The Power Cycle - Combustion and Exhaust

Session Time: Four, 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)

Innovations in aviation are driven by the desire to make aircraft safer, more capable, and more efficient. (EU3)

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

ESSENTIAL QUESTIONS

1. How does an aircraft develop power?
2. How does an aircraft engine stay cool?
3. How do engine-related systems work together to ensure smooth operation?

LEARNING GOALS

Students Will Know

- How engines produce power
- How engines are cooled
- How to detect an ignition fault using a magneto check
- Why oil and cooling systems are an essential part of an engine
- Common problems with combustion

Students Will Be Able To

- *Describe* multiple ways to start an aircraft engine. (DOK-L2)
- *Construct* a video or storyboard that educates pilots on proper engine management procedures. (DOK-L4)
- *Explain* how an airplane engine is cooled. (DOK-L3)
- *Describe* the causes and consequences of abnormal combustion. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students watch two videos of Topfuel dragsters and answer guiding questions about temperatures and pressures created during combustion and make inferences about features an engine must have to handle the fire and heat.

Formative Assessment
In small groups, students will use Internet research and complete a graphic organizer to learn about detonation and pre-ignition.

Students construct a very simple heat exchanger and observe which cools better—air or water. Students answer questions regarding the advantages and disadvantages of air-cooled and liquid-cooled engines.

Summative Assessment
Students play the role of AOPA Air Safety Institute video producers that are working to reduce the general aviation accident rate. Students must create a video-based outreach message on one of three accident trends to grab the attention and educate pilots on proper engine management procedures.

LESSON PREPARATION

MATERIALS/RESOURCES

- The Power Cycle - Combustion and Exhaust Presentation
- The Power Cycle - Combustion and Exhaust Student Activity 1
- The Power Cycle - Combustion and Exhaust Student Activity 2
- The Power Cycle - Combustion and Exhaust Student Activity 3
- The Power Cycle - Combustion and Exhaust Teacher Notes 1

Air or Water? Activity (per group)

- Two small cups
- Two large cups (such that the small cups fit into the larger ones)
- Hot water
- Water at room temperature (may dye with food coloring)
- Two thermometers
- Stopwatch

Recommended Student Reading

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

LESSON SUMMARY

Lesson 1 - Reciprocating Engines
Lesson 2 - Propellers
Lesson 3 - The Power Cycle - Intake Systems
Lesson 4 - The Power Cycle - Combustion and Exhaust
Lesson 5 - Turbochargers and Superchargers

To begin this four-session lesson, students will watch two videos of Topfuel dragsters and answer guiding questions about temperatures and pressures created during combustion and make inferences about features an engine must have to handle the fire and heat.

During a class discussion, students will learn about how an airplane engine starts, components of an airplane's ignition system, and the importance of built-in redundancies.

In the second session, students will learn about normal and abnormal combustion. They will use Internet research and complete a graphic organizer to learn specifically about detonation and pre-ignition. The third session of this lesson explores the oil system and the essential functions it performs. They will also discuss cooling systems and construct a very simple heat exchanger and observe which cools better—air or water. Students answer questions regarding the advantages and disadvantages of air-cooled and liquid-cooled engines.

In the last session, students will learn that the final part of the power cycle—exhaust—is to vent the gases produced in combustion to the outside and make room for new fuel and air to be introduced into the cylinders for combustion. As a summative assessment, students play the role of AOPA Air Safety Institute video producers that are working to reduce the general aviation accident rate. Students must create a video-based outreach message on one of three accident trends to grab the attention of and educate pilots on proper engine management procedures.

BACKGROUND

Airplanes require thrust to fly. The development of this thrust can be achieved in a variety of ways, most notably in light general aviation aircraft by the use of internal combustion engines similar to the type used in most cars and trucks today. An understanding of the basic components and functions of an internal combustion aircraft engine is a fundamental requirement of any flight training program.

Students learned about the four-cycle process of an internal combustion engine in the first lesson of this unit; intake, compression, power (combustion), and exhaust. In this lesson, students will focus on the components and systems related to combustion and exhaust.

The ignition system provides the electrical current that feeds the spark to each cylinder needed to ignite the fuel. The ignition system of the engine is completely separate from the airplane's electrical system. The magneto type ignition system is used on most reciprocating aircraft engines. Magnetos are engine-driven, self-contained units supplying electrical current without using an external source of electricity. However, before they can produce current, the magnetos must be actuated as the engine crankshaft is rotated by some other means. To accomplish this, the aircraft battery furnishes electrical power to operate a starter, which through a series of gears, rotates the engine crankshaft. This in turn actuates the armature of the magneto to produce the sparks for ignition of the fuel in each cylinder. After the engine starts, the starter system is disengaged, and the battery no longer contributes to the actual operation of the engine. Modern airplane engines have a dual ignition system; that is, two separate magnetos supply the electric current to the two spark plugs contained in each cylinder.

The oil system supplies lubrication to the moving parts, keeping them cool and preventing excessive friction and metal expansion that could cause engine failure. Reciprocating engines use either a wet-sump or a dry-sump oil system.

Combustion produces considerable heat. This heat is controlled by the cooling system, responsible for maintaining proper engine temperature. Although oil systems help reduce internal engine temperatures, without additional cooling, the engine would overheat. Most commonly, piston aircraft engines utilize air cooling, although some may also utilize a liquid cooling system.

Engine exhaust is the byproduct of combustion and must be routed away from the engine. The exhaust system is made up of a series of pipes attached to the cylinders. A muffler and muffler shroud allow engine exhaust to heat outside air in order to provide heat for the cabin and windscreen defrost.

In order for normal combustion to occur, a pilot must carefully regulate the relative amounts of air and fuel that go into the cylinders, using only the proper grades of fuel, and maintain the aircraft so it performs as intended by the manufacturers. Recent developments in electronic engine controls have made it possible to regulate engine function automatically to within tolerances difficult to achieve through human control alone.

MISCONCEPTIONS

A common misconception is that airplane engines are more advanced than car engines. In most cases, the opposite is true. Aircraft engines must be reliable. When a car engine stops, you can simply pull off the road. Aircraft don't have that luxury. The need for reliability slows innovation in aircraft engines since all innovation comes with risk.

Another factor impeding innovation in aircraft engines is the need for certification. An automobile manufacturer can redesign an engine with practically no government involvement. Any change in aircraft engine design means a lengthy and costly approval process by the FAA. All of those costs must be shared over a small number of airplanes instead of the tens of thousands or even millions of automobile engines that would be produced.

Due to the cost of change and reluctance to change something that works already, a typical car engine has more advanced features than an aircraft engine.

DIFFERENTIATION

To help students comprehend technical systems knowledge and to encourage them to shape and inform each other's understanding of readings, organize students into learning circles and ask them to read pages 7-15 through 7-19 of Chapter Seven, Aircraft Systems of the Pilot's Handbook of Aeronautical Knowledge.
https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/09_phak_ch7.pdf

LEARNING PLAN

ENGAGE

Teacher Material: The Power Cycle - Combustion and Exhaust Presentation

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

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

Warm-Up

Have students watch two videos of Topfuel dragsters and answer the guiding questions on the slide. They should note the flames coming out of the exhaust stacks and conclude that there is fire inside the engines, as well. They may also conclude that a large amount of heat and pressure is being created inside the engine. Students might hypothesize that engines include features like fireproof and heat resistant parts, cooling systems to dissipate heat, air intake systems, etc.

Tell students the process of combustion produces intense heat. Explain to them that throughout this lesson, they will learn various ways in which aircraft engines are cooled in order to prevent the loss of power, excessive oil consumption, and serious engine damage.

- "Topfuel Dragster" (Length 00:36)
  http://video.link/w/g8sg
- "Topfuel Dragster Slow Motion" (Length 1:54)
  http://video.link/w/Gftg

[DOK-L2; *make observations, infer*]

EXPLORE

Teacher Material: The Power Cycle - Combustion and Exhaust Presentation

Slide 5: Remind students they have already learned about the four-stroke cycle (intake, compression, power or combustion, exhaust) in the first lesson of this unit. During the power stroke, engines use fuel, air, and an ignition source (often sparks from spark plugs) to create a powerful combustion process.

Explain that, in order to start that process, engines need an outside source of power to initiate what becomes a self-perpetuating four-stroke cycle. Something needs to get the engine turning over at the beginning.

The function of the starter system is to provide the initial turning motion (the rotational force) necessary to begin the engine's four-stroke cycle. The system consists of several parts:

- Source of electrical power - The power to run the starter motor can come from either a battery or external power source, like a jumper or power cart. Most general aviation aircraft rely on batteries to turn the starter motor.
- Ignition switch - The starter motor is turned on from inside the cockpit by a switch or key, like a car. When turned on, the switch sends an electric signal via wires to the starter motor. Keyed ignition switches in general aviation normally feature five positions: Off, Right, Left, Both, and Start.
- Electric starter motor - The heart of the starting system is the starter motor itself. The starter motor turns an internal shaft when supplied with electric power from the battery or other source. At the end of this shaft is a gear called a 'drive pinion.' It is this drive pinion that engages and turns the engine's flywheel to begin the starting process.

Slide 6: Explain that airplane engines start in much the same way as cars. Airplanes usually start with a key in an ignition switch, and like a car, turning the key begins a series of activities within the starting system.

In general aviation airplanes, the key switch has five positions: Off, Right, Left, Both, Start. When the pilot turns the key to the "Start" position or pushes the start button in the cockpit, an electrical signal is sent from the battery to the starter. Now that the starter has power, it turns an internal shaft that has a gear on the end of it. The gear connects with the engine's flywheel which then turns the engine's crankshaft which causes the pistons to move up and down in the cylinders.

This 'turning over' of the engine energizes the magnetos, which begin sending electrical current to the spark plugs. The spark plugs ignite the fuel-air mixture in the cylinders, causing the engine to start.

Once the engine starts, the pilot sets the key back to "Both" or stops pushing on the start button, which turns off the starter. The gear on the end of the internal starter shaft disengages from the flywheel and the starter motor stops turning.

Show students a simple video of an aircraft engine start sequence. Ask students to point out the starter, internal starter shaft with gear, and the flywheel.

- "How It Works - Aircraft Starter" (Length 00:39)
  http://video.link/w/SYsg

Slide 7: Have students recall that one part of the starting system is the electrical power source. On most general aviation airplanes this is a battery similar to those found in cars and trucks. Explain that most of the time these batteries are located on the airplane, but sometimes they can be in the form of an external power source. Wherever the battery is located, its function is to provide power to the starter motor to begin the starting sequence.

Airplane batteries are usually located in the engine compartment, but can also be found under a seat in the cockpit or even behind the seat near the rear of the airplane. External power sources are always outside the airplane, and are used only for starting and are then removed. Sometimes, at airports, these external sources, known as ground power units (GPUs), are found in mobile carts that are wheeled out to the airplane to help start it. They consist of powerful batteries that provide electrical current to the airplane through a cable that connects to a special port on the outside of the airplane.

Once the engine starts, there is no longer a need for the battery to provide power to the starter. With the engine running, the magnetos now provide all the electrical current the spark plugs need to ignite the fuel-air mixture, so the batteries are only needed for the lights, instruments, and radios in the airplane.

Slide 8: Explain that another way to start an airplane is to manually turn the propeller. This is commonly called "hand propping."

This method is common with airplanes that do not have an electrical system, such as many older airplanes and some newer experimental designs. It is also used on smaller general aviation airplanes when they have a dead battery.

In this method, a person takes the place of the starter motor and turns the propeller by carefully pushing down rapidly on the downward blade, causing the engine to turn over much the same way as would occur with an electric starter. The process of pushing down on the propeller is often called "pulling the propeller through."

This method requires careful coordination between the pilot and the person pulling the propeller through. For example, the pilot must turn on the magnetos so that they are capable of generating spark once the engine is turned over. Also, the person pushing the propeller through must communicate clearly with the person in the cockpit when they are ready to begin so no one is surprised when the engine starts.

Show students a video of a pilot hand propping an airplane alone. Hand propping an airplane by oneself can be completed safely when all precautions have been taken.

- "Hand Propping for One Person" (Length 00:54)
  http://video.link/w/lttg

Manual starting can be very dangerous if not done properly. Care must be taken by the person pulling the propeller through that they do not lose their balance or fall forward after the engine starts. Many serious and even fatal accidents have occurred as a result of manual starting, but also thousands of airplanes are started every day using this method without incident.

Show students a hand propping mishap video. In this incident, the passenger in the right seat had not been instructed on how to properly hold the brakes during engine start. Show students the first 45 seconds of the video.

- Cirrus SR-22 Hand Propping Accident in Iowa (Length 2:33)
  https://www.youtube.com/watch?v=7KpOg9Ci284

Manually starting an aircraft should always be done very carefully, and always with an assistant, if able. Remind students that nobody should ever try this without extensive training and pilots and others must follow basic safety procedures at all times.

Slide 9: Pilots must be very careful before starting their engine(s). Rapidly rotating propellers, prop blast that scatters debris, and sudden loud noise can create hazards to people nearby. As a result, when starting their engines pilots follow a routine that minimizes the risk to people and property.

1. For airplanes with an electrical system, the rotating beacon is turned on anytime the pilot is in the cockpit with the intent of starting the engine. The presence of this lighted beacon indicates to all in the area that the airplane could start at any time and that they should beware and take precautions.
2. Once the pre-start checklist has been completed and the pilot is ready to start the engine, the pilot will look all around outside the airplane to make sure nobody is nearby, set the parking brake or hold the brakes manually, and open a window and yell 'Clear!' in a loud voice. This is a verbal announcement that the airplane is about to start, and anybody nearby should stand back.
3. Once the engine has started, the pilot will exercise extreme caution while taxiing to not allow the propeller wash to throw rocks or debris onto neighboring aircraft or structures.

Slide 10: Once the engine is rotating, most internal combustion engines use spark plugs to ignite and burn the fuel-air mixture. The spark must be delivered to each cylinder at precisely the right moment to initiate combustion. Timing problems can prevent an engine from running smoothly or cause it to stop.

Slide 11: Because an aircraft can't just "pull over" if it experiences engine trouble, aircraft engines include many redundancies not found in cars. Aircraft engines typically have two spark plugs for each cylinder, so that if one fails the engine will continue to run. This has the added benefit of increased efficiency since it helps burn the fuel-air mixture more completely.

In addition, each of the two spark plugs is powered by a different electrical source, called a magneto. A magneto is a small mechanical generator whose sole purpose is to deliver an electrical impulse to the spark plug. This system means that the engine will keep running even if one magneto fails. In addition, magnetos are separate from the aircraft electrical system. This ensures that the engine will continue to run even if the battery is depleted and the alternator fails.

Slide 12: Two magnetos are attached to, and driven by, the airplane's engine. The magnetos are attached to the back side of the engine and are about the size of a grapefruit. They are usually painted black, and the spark plug wires come out of each magneto and go to their respective plugs.

As the engine runs, it causes the magneto shaft to rotate and pass magnets along coils of wire. Passing a magnetic field along wires creates an electrical current. The electricity generated by these magnets rotating around wire coils is distributed to the spark plugs. As long as the magneto is intact and rotating, it will produce electricity for the spark plugs.

It is vital that the magnetos shoot current to the spark plugs in the cylinders at EXACTLY the right time. If the spark occurs at the wrong time, the engine will run rough, generate less power, and possibly cause damage. Remind students that each magneto provides spark to one spark plug in each cylinder, so if one magneto fails, the engine will continue running with the remaining magneto feeding spark to the other spark plug in each cylinder.

Engineers have designed some magnetos with an 'impulse coupling' to assist with energizing the spark plugs during engine start. Impulse couplings are specialized internal springs which help spin the magnetos quickly enough during start-up to fully power the spark plugs even at low RPM. Tell students that if the magnetos aren't properly turned off and the propeller is turned, the impulse coupling may cause the engine to inadvertently start, causing a very dangerous situation.

A short video provides an overview of magneto function, location on the engine, and reinforces the importance of system redundancy for flight safety.

- "Magnetos - 60 Second Flight Training" (Length 1:36)
  http://video.link/w/voDf

Slide 13: Magnetos can be individually turned on and off by a key or switch inside the cockpit. The "Off" position of the magneto switch is different from that of other electrical switches. The "Off" position of the magneto switch does not actually remove electricity from the magneto because the magneto is what makes the electricity. Turning the magneto switch "Off" actually causes a short circuit (called grounding) in the magneto coil that prevents it from working.

Airplane engines are normally operated with the magneto switch turned to "Both", that is, with both mags running. When the switch is turned to "Left" or "Right" (meaning one mag is turned off), the magnetos are still producing electrical current, but one is grounded so its current is not distributed to the spark plugs. This ability to turn one or both magnetos on and off with the turn of a switch is an important safety feature, and enables the simple detection of a possible fault in the system during preflight checks.

Pilots do several inspections and checks before beginning their flight to make sure that everything is working properly and that the flight can be completed safely. Testing the ignition system is an important part of these preflight checks.

The objective of the magneto test is to confirm that both magnetos are functioning properly and will continue to provide current to the spark plugs during flight.

The "mag check" begins with the engine running and the magneto switch or key in the cockpit set to the "Both" position, meaning both magnetos are providing power to both sets of spark plugs. The pilot then advances the throttle to a specified power setting (usually around 1700-1800 RPM), then turns the key or switch to the 'Left' position, which grounds the right magneto so that only one spark plug in each cylinder is firing. The pilot should see a slight reduction in engine RPM on the tachometer inside the airplane. The pilot then turns the key or switch back to 'Both' and notes that the RPM increases back to its original value. He or she then turns the key or switch to 'Right,' which grounds the left magneto and stops current from flowing to its associated set of spark plugs. Again, the pilot sees a slight drop in RPM, then returns the key or switch back to 'Both,' noting the expected rise back to the original RPM value.

While RPM is expected to drop slightly during testing, manufacturers have set a maximum drop value for their magnetos. If the observed drop in RPM is greater than the maximum allowable value for either magneto, there could be a problem with the ignition system and the airplane should not be flown. Likewise, if the difference in mag drop between the two magnetos (e.g. one drops more than the other) exceeds a certain RPM, the airplane should not be flown.

Another test pilots often perform on their magnetos takes place during shutdown. By turning the key or magneto switch all the way to the 'Off' position with the engine running, the engine should quit, since no current is being sent to the spark plugs. If it does not quit, but continues to run even after the switch has been turned to 'Off,' that is an indication that at least one magneto is not grounding and is continuing to send current to the spark plugs. This can be dangerous, as the engine could start just by the pilot or another person pulling on the propeller, sometimes even just slightly, creating an unexpected spinning propeller and possible serious injury. Prop injuries can be deadly, so pilots are careful and diligent about checking that their magnetos are always functioning properly.

Slide 14: End the first session with a quick "exit slip" assessment.

Check student comprehension by asking them to write several sentences in response to the following prompts.

Questions

1. Briefly describe two ways to start an airplane engine.
   Students may answer that using the electric starter system consisting of the battery, ignition switch, starter motor, and flywheel are a convenient way to get the engine moving and running on its own. A pilot can also manually turn the engine to get the engine started using the hand propping method. Hand propping requires specific training, and care must be taken to prevent injury to pilots, bystanders, or the airplane.

2. Describe how an airplane's ignition system has built-in redundancies.
   Students may describe the dual magneto or dual spark plug ignition system that allows an airplane's engine to run even when half of the system is inoperative.

EXPLAIN

Teacher Materials: The Power Cycle - Combustion and Exhaust Presentation, The Power Cycle - Combustion and Exhaust Teacher Notes 1
Student Materials: The Power Cycle - Combustion and Exhaust Student Activity 1, The Power Cycle - Combustion and Exhaust Student Activity 2

Slide 15: In the second session, students will learn more about normal and abnormal combustion.

A key step in the four-stroke cycle is the smooth combustion of the fuel-air mixture during the power stroke. It requires precise timing to coordinate the optimal position of the piston, firing of the spark plug, and the compression of the fuel-air mixture. Normal combustion occurs when the fuel burns in a controlled manner, causing a smooth buildup of temperature and pressure within the cylinder.

In normal combustion, when the spark plugs ignite the fuel-air mixture, the gases expand quickly and provide the maximum amount of force downward against the pistons. This downward force is the power stroke of the four-stroke cycle. The most efficient power stroke occurs with normal combustion.

Normal combustion depends on several factors, including proper fuel for the engine and the correct timing of spark to each cylinder. If the wrong fuel is used, or the timing of the spark is just slightly off, the combustion will not produce the maximum power to the pistons and engine performance will suffer.

Slide 16: Abnormal combustion occurs when the fuel-air mixture is not burned evenly, but instead ignites in an uncontrolled or poorly timed manner.

There are two main types of abnormal combustion: detonation and pre-ignition. Abnormal combustion reduces engine efficiency by failing to burn the fuel-air mixture at the proper time or at the proper temperature. The result is incomplete burning and a loss of performance.

Both detonation and pre-ignition reduce engine efficiency, sometimes dramatically. Poor ignition timing or improperly burned mixtures are incapable of producing maximum power and can result in severe or catastrophic damage to the engine.

Complete the **Formative Assessment**.

Formative Assessment

In small groups, students will use Internet research to learn about detonation and pre-ignition. Provide a copy of **The Power Cycle - Combustion and Exhaust Student Activity 1** and ask students to complete the graphic organizer.

Answers are provided in **The Power Cycle - Combustion and Exhaust Teacher Notes 1** or review slides 17 through 23 with the class, which also provide answers to each of the questions.

[DOK-L1; *summarize*]

Slide 17: Detonation occurs when the fuel is not burned evenly, but rather explodes in the cylinder creating extremely high temperatures and pressures. Compare the pressures exerted on the piston through detonation to hitting the top of the piston hard with a sledgehammer.

Extended periods of detonation can cause severe engine damage, including burned valves, and failed pistons and cylinders. It can also cause engine overheating, power loss, and engine roughness.

Detonation makes a distinct sound in the engine. Known as “knocking” or “pinging,” detonation often sounds like a rattle as the fuel burns unevenly across the combustion chambers. Sometimes the detonation is so mild that it cannot be heard, and often the first sign of a problem is a rough-running engine or loss of power.

Slide 18: The main cause of detonation is the burning of an improper fuel, that is, fuel that is rated lower than that recommended by the manufacturer. For example, if the engine manufacturer specifies using 100LL (low lead) aviation fuel and the engine is running on 80 octane fuel, the result would probably be detonation.

Another cause is by operating the engine at a high power setting (high manifold pressure) with low propeller RPM. Running a mixture that is too lean can also lead to detonation. Recall that leaning the mixture means to reduce the amount of fuel going into the engine to be burned. Lean mixtures tend to run hotter than rich (more fuel) mixtures.

A common cause of detonation is running the engine too long in conditions that do not allow for engine cooling. As students will learn later in the lesson, most airplane engines are cooled by air flowing over the cylinders, normally at high speed while in flight. Low speed conditions, such as idling on the ground, taxiing, or extended steep climbs reduce the airflow over the cylinders and lead to overheating, causing detonation.

In a class discussion, ask students to describe a few things a pilot might do to avoid detonation. Answers are found on the following slide.

Slide 19: The best treatment for detonation is prevention, and pilots can take several steps to ensure that detonation does not endanger the engine.

Using the proper fuel is the first step. Aviation fuel is color-coded so it's easy to determine whether the correct fuel is in the tanks. 100LL fuel is blue, 100 octane is green, and 80 octane is red. Pilots should always confirm that the correct fuel is in the fuel tanks before each flight. A simple check for color can prevent an expensive engine repair.

Keeping the engine cool throughout all phases of flight is another preventive measure. Avoid lengthy steep climbs at low airspeeds; instead, plan to climb at a more shallow angle and higher speed to keep the air flowing over the cylinders. Fuel is a cooling element, so the more fuel in the cylinders the cooler those cylinders will run. If high engine temperature is a concern, avoid leaning the mixture during climbs. Though leaning saves money in gas, it can result in very expensive engine repair if detonation causes damage to pistons and valves. Pilots may also open the cowl flaps to improve circulation in the engine compartment. As students will learn later in the lesson, cowl flaps are small doors located in the bottom of the engine cowling that allow for greater cylinder cooling during takeoff and climb. The pilot operates the flaps by opening and closing them via mechanical or electrical controls in the cockpit.

Slide 20: Pre-ignition is the other major form of abnormal combustion. In pre-ignition, the fuel-air mixture ignites in the combustion chamber BEFORE the spark plug activates.

Pre-ignition can cause major problems with engines. With fuel burning and gases expanding inside the combustion chambers at the wrong time, excessive pressures can develop, especially during the compression stroke when both valves are closed. This excessive pressure can cause severe damage to pistons and connecting rods, sometimes causing engine failure.

A common sign of pre-ignition is power loss. Since the mixture in the cylinders is combusting at the wrong time, the downward push on the piston during the power stroke is weakened. Cylinders that fire with one of the valves partially open also cannot develop the internal pressure needed to push the piston down with maximum force. Running excessively hot, or even overheating, is another common sign of pre-ignition.

Engines that continue to run on for a few moments after being shut down are displaying pre-ignition. The fuel in the cylinders is igniting even though there is no longer a spark being delivered by the magnetos. Engine run-on is often a sign that the engine is being operated improperly, often too rich (too much fuel in the fuel-air mixture).

Slide 21: Pre-ignition is caused by hot spots in the combustion chamber igniting the fuel before the spark reaches the mixture.

Carbon deposits are the most common cause of hot spots, as fuel that is not efficiently burned leaves residue behind to form on the spark plugs and other parts of the combustion chamber. As these deposits build up they can form clumps that are heated by combustion and do not cool down before the next compression cycle occurs. When fuel and air are fed back into the combustion chamber, these hot spots can set it off before the spark arrives, causing an imbalance in the firing of the cylinders.

Hot spots are created in three ways: 1) heat from detonation that results in spark plug tips getting too hot and causing fuel to explode even before the spark reaches the cylinder, 2) carbon deposits building up on spark plugs or in the combustion chamber, usually caused by running too rich a mixture, 3) damaged or cracked spark plug insulators that serve as host to carbon deposits. Pre-ignition occurs when these carbon deposits get so hot they ignite the fuel before the spark arrives.

Ask students to list a few actions pilots could take to avoid pre-ignition. Answers are on the next slide.

Slide 22: The key to preventing pre-ignition is to avoid creating hot spots in the combustion chamber. Maintaining the engine according to the manufacturer's recommended inspection schedule can go a long way toward avoiding pre-ignition. Making sure the spark plugs are removed, cleaned, and inspected on a regular basis can prevent carbon from building up, lessening the risk of hot spots and pre-ignition.

Leaning the mixture during taxi, climb, and cruise flight can reduce the chance of carbon deposits resulting from running a too-rich mixture. Long periods of low power settings, like waiting in line for takeoff, can increase the possibility of developing pre-ignition, so leaning the mixture during extended ground operations can help by reducing carbon residue buildup.

The discussion on detonation and pre-ignition will conclude the second session of the lesson.

Slide 23: The third session of this lesson explores the oil system and the essential functions it performs.

As an attention-getter, set up the background to a video where two hosts of a car show have decided to run an engine at full power while draining the oil from it as an "experiment."

Before viewing, have students predict what might happen to the engine once it is running at full speed and give reasons for their predictions. Students might predict that it will get very hot, catch on fire, seize up, explode, or just stop working.

- "What Happens When You Drain the Oil And Run The Engine to Redline?" (Length 2:28)
  http://video.link/w/xG0g

After viewing the video, have students use their observations to predict the benefits that oil provides to a running engine. Students might answer that oil provides cooling or lubrication as evidenced by the smoke, rising temperature, and fire that eventually started after running without oil.

Slide 24: Oil is the lifeblood of an aircraft engine. Ask students if they know how to check the oil in their car at home, or if they know of anybody who has ever run out of oil in their car.

Oil serves many purposes in an airplane engine. Without oil, or enough oil, the engine will either run poorly or, eventually, quit running altogether.

The oil system serves a variety of functions from basic lubrication to thermal management, contaminant removal, and corrosion protection.

- Lubrication - Perhaps the most obvious function of oil is to provide a slippery surface between the moving parts of an engine. A thin layer of oil on metal surfaces prevents those surfaces from coming into direct contact with each other. The slick, slippery nature of the oil provides a fluid barrier between moving parts to prevent friction and wear.

> **Teaching Tips**
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> As an optional demonstration, have students compare the friction and heat they feel when rubbing their hands together like someone would to warm them in winter, versus performing the same action with lotion or baby oil.

- Cooling - Oil prevents the moving parts of the engine from creating too much friction, which causes heat. By limiting friction, oil helps prevent an engine from overheating. Engines run far cooler when they have enough oil to lubricate the moving parts.

Another way oil cools the engine is by carrying heat away from hot surfaces through circulation. In most airplane engines, a small reservoir at the bottom of the engine holds the oil, which is then pumped up into the engine for lubrication. The oil then returns to the oil reservoir (sump) by gravity. As the oil drips off the hot surfaces on its way back to the sump, it takes heat with it. The more the oil circulates, and the more oil there is, the better job it does of absorbing heat away from the pistons and cylinder walls.

- Sealing - When oil works its way between metal surfaces, it forms a thin membrane between those surfaces and 'seals' them. A prime example of this is the seal that oil forms between the cylinder walls and piston rings. The function of the piston rings is to form a tight seal against the cylinder walls so that the fuel-air mixture above does not leak down and cause the cylinder to lose compression. A thin layer of oil provides that good seal.
- Cleansing - As the oil coats the engine surfaces and drips back down into the sump, it not only carries heat with it, but also dirt and other contaminants. These contaminants may include products of combustion, ash, or carbon —anything that might come to rest within the interior of the engine.

Slide 25: Aircraft engine oil is constantly circulated throughout the engine while it's running. During the circulating cycle, oil is pumped from a storage tank to the parts of the engine that need oil. The oil is then returned to the storage tank, where it starts the cycle over again.

The holding tanks where oil is stored in engines are called reservoirs or, more often, sumps. Oil sumps serve two important purposes: 1) they provide a place for oil to be stored for use by the engine or when the engine is not running, 2) they are the holding tank for oil to cool between uses.

Engines with sumps located at the bottom of the engine itself are known as 'wet sump' designs. Most general aviation airplanes utilize wet sump engines because they are simpler and require less maintenance.

Some airplane engines, however, store oil 'offsite,' that is, in a tank or reservoir located somewhere other than in the engine itself. These engines are referred to as 'dry sump' engines, and require additional oil lines, hoses, and different pump designs to move the oil from the sump to the engine.

Oil is circulated to the internal engine components by an engine-driven oil pump. While the engine is turning, the mechanical pump runs, providing oil and pressure to the system. When an oil pump fails, the flow of oil is greatly reduced or eliminated, resulting in severe overheating due to lack of lubrication and leading to engine damage or catastrophic failure.

Once back in the sump, the oil is allowed to cool before being sent back to the top of the engine again. Many engines have an 'oil cooler,' a small radiator-like device that helps the oil cool even faster. Keeping the oil in the engine at the right temperature is an important function of the oil system.

Slide 26: If oil is doing its job, it should be dirty. Oil suspends dirt, metallic materials, and unburned carbon—contaminants that need to be cleaned from an engine. Aircraft engines use oil screens and filters that catch the contaminants, thereby giving oil a longer useful life before needing to be changed.

Oil screens and filters cannot remove all contaminants, so the oil must be changed at regular intervals to maintain best efficiency. Failing to change the oil can cause metal fragments, grit, dirt, and other contaminants in the oil to create more friction between moving parts, increasing the wear and tear. During oil changes, aviation maintenance technicians not only replace the old oil, but also clean the oil screens and replace the filters.

Slide 27: Oil must be delivered to the engine at the right temperature and pressure. Oil that is too hot or too cool will not perform all of its functions optimally.

Two instruments inside the cockpit, the oil temperature gauge and the oil pressure gauge, provide the information a pilot needs to assess the performance of an engine's oil system.

If the oil temperature is too low, the engine may not develop enough heat to burn the fuel-air mixture most efficiently. The result is a reduction in the amount of power produced by the engine, a potentially critical deficiency during takeoff when maximum power is needed. Pilots are careful to ensure that the engine oil has warmed sufficiently before takeoff to allow for maximum power during this important phase of flight.

If the oil temperature is too high, it could indicate either an insufficient supply of oil in the sump or a problem within the engine that is creating too much friction and heat. High oil temperatures often indicate bearings or other moving parts that are getting ready to fail. High temperatures can damage engines, causing critical metal parts to expand, crack, or fail. High temperatures can also indicate a leak in the oil system allowing oil to escape. Airplanes should not be flown with evidence of oil temperatures running too high or low.

Oil pressure is another critical factor in engine health. Oil pressure that is too low indicates that oil may not be reaching the internal engine parts with sufficient force to lubricate, cool, seal, and cleanse them. This can be caused by a broken or leaking oil line, a deteriorating or failing oil pump, too little oil in the sump, or a failing bearing or other part deep inside the engine. Operating the engine with low oil pressure can lead to major engine damage or even failure.

Oil pressure that is higher than that specified by the manufacturer is another indication of problems within the engine. High oil pressure can be caused by internal component failure or the failure of the pressure relief valve that is built into the engine to relieve oil pressure if it gets too high. As with low oil pressure, engines displaying excessively high oil pressure should not be run until the reason for the pressure increase can be found and remedied.

Slide 28: The purpose of the following video is to educate new pilots on important functions of the oil system in a small aircraft. After watching the video, ask students to answer two questions.

- "Aircraft Systems - Oil System" (Length 2:02)
  https://www.youtube.com/watch?v=cWDCXFwPLIs

Questions

1. What was the most effective point the video producers made about oil systems? Explain your choice.
   Student answers will vary, but they may point out a theme that understanding the oil system helps a pilot more safely operate the aircraft within its design parameters.

2. Based on what you learned about oil systems in this session, what point or topic would you add to the video? Explain your reasoning.
   Student answers will vary, but they may select something like what could happen to an engine when it runs out of oil (e.g., fire, seizing, etc) or the symptoms that an engine gives when the oil system is malfunctioning (e.g., high temperature or pressure readings, reduced power, etc).

Teaching Tips

To help make the next section on cooling more interactive, have the students create a review question on an index card after completing each slide. At the end of the cooling system section, have students form small teams of 3-4 people to answer the questions they created. Each team should work to form consensus answers for each review question and write them down. When all questions are answered, pass the stack of index cards to another team for review.

[DOK-L2; *summarize*]

Slide 29: Although oil systems help reduce internal engine temperatures, without additional cooling, an aircraft engine would overheat. Most commonly, piston aircraft engines utilize air cooling, although some may also utilize a liquid cooling system.

Engines burn fuel and air (combustion) to produce power, and in so doing generate a lot of heat. It is not uncommon for metal temperatures in the engine to reach several hundred degrees Fahrenheit, with the exhaust gases topping 1,000 degrees Fahrenheit. At these temperatures, metals get stressed, can expand and contract, and can crack or fail if the temperatures exceed manufacturer limits. For this reason, engines have cooling systems that are designed to expel much of the heat that comes from combustion and to keep the engine operating at just the right temperature.

Cooling systems are carefully engineered to expel just the right amount of heat without expelling too much. Engines that run too cool cannot generate full power, as the best temperature for combustion is not achieved. A properly functioning cooling system keeps the engine operating at the right temperature—not too hot, and not too cold.

Modern engines are cooled in one of two ways: by air flowing across the cylinders, or by liquid (usually water or special coolant) circulating through the engine.

Slide 30: The easiest and least expensive method is the air-cooled system. In this method, air is brought in from the outside and routed to the cylinders (the primary heat source) where the passage of the air over the cylinders cools them down, much like blowing on hot soup. To increase the efficiency of this method, cylinders are designed with special cooling fins. Heat from the cylinders is dispersed outward to the fins, which dramatically increases the hot surface area exposed to the cooling air. The additional surface area allows for faster cooling.

Most general aviation aircraft engines are of the air-cooled design. Air cooling enables engineers to build lighter weight engines, improving cost efficiency while still producing engines large and powerful enough to meet their mission requirements.

Slide 31: Outside air flowing over the cylinders cools the engine, but certain aircraft structures help route the air to where it is most needed.

Vents in the nose of the aircraft expose the engine to the outside air. In many designs, the engine is exposed to the head-on flow of air as the airplane passes through the air. The faster the airplane goes, the more and faster the air flows over the cylinders. In other designs, the direct exposure to the air is at least partially restricted by a sheet metal cowling; the direct head-on flow of air is replaced by pipes that route the air from the outside to the engine compartment. In both cases, cooling is achieved by untreated air flowing over the cylinders and engine components.

Specially-designed aluminum plates with flexible seals, called 'baffles,' direct incoming air from the vents to specific parts of the engine to concentrate the cooling effect. These baffles are adjustable by technicians, so the air flow can be similarly adjusted to achieve the desired level of cooling. Often, when an engine is starting to show signs of overheating, it is because some of the baffles have slipped from their original position and are directing air either away from the cylinders or toward the wrong part of the engine. In these cases, a minor adjustment of the baffling is all that is needed to solve the problem.

Air-cooled engines are cooled best when the air passing over the cylinders is at high speed, such as during flight. Ground operations, when the airplane is parked with the engine running or taxiing, produce very little airflow over the cylinders. It is at these times that the engine is most prone to overheating. Pilots are trained to monitor engine temperatures during ground operations, and and have several techniques for keeping temperatures under control.

Slide 32: Not all engines are cooled by air flowing over the cylinders; some (not many) airplane engines are cooled by liquid flowing through the engine and cylinders.

Liquid-cooled systems are more complex. In these designs, coolant flowing through hollow channels, or "water jackets" absorbs the heat from the engine. The coolant is then routed to the radiator, where many pipes and small fins dissipate the heat from the coolant into the airflow. The system is closed, and the coolant flows back to the engine to absorb heat to be sent back to the radiator for cooling in a continuous loop.

Liquid cooling is a more effective method for controlling the temperature of an airplane engine (as compared to air cooling), but it requires more complexity than that found in air-cooled designs. The liquid-cooled engine requires a mechanical pump to circulate the liquid through the engine, then back into the radiator. Considerable piping and tubing is necessary, and the system requires more maintenance than that for air-cooled engines. Lastly, all this extra equipment, and the cooling liquid, adds weight to the airplane, a factor that engineers try to minimize when designing aircraft.

Slide 33: Engines that run too hot or too cold can be damaged, and engine and aircraft design help keep the engine running at the correct temperature.

Engines that run too hot can cause excessive oil consumption, detonation, or cracked cylinders or damage to other parts that can cause the engine to quit or produce only partial power. While good cooling system design minimizes the possibility of overheating, it can still occur in circumstances such as steep climbs. Temperatures need to be closely monitored by the pilot.

While overheating is a problem with airplane engines, so is running at temperatures lower than those specified by the manufacturer. Engines that run too cool cannot generate power to their full capacity, as the best temperature for combustion is not achieved. In addition, pilots who undertake rapid descents at low power settings can push too much air over the engine and cool it too quickly, producing 'shock cooling' which can stress metal parts and create cracks in critical engine components, like cylinders.

Slide 34: There are two main gauges inside the cockpit that enable the pilot to monitor engine temperature. The oil temperature gauge indicates the temperature of the oil in the engine. The gauge itself features a green arc and a red line. The green arc represents the normal operating range. As long as the temperature reading remains within the green arc the engine is cooling as designed. The red line, however, represents the overheat or danger level. If the gauge needle touches the red line, the engine should be checked for possible problems.

The cylinder head temperature gauge (CHT) indicates the temperature of the cylinders, a critical factor in controlling temperature and preventing damage. Cylinders that run too hot risk damage or even failure. Cylinders that are too cool, while not dangerous to the engine, will not achieve the temperatures required for efficient combustion.

The pilot can control temperatures somewhat. The easiest way is to increase airspeed. During climbs, the engine is working hard and there is less airflow. If heat becomes a problem, climbing at a shallower angle and faster airspeed will help cool the engine.

Pilots also regulate temperature with the mixture control. By increasing the relative amount of fuel (enriching the mixture), the combustion temperature can be reduced, aiding engine cooling. As students learned earlier, this can also help prevent detonation.

And, as mentioned earlier, cowl flaps help regulate the temperature of the engine by controlling the amount of air flowing over the cylinders and other engine components. With the cowl flaps open, more air is allowed into the engine compartment, aiding in cooling. With the cowl flaps closed, there is less airflow and the engine runs hotter. Typically, pilots will fly with the cowl flaps open during ground operations and while climbing. The cowl flaps are usually closed during cruise, when less airflow for cooling is needed.

Slide 35: In this activity, students observe and record the cooling of water in two conditions—in water and in air. They construct a very simple heat exchanger using cups, with water and air being the heat transfer fluids. They see first hand that water has better heat transferring properties than air.

Divide students into groups of three and provide each with **The Power Cycle - Combustion and Exhaust Student Activity 2**.

Once students have completed their observations, ask them to share their answers to the questions found at the end of the activity. This activity will complete the third session of this lesson.

[DOK-L1; *measure,* DOK-L2; *predict, make observations, infer*]

Questions

1. Which material, air or water at room temperature, cooled down the cup of hot water faster? Was this consistent with your prediction?
   Students should find that the cup of hot water surrounded by room temperature water cooled faster than the cup surrounded by air. This is because water is a better conductor of heat than air.

2. Explain the advantages and disadvantages of air-cooled engines and liquid-cooled engines.

   - *Air-cooled engines*
     Advantages - less equipment involved, lighter-weight
     Disadvantages - not as efficient in transferring heat, not sufficient for large engines, not efficient when on the ground

   - *Liquid-cooled engines*
     Advantages - more effective in transferring heat
     Disadvantages - extra equipment needed to drive the liquid through the engine, added weight, need additional power source to run the equipment

Teaching Tips

Students may ask why water is such a good conductor of heat. Water is able to absorb heat—without increasing much in temperature—better than many substances, because for water to increase in temperature, water molecules must be made to move faster within the water; this requires breaking hydrogen bonds, and the breaking of hydrogen bonds absorbs heat.

EXTEND

Teacher Material: The Power Cycle - Combustion and Exhaust Presentation

Slide 36: In the fourth session, students will learn that the final part of the power cycle—exhaust—is to vent the gases produced in combustion to the outside and make room for new fuel and air to be introduced into the cylinders for combustion.

Something has to be done with the gases in the combustion chamber after the spark plugs ignite the fuel. The purpose of the exhaust system is to provide a piping pathway from the cylinders to the outside where the gases can be discharged into the air. The process of combustion is very noisy, as thousands of little explosions are taking place inside the combustion chambers every minute as the fuel and air are ignited in the cylinders to produce power. The exhaust system also provides for the dampening, or muffling, of some of these noises, especially if a special device called a muffler is installed in the system.

Another important function of the exhaust system is to prevent shock cooling of the engine during periods of low power and and high airspeed, such as in long descents from high altitudes. The heat from the piping helps keep the engine warm, reducing the chance of excessive cooling.

Airplanes, like cars, have heaters and windshield defrosters. The heat for these systems comes from the exhaust system. Note that the air that comes into the cockpit for the heater and defroster is not exhaust air, which contains toxic gases, but rather fresh air that is simply heated by the exhaust so that it's safe to use for pilots and occupants to breathe.

Teaching Tips

To demonstrate the concept of shock cooling, show this video of glass shattering in an extreme temperature change. While metal doesn't crack as dramatically or quickly, metal engines can experience failures like cracked cylinder heads, bent pushrods, and warped valves.

- 'Why Does Glass Shatter? Breaking Glass for Science" (Length 2:40)
  http://video.link/w/1e7g

Aircraft engine manufacturer Lycoming explains how to avoid shock cooling:
https://www.lycoming.com/content/how-avoid-sudden-cooling-your-engine

Slide 37: The exhaust system on an airplane is pretty simple. Special pipes connect to each cylinder and then to a pipe that connects to the outside, providing for the removal of the gases of combustion. This pipe then connects to a muffler that works just like a car muffler, suppressing the explosive sounds of combustion as the fuel-air mixture burns.

The muffler then connects to the exhaust pipe that leads to the outside of the airplane, where the exhaust gases are released.

Slide 38: Airplanes have heaters and defrosters, just like cars. Like cars, these systems have to get their heat somewhere, and with airplanes, it comes from the heat being distributed by the exhaust system.

The muffler serves as a heat source for cabin air and the windshield defroster. As outside air is drawn into the engine compartment, it flows between the muffler and the muffler shroud, warming it along the way. This is not exhaust gas, but rather fresh air that free flows over the hot muffler and gets warmer. Special ducts then run from the muffler shroud to bring warm air into the cabin. Other ducts branch off and direct the warm air into special vents below the windshield, creating defrosters. These defroster vents are aimed upward and blow heated air onto the interior of the windshield to remove frost and fog.

Slide 39: Airplane heaters/defrosters can be dangerous, and require regular inspections and maintenance to ensure their safe operation. If the muffler develops a leak that allows carbon monoxide (CO) and other exhaust gases to mix with the fresh air being warmed in the muffler shroud, those toxic gases can be introduced into the cabin when the heater or defroster is turned on. Exposure to carbon monoxide can be deadly, and the gas itself is colorless and odorless so it's difficult to detect.

A carbon monoxide detector is an important tool in every cockpit. This inexpensive detector warns the pilot and passengers when the level of CO is too high. The pilot can then take the appropriate steps to minimize the effect of the exposure. A thorough examination of the muffler and heating shroud is an important part of every aircraft inspection, and any affected part or component should be replaced immediately.

Another danger from exhaust system leaks or damage is engine fire. The hot gases from the exhaust can easily ignite flammable surfaces in the engine compartment and cause an in-flight fire. Fire in flight is one of the most dangerous emergency conditions in aviation.

Exhaust system damage can also affect the performance of an airplane. Exhaust systems are designed to vent gases and maintain an internal engine pressure best suited for maximum performance of the engine. Having a certain amount of 'back pressure' is needed for optimal engine operation; an exhaust leak can decrease that back pressure, resulting in a decrease in engine performance.

Slide 40: Many aircraft with piston engines feature a temperature probe in the exhaust stream that connects to an exhaust gas temperature (EGT) gauge in the cockpit. By monitoring the EGT gauge, pilots can see how hot the exhaust gases are and can use that to assess the efficiency of the engine.

Exhaust gas temperature can be controlled from the cockpit using the mixture control. When the exhaust gas temperature is too high, enriching the mixture will cool it.

The EGT gauge can be used as an alternative to the tachometer for engine leaning. The EGT is more precise when it is available.

EVALUATE

Teacher Material: The Power Cycle - Combustion and Exhaust Presentation
Student Material: The Power Cycle - Combustion and Exhaust Student Activity 3

Slides 41-46: Quiz students on questions from the Private Pilot Knowledge Test.

Slide 47: Conduct the **Summative Assessment**.

Summative Assessment

Students play the role of AOPA Air Safety Institute video producers that are working to reduce the general aviation accident rate. Three trends are driving the accident rate: poor engine operation where preignition and detonation were suspected, injuries from people being hit by the propeller during ground operations both from hand propping and improperly grounded magnetos, and engine damage and failures related to improper leaning and poor temperature management procedures. Students must create a video-based outreach message on one of the trends to grab the attention and educate pilots on the proper procedures. Videos or scripts should be no more than two minutes. Samples of videos from AOPA's Air Safety Institute can be found here: https://www.youtube.com/user/AirSafetyInstitute

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Video or storyboard/script:
    - Accurately explains safety procedures for the selected scenario
    - Creatively grabs the attention of general aviation pilots who have received related training in the past
    - Succinctly addresses the factors contributing to accidents in the selected scenario
    - Adheres to the two-minute maximum length requirement
- Uses proper grammar and spelling

- Demonstrates a conscientious effort for professional neatness and quality of presentation

[DOK 3; *construct,* DOK 4; *create]*

Points **Performance Levels**

9-10 Accurately explains best safety practices of the chosen accident trend area; employs creativity in engaging audience; successfully addresses the factors contributing to accidents in the selected scenario; shows exemplary effort at professional presentation with few to no spelling/grammar errors

7-8 Accurately explains best safety practices of the chosen accident trend area; makes a clear attempt to engage audience; addresses the most important factors contributing to accidents in the selected scenario; shows clear effort at professional presentation with few spelling/grammar errors

5-6 Accurately explains some best safety practices of the chosen accident trend area; addresses at least one factor contributing to accidents in the selected scenario; shows some effort at professional presentation with several spelling/grammar errors

0-4 Fails to explain best safety practices in the chosen accident trend area; little effort at professional presentation with numerous spelling/grammar errors

GOING FURTHER

As an optional activity, have students build a classroom generator (magneto) that can power a small light bulb: https://study.com/academy/lesson/electric-generator-science-project.html

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **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
    - Asking Questions and Defining Problems
    - Constructing Explanations and Designing Solutions
  - Disciplinary Core Ideas
    - ETS1.A: Defining and Delimiting Engineering Problems
  - 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.9-10.2** - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of 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.9-10.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- **WHST.9-10.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

REFERENCES

https://www.aopa.org/news-and-media/all-news/2002/january/flight-training-magazine/the-magneto-check
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