In the third session, students will learn about the different types of landing gear as well as their advantages and disadvantages. Although not all landing gear systems require hydraulics, the instructor should help the student to correlate the usage. During this session, students will also learn about braking.

Finally, students build a simple hydraulic system to model landing gear.

BACKGROUND

The concepts and use of hydraulics date back to the 1600s. Hydraulic power can also be viewed as "fluid power." Hydraulics utilize the non-compressibility of liquid combined with pressure to develop power. Pascal's Law ("pressure exerted anywhere in a confined incompressible fluid is transmitted equally in all directions throughout the fluid such that the pressure variations (initial differences) remain the same") is the foundation for why and how hydraulics operate. A hydraulic system allows a minimal amount of work or force to be applied to accomplish a movement to operate a system or component that requires significantly more force to operate. If familiar with how a pulley system reduces the work required to lift an object, hydraulics use liquid force to achieve similar results.

MISCONCEPTIONS

Students may assume that hydraulics are used only in heavy industries, such as construction, manufacturing, and mining. However, hydraulics can be found in many everyday applications, such as to control door closers, car jacks, and aircraft.

Students may assume hydraulics only utilize water, based on the root word. While primitive hydraulic systems did utilize water, modern hydraulic systems use hydraulic fluids, which are comprised of oils that help add viscosity (or thickness) to maintain seals. Modern fluids are also developed to prevent evaporation, combustibility, and freezing.

DIFFERENTIATION

To support students' memory and recall, have them create a graphic organizer for the beginning of the second session in the **EXPLORE** section of the lesson plan. Within this graphic organizer, students will want to fold a sheet of paper in thirds, creating three columns. In the first column, have students write the different types of landing gear, leaving a few lines between each type. In the second column, have them write the heading "Notes" at the top. Then in the third column, have them write the word "Questions" at the top.

To support struggling students, have them work in small groups or as pairs for the formative assessments located in the **EXPLAIN** section. You may also want to allow students to use the notes they've created (see above). These additional supports can help improve student motivation and engagement.

LEARNING PLAN

ENGAGE

Teacher Material: Hydraulics and Landing Gear Presentation

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

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

Warm-Up

To activate prior knowledge about fluids, ask students to divide into pairs and discuss the following question:

- How does a squirt gun expel fluid at a high pressure?
  Possible response includes: Squeezing the triggers moves a piston which forces water out of the squirt gun.

Give students a few minutes to discuss, and then elicit responses from student volunteers.

Then, ask students to predict how the features of a squirt gun relate to a hydraulic system. Point out the features of the squirt gun that will later correlate to a hydraulic system.

- *There is a trigger lever, which activates a small pump.*
- *This pump is attached to a plastic tube that draws water from the bottom of the reservoir.*
- *The pump forces this water down a narrow barrel and out a small hole at the gun's muzzle.*
- *The hole, or nozzle, focuses the flowing water into a concentrated stream.*
- *The main moving element is a piston, housed inside a cylinder. Inside the cylinder is a small spring. To operate the pump, you pull the trigger back, pushing the piston into the cylinder. This compresses the spring, causing it to push the piston back out of the cylinder when you release the trigger.*

[DOK-L2; *describe*]

EXPLORE

Teacher Materials: Hydraulics and Landing Gear Presentation, Hydraulics and Landing Gear Teacher Notes 1
Student Material: Hydraulics and Landing Gear Student Activity 1

Slide 5: Introduce the meaning of the word *hydraulics* and discuss Blaise Pascal, the inventor of the syringe and hydraulic press (both of which use hydraulic forces).

Teaching Tips

Ask students to predict what they will learn in this lesson, based on what they have learned about Blaise Pascal in their science classes.

Slide 6: Introduce Pascal's Law. Pascal's law states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container.

Use the following video to explain Pascal's Law. While showing the video discuss how the force on the smaller portion of the tube will raise the larger portion, as fluid cannot be compressed and has to force the larger (heavier side) up.

Use the example of a U-tube to describe the law. If a U-tube is filled with fluid and pistons are placed at each end, pressure exerted against the left piston will be transmitted throughout the liquid and against the bottom of the right piston. (The pistons are simply "plugs" that can slide freely but snugly inside the tube.) The pressure that the left piston exerts against the fluid will be exactly equal to the pressure the water exerts against the right piston. Suppose the tube on the right side is made wider and a piston of a larger area is used; for example, the piston on the right has 50 times the area of the piston on the left. If a 1 Newton load is placed on the left piston, an additional pressure due to the weight of the load is transmitted throughout the liquid and up against the larger piston. The difference between force and pressure is important: the additional pressure is exerted against the entire area of the larger piston. Since there is 50 times the area, 50 times as much force is exerted on the larger piston. Thus, the larger piston will support a 50 Newton load - fifty times the load on the smaller piston.

- “Application of Pascal’s Law” (Length 4:44)
  https://video.link/w/EAFh

Slide 7: Provide a basic overview of hydraulic systems. Unlike gases, which can be compressed into a container, fluids cannot be compressed, and thus the transfer of the fluid provides control of the components attached to the device. Solids are also non-compressible, but they cannot be easily transferred.

Slide 8: Machines help people do things that they normally couldn’t do on their own. This is called a mechanical advantage. A machine makes work easier by increasing the amount of force that is exerted on an object. This produces a mechanical advantage, which is the amount of force that is multiplied by the machine. The force applied to the machine is the input force. The force that is applied to the object (by the machine) is the output force.

Split students into small groups and ask them to research and describe the mechanical advantage of a simple hydraulic system.

Questions

Research and describe the mechanical advantage of a simple hydraulic system.

In hydraulic systems, the pressure is created using a piston. The input piston is used to apply force to the fluid, which creates pressure in the fluid. The fluid transfers this pressure to the output piston. This pressure exerts a force on the output piston and the result is a mechanical advantage that makes the hydraulic system very useful. The mechanical advantage in a hydraulic system comes from the fluid pressure in the system.

The reason for the large mechanical advantage in a hydraulic system is the ability of the fluid to transmit pressure equally. It allows for the use a small force on the small piston to produce a larger force on the large piston. From Pascal’s law, we know that the pressure the small piston creates is the same everywhere in the fluid. So, the large piston has a larger area and is able to multiply the pressure because of its larger area.

Slide 9: Once students have described the mechanical advantage of a hydraulic systems, review the advantages of a hydraulic system.

- Smaller machinery can accommodate larger loads, similar to how a car jack can lift the weight of a car.
- It is one system for multiple functions; most hydraulic pumps can operate several subsystems. In the CH-47 “Chinook” helicopter, for example, a single hydraulic system operates the steering wheel, wheel swivel locks, the rescue hoist, a cargo hook, the aft ramp, and the starting of the Auxiliary Power Unit (APU). It also provides limited operation of the flight controls in an emergency.
- It is easy to control and has a simple design; it is generally operated by a single switch or valve that controls the intended subsystem.

- Torque remains constant with variable operation speeds. The available power remains constant, but the operator can normally control the system as needed. For instance, when applying toe brakes, the operator's foot pressure controls how tight the squeeze is of the brake onto the rotor.
- It works well in hazardous environments. The closed system and chemistry of the hydraulic fluid prevents exposure to the atmosphere.

Slide 10: As an optional demonstration, borrow a hydraulic car jack and use the jack to lift something heavy, such as a box of books or a cinder block. Ask students to explain how the car jack works and why a person is able to lift a vehicle with minimal effort.

Slide 11: In this activity, students will use syringes to model a hydraulic system. The necessary materials and instructions for this activity are provided in **Hydraulics and Landing Gear Student Activity 1** and **Hydraulics and Landing Gear Teacher Notes 1**.

This activity will complete the first day of this lesson.

EXPLAIN

Teacher Material: Hydraulics and Landing Gear Presentation

Slide 12: First, introduce the list of parts in a hydraulic system. Describe and point to each part of a hydraulic system on the diagram.

Then, proceed through the slides to explain and show examples of each part in more detail.

Slide 13: Hydraulic fluid is the conduit which transmits power to the intended subsystem. While its primary function is to convey power, there are other important functions of hydraulic fluid such as protection of the hydraulic machine components. It is the lifeblood of a hydraulic system. Fluids are developed based on the intended operational environment. A fluid that may work on car brakes on the ground will not work the same on aircraft brakes that are subjected to sub-arctic temperatures.

A mineral based fluid is most commonly used in small aircraft. It has good lubricating properties and prevents corrosion. It has very little viscosity change with a change in temperature. The "thickness" of a fluid, or its viscosity, determines how much internal friction a fluid has. For example, water has a low viscosity, and tar has a high viscosity. Viscosity is a critical property of hydraulic oil, as it affects the performance and efficiency of the system. Determining the right fluid viscosity is a balancing act. As oil temperature rises, viscosity drops and it flows more easily—to a point. If the oil gets too thin, volumetric efficiency suffers and the system becomes less responsive and can lead to overheating, high wear and shorter component life. At the other extreme, if fluid viscosity is too high, mechanical efficiency is low and that leads to friction during startup, sluggish operation and, in the worst case, cavitation and mechanical failure. (Cavitation occurs when bubbles form in the hydraulic fluid. This can have detrimental effects on a hydraulic pump.)

Discuss why hydraulic fluid must be chemically stable and cannot deteriorate over time or during exposure to various temperatures. Finally, discuss fire and flash points, and make sure students understand what each means and why they are important. The fire point is the temperature where vapor can ignite and continuously burn when exposed to spark or flame. The flash point is the temperature where vapor can momentarily ignite when exposed to spark or flame.

Slide 14: The hydraulic reservoir stores non-pressurized hydraulic fluid to power the system, including a reserve to cover any losses from minor leakage and evaporation. The reservoir can be designed to provide space for fluid expansion, permit air entrained in the fluid to escape, and to help cool the fluid. The metal walls of the reservoir cool the fluid by allowing heat to escape. The reservoir is also where the hydraulic fluid can be serviced via the filler assembly. Some means of checking the fluid level is usually provided on a reservoir. This may be a glass or plastic sight gauge, a tube, or a dipstick.

Slide 15: Hydraulic pumps transfer the fluid from the reservoir to the hydraulic system. This transfer raises the energy level of the fluid by increasing its pressure. The pump may be engine-driven, electricity-driven, or even operated by hand. Hand pumps are usually used as backup systems for emergencies or to help re-pressurize a system after adding fluid should a leak occurs or following maintenance.

Slide 16: A selector valve is used to control the direction of movement of a hydraulic actuating cylinder or similar device. It provides for the simultaneous flow of hydraulic fluid both into and out of the unit. Hydraulic system pressure can be routed with the selector valve to operate the unit in either direction and a corresponding return path for the fluid to the reservoir is provided. Directing the flow of hydraulic fluid is necessary for operations such as the retraction and extension of landing gear, where fluid must flow in one direction to pull up the gear, and the opposite direction to extend the gear.

Slide 17: A hydraulic actuator consists of a cylinder or fluid motor that uses hydraulic power to facilitate mechanical operation. Because liquids are nearly impossible to compress, a hydraulic actuator can exert considerable force. The hydraulic cylinder consists of a hollow cylindrical tube along which a piston can slide. Consider using this video to show how a hydraulic actuator works.

- "How Do Hydraulic Actuators Work?" (Length 2:05)
  https://video.link/w/REVg

Slide 18: The filter is a screen or strainer that helps to clean the hydraulic fluid and removes contaminants from the system. Impending fluid bypass is normally identified by a button that pops up on the filter container as pressure builds to a pre-set setting. If the filter is not changed, the relief valve will be activated to allow for continued operation; however, the fluid will bypass the filter and contaminants could enter the system.

Slide 19: A relief valve is associated with the filter assembly. When fluid pressure exceeds a set pressure, the relief valve opens to reduce pressure and routes fluid back to the reservoir. This normally occurs when the filter becomes contaminated or plugged.

Slide 20: As a review, show students this video that describes a simple aviation hydraulic system. To complete this session, ask students to draw and label a simple hydraulic system using the components they just learned about. Ensure that each student includes a short description describing what each component does.

- "Aircraft Systems - Hydraulic Systems" (Length 1:40)
  https://www.youtube.com/watch?v=M1UddxRAjbc

EXTEND

Teacher Materials: **Hydraulics and Landing Gear Presentation**, **Hydraulics and Landing Gear Teacher Notes 2**
Student Material: **Hydraulics and Landing Gear Student Activity 2**

Slide 21: To begin the third session, use this slide to begin the transition to apply what the students have learned about hydraulics to their application in aviation.

Questions

Ask students to predict which systems are hydraulically operated in an aircraft.

Responses should include flight controls, flaps, spoilers, wheel brakes, air brakes, steering wheels, and landing gear. Additional components like hoists, cargo winches, cargo doors, and cargo hooks may also be mentioned.

Slide 22: Use this video to provide a short overview of hydraulic systems on a Boeing 737.

- "Boeing 737 Hydraulics" (Length 1:35)
  https://video.link/w/pDVg

Slide 23: Use this diagram to review all of the components that are hydraulically operated (from left to right): nose landing gear, clamshell thrust reverser, variable pitch prop, flaps and spoilers.

Slide 24: In the next few slides, students will compare the advantages of different types of landing gear systems and learn about wheel brakes.

Briefly introduce different types of landing gear. Students were first introduced to landing gear in the last semester, so they should be familiar with many of these terms.

Fixed vs. Retractable Landing Gear:

- Fixed gear is hard mounted and remains down in landing configuration during flight.
- Retractable gear uses hydraulics, electrical motors, or a hand operated mechanism to pull landing gear into the aircraft during flight.

Tricycle vs. Tailwheel Fixed Gear:

- Tricycle gear places a single nose gear on the front of the aircraft and two main gear under the center of the aircraft.
- Tailwheel gear place the main gear towards the front of the aircraft and a smaller wheel under the tail.

Skis, Floats, Helicopter Gear:

- Skis allow for landing on snow.
- Floats allow for landing on water. More complex systems include wheels so landing on hard surfaces can also be achieved.
- Helicopter gear includes skids (undercarriage with flat bars) and/or wheels. Some wheeled helicopters can also be equipped with skis for snow operations. Floats are also available in lieu of skids.

Slide 25: Tricycle landing gear has a single gear under nose and the main gear under the center of the fuselage. This is the most common landing gear style on modern aircraft. It allows for more forceful operation of brakes and improved visibility during ground operations. It also provides directional stability due to center of gravity (CG) being forward of aft wheels.

Slide 26: Tailwheels place the main gear towards the front of the aircraft and a smaller wheel under the tail. This configuration provides the ability to land on shorter runways and provides greater prop clearance for unimproved surfaces.

Review the main advantages and disadvantages of tailwheel landing gear.

Pros

- Allows for more ground clearance of propeller
- Shorter roll after landing
- Desirable for unimproved landing surfaces

Cons

- Directional control difficult due to center of gravity (CG) being behind main gear
- Limited visibility during ground taxi

Slide 27: Review the main advantages and disadvantages of fixed versus retractable landing gear. Ask students to identify which characteristics are pros and which are cons.

Retractable

- Less drag = higher speed (pro)
- More maintenance = higher cost (con)
- Possibility of gear up landing due to inoperative equipment or human error (con)

Fixed

- Always extended (pro and con)
- Creates more drag (con)
- Low maintenance = lower cost (con)

View this short video to show the extension of retractable landing gear.

- "747 Retractable Landing Gear Deployment" (Length: 0:51)
  https://video.link/w/1qjh

Slide 28: Explain to students that they will briefly learn about wheel brakes. Describe the main characteristics of wheel brakes. An aircraft's wheel brakes are similar to car brakes or disc brakes on a mountain bike. An aircraft's disc brakes are located on main gear wheels. The braking mechanism is controlled by hand or foot pedals. Foot pedals work similar to a car's brakes. However, foot pedals allow for differential braking to help steer the airplane on the ground. The right pedal controls the right brake, and the left pedal controls the left brake.

Acknowledge that aircraft have multiple other braking systems so it is important to specify this is only about wheel brakes. Other brakes includes air brakes and thrust reversers, for example. Thrust reversers slow the aircraft by diverting engine thrust forward after landing to slow aircraft. Air brakes or speed brakes create drag on an aircraft to slow an airplane down in flight.

Slide 29: Use these photographs to introduce another type of fixed landing gear: skis and floats. This landing gear is designed for landing on water or snow, but may also have wheels for ground landings.

Slide 30: Use these photographs to explain that helicopters can have fixed landing gear with skids or wheels.

Slide 31: Review the advantages and disadvantages of skids for a helicopter's landing gear.

Pros - Skids are generally lighter and cheaper than a wheeled gear and thus require less maintenance. Skid "skins" are often strapped to the bottom of the skids to protect the skid. Skids work well on unimproved surfaces, or areas covered in snow as they effectively distribute the aircraft's weight better than wheels.

Cons - Powered ground taxi is not an option, so hover taxi is required, potentially creating rotor wash problems for objects or people in the vicinity of the aircraft. When the aircraft is not running, it must be moved by attaching ground handling wheels or by landing on a wheeled dolly.

Slide 32: Review the advantages and disadvantages of wheels for a helicopter's landing gear.

Pros - Wheeled landing gear on helicopters allows for ground taxiing while powered and simplifies towing of an aircraft. If retractable, this reduces drag and allows for increased airspeed.

Cons - Wheeled gear is often heavier than skids and requires more maintenance. Wheeled gear does not perform as well on unimproved surfaces, as the aircraft's weight is not as evenly distributed. In snowy conditions, wheeled landing gear may be outfitted with skis to prevent sinking into the snow.

Slide 33: Complete the **Formative Assessment**.

Formative Assessment

Distribute a copy of **Hydraulics and Landing Gear Student Activity 2** to each student. In this activity, students will identify the type of landing gear for each aircraft shown, including as many details as possible, and then explain the advantages and disadvantages of each type.

Correct responses are provided in **Hydraulics and Landing Gear Teacher Notes 2**.

[DOK-L2; *compare*]

EVALUATE

Teacher Materials: Hydraulics and Landing Gear Presentation, Hydraulics and Landing Gear Teacher Notes 3
Student Material: Hydraulics and Landing Gear Student Activity 3

Slide 34: Conduct the **Summative Assessment**.

Summative Assessment

Divide the class into small groups, depending on the amount of materials available, and distribute a copy of **Hydraulics and Landing Gear Student Activity 3**. If short on time, consider preparing the popsicles sticks before class by following steps 1 through 9, so that students begin with step 10. Once students have completed the assembly and experimented with the hydraulic system, direct them to answer the questions at the end.

Possible correct responses and detailed instructions are also provided in **Hydraulics and Landing Gear Teacher Notes 3**.

[DOK-L4; *create*]

Summative Assessment Scoring Rubric

- Follows assembly instructions
- Models and answers to questions show evidence of one or more of the following:
  - Understanding of Pascal’s Law
  - Thorough explanation of how a hydraulic system could be made more powerful
- Contributions show understanding of course of the concepts covered in the lesson
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 Follows the procedure correctly to assemble the Scissor Lift and the Hydraulic System. Answers the questions in a way that reflects full understanding of the activity and lesson objectives.

7-8 There are minor errors in the assembly of the Scissor Lift and the Hydraulic System. Answers the questions in a way that reflects a sufficient understanding of the activity and lesson objectives.

5-6 There are many errors in the assembly of the Scissor Lift and the Hydraulic System and did not follow the procedure as outlined in the activity sheet. Answers to questions show gaps in understanding of the activity and lesson objectives.

0-4 The procedure to assemble the Scissor Lift and the Hydraulic System was not followed. Answers to questions show little or no understanding of the activity and lesson objectives.

GOING FURTHER

If the classroom simulator is capable, have students encounter a hydraulic system failure while operating the simulator. This could be a failure for the landing gear to lower, failure of flaps, etc. The students should be able to identify the failure, complete the emergency procedure per the aircraft's operator's manual, and be able to articulate reasons why the failure may have occurred. If time permits, introduce additional hydraulic emergency procedures, such as low hydraulic pressure and hydraulic fluid over temp.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS3-3** - Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy
  - Science and Engineering Practices
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - PS3.A: Definitions of Energy
    - ETS1.A: Defining and Delimiting Engineering Problems
  - Crosscutting Concepts
    - Cause and Effect
    - Systems and System Models
    - Energy and Matter
- **HS-ETS1-2** - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering
  - Science and Engineering Practices

        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.C: Optimizing the Design Solution
    - Crosscutting Concepts
        - None
- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
    - Science and Engineering Practices
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.B: Developing Possible Solutions
    - Crosscutting Concepts
        - None

COMMON CORE STATE STANDARDS

- **RST.9-10.3** - Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.
- **RST.9-10.4** - Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.
- **WHST.9-10.2** - Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

REFERENCES

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