Electrical Systems

Session Time: Two, 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, which enables a pilot to fly an aircraft to its maximum capabilities in both normal and abnormal situations. (EU5)

ESSENTIAL QUESTIONS

1. What do pilots need to understand about the electrical system to fly safely?
2. What should pilots do in the event of an electrical system failure?

LEARNING GOALS

Students Will Know

- The operation and purpose of the key components of an aircraft electrical system
- The most common reasons for electrical failure and how to handle them while in flight

Students Will Be Able To

- *Describe* the components of aircraft electrical systems and their purpose. (DOK-L2)
- *Assess* the causes and predict the results of an electrical system failure. (DOK-L3)
- *Determine* the best procedure to use in order to solve in-flight electrical problem scenarios. (DOK-L3)

ASSESSMENT EVIDENCE

Warm-up
Students will generate a list of everyday items and cockpit items that are powered by electricity to help them realize how much we depend on electricity in daily life and in aviation.

Formative Assessment
Students will identify the major parts of an airplane electrical system and explain how each of them operates as part of the larger system.

Summative Assessment
Students will use a series of scenarios to predict the causes of electrical system failures and propose corrective actions.

LESSON PREPARATION

MATERIALS/RESOURCES

- Electrical Systems Presentation
- Electrical Systems Student Activity 1
- Electrical Systems Student Activity 2
- Electrical Systems Student Activity 3
- Electrical Systems Student Activity 4
- Electrical Systems Teacher Notes 1
- Electrical Systems Teacher Notes 2
- Electrical Systems Teacher Notes 3

Build a Model Electrical System (per group)

- Ten (10) alligator leads
- One (1) sheet of florist foam (approximately 1" x 12" x 18")
- Seven (7) greening pins (or similar metal pin; metal must be exposed or insulation removed)
- Three (3) 2"-long pieces of 12 gauge (or thinner) solid copper wire
- One (1) small electric drone motor (with propeller)
- Two (2) LED bulbs
- Two (2) AA batteries
- Battery holder with leads for two AA batteries
- Multimeter capable of reading 2000u amp

LESSON SUMMARY

Lesson 1 - Fuel Systems
Lesson 2 - Electrical Systems
Lesson 3 - Hydraulics and Landing Gear

The lesson begins with a warm-up in which students are prompted to consider the many ways they use electricity in everyday life. Next students are introduced to the "water analogy"—a common way of explaining electric circuits in terms of something students may find more familiar. Students are introduced to the concepts of voltage and current and the role they play in electric circuits.

In the next part of the lesson, students gain a basic understanding of simple electrical circuits, then begin an activity that will be spread throughout the lesson—building a simple model of an aircraft electrical system. Throughout this section, students will be introduced to key components of the electrical system, then will return to their model and add elements to simulate the effect of these components.

In the formative assessment, students will us what they've learned to identify where various electrical system components belong, explain their function, and draw a simple diagram of an aircraft's electrical system. Students will then go on to consider electrical system failures, including the components that are most likely to fail, the causes of such failures, and how to respond in flight.

Next, students will put their learning to use by answering a series of Private Pilot Knowledge Test questions before completing the summative assessment, in which they will analyze a series of electrical failure scenarios to determine the likely cause and the best corrective action to take.

BACKGROUND

Students will come to this lesson with varying degrees of understanding regarding how electricity works. The water analogy provides them with a baseline to understand electrical circuits by equating them with something more familiar—water running through pipes. Switches, resistance, pressure, and flow are all addressed in the analogy.

Students must understand that a complete (closed) circuit is necessary for electricity to do work, such as powering a motor or a light. Circuits can be broken intentionally, for example using switches to stop the flow of electricity to one or more parts of the electrical system. But they can also be broken unintentionally, as when a circuit or fuse is tripped or a wire becomes disconnected. Unintentional disruptions in the flow of electricity result in electrical system failures.

While batteries power many familiar electrical items students may be familiar with, they are insufficient to keep an airplane's electrical system running for extended periods of time. That's why an alternator or generator is typically part of an aircraft electrical system. The alternator (most common) provides power to equipment and recharges the aircraft battery to ensure there's sufficient power to run everything from lights and flaps to avionics and landing gear.

Aircraft avionics are highly sensitive and must be protected from power surges. Most aircraft electrical systems do this by putting avionics on a separate bus from the rest of the electrical system. Depending on the complexity of the aircraft, there may be multiple electrical buses, but in most small aircraft there are at least two—a main bus, which is activated with a master switch, and an avionics bus with its own avionics master switch.

MISCONCEPTIONS

Students may be unclear as to the role of electrical system in an aircraft. In a previous lesson they learned about how electricity is used to help start an airplane motor and how magnetos are used to provide electricity to the spark plugs independent of the electrical system. But they may wonder just how important the electrical system really is and if the airplanes will keep flying in the event of an electrical system failure. Although the electrical system may operate many important pieces of equipment, including flaps, landing gear, lights, radios, and navigation systems, the truth is that the airplane will fly just fine even in the event of an electrical failure. In this lesson students will learn how to troubleshoot electrical failures and recommended procedures in the event of a failure.

DIFFERENTIATION

To help students who may have difficulty conceptualizing various circuit configurations, ask them to draw a simple diagram of their circuits at each step of **Electrical Systems Student Activity 1**—a diagram of the simple circuit with a light bulb and switch, a diagram of the circuit with the ammeter added, etc. This will allow them to clearly see how connections are made and changed as they build out their model of the aircraft electrical system.

LEARNING PLAN

ENGAGE

Teacher Material: Electrical Systems Presentation

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

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

Warm-Up

Have students generate a list of the everyday electrically powered items they use, those they can identify in the cockpit picture on Slide 4, and other items in an aircraft that they think might be powered by electricity.

Introduce the concept that modern aviation is heavily dependent on electricity to power most of the non-engine related systems on an aircraft (e.g. communication radios, navigation, glass panel flight displays, flaps, landing gear hydraulic pumps or motors, fly-by-wire flight controls, etc.). Explain that while we might be very inconvenienced by not having our favorite electrical devices, pilots are incredibly dependent on electrical systems for the safe operation of the aircraft. Having a thorough knowledge of how the electrical systems works can help the pilot troubleshoot and adjust when things go awry in the air. This lesson will help them understand how an airplane's electrical system works and some of the standard procedures pilots use to deal with electrical problems while in flight.

Questions

Use the following questions to spark a discussion to help students realize how important electricity is. Don't worry if students have unclear or unrealistic expectations about how loss of power could affect flight. They will learn the correct answers during this lesson.

How would not having the everyday items you listed affect you?
Student responses will depend on the items they listed but may include things like not having their phones or other devices, not being able to watch TV or play video games, not having lights in their homes, etc.

How might a pilot be affected by losing power in flight?
Student answers may vary from things like not having access to GPS and some types of flight instruments to not being able to raise and lower flaps and landing gear. Some may even have the misconception that an aircraft cannot fly without electricity.

Following the class discussion, show students this short overview video of the airplane electrical system.

- Electrical System Overview (Length 0:40)
  https://video.link/w/IS7h

EXPLORE

Teacher Materials: Electrical Systems Presentation, Electrical Systems Teacher Notes 1
Student Material: Electrical Systems Student Activity 1

Slide 5: Explain to the students that understanding some basic electrical concepts will allow them to better understand how an aircraft electrical system works and, more important, how to effectively handle electrical problems in flight. A common way to explain how electricity works is through the "water analogy." In this analogy, the flow of water represents electricity, the pipes represent the wires, and the water pump is a power source, like a battery or generator.

Have students watch this video to introduce the idea of the water analogy.

- Basic electricity: Analogy (Length 2:37)
  https://video.link/w/uD6h

Emphasize to them the concept that the battery (or water pump) provides pressure that pushes the flow of electricity around the system. Also explain that the curved line, explained in the video as resistance, could also be any electrical device that does work (e.g., a light bulb or motor). This resistance slows down the flow of the electricity as it moves through the system.

Slide 6: Two important concepts about electricity are the pressure and flow that are required to make the system work. Explain that electrical pressure is called voltage. It is provided by power sources like a battery, generator or alternator. If the battery is used up or if the alternator stops working, no pressure is available to the electrical system and therefore no electricity will flow. In the water analogy, voltage is represented by the water pressure provided by the water pump. Without the pump, no water will flow.

The second concept is current. In the water analogy, this is the amount of water flowing through the pipes. Devices attached to the system use the flow of water, or current, to power them. In terms of electricity, current is the amount of electrons that a device, like a light bulb or motor, uses to do its work. Electrical current is measured in amps.

Explain to students that electrical devices need a combination of both voltage and current to operate. The voltage provides the necessary pressure to move the electricity throughout the system. Without voltage, there will be no current. Devices also need enough electrons or current, measured in amps, to operate. More powerful devices typically require both more pressure (volts) and current (amps) to work. The current used by devices is referred to as a "draw" on the system. More powerful devices have a greater draw than less powerful ones.

Slide 7: The pathway the electricity follows is called a circuit. As the name implies, in its simplest form a circuit is like a circle with current flowing from the power source (battery) around the circle, through the device that does the work (in this case a lightbulb), and back to the power source (battery). For the circuit to work, the pathway has to be unbroken. Breaking the pathway, disrupts the circuit and prevents the electricity from flowing. Opening a switch, breaks the pathway.

Slide 8: Over the course of the lesson, students will be building a model of the airplane's electrical system, starting with a basic circuit.

Show students the diagram of a simple circuit incorporating a battery, a switch, and a light bulb that appears on this slide. Explain that the battery uses a chemical reaction to provide the voltage and supply of current that powers the circuit. The light bulb uses the flow of electricity and converts the electrical energy into light. In this simple example, the light bulb draws just a few amps of power to do its work. Point out to students the simple switch mechanism. If the wires are connected in a closed loop, the light bulb will remain on as long as the battery has enough power to illuminate it. A switch works by breaking the circuit. If the wires are not connected, electricity will not flow, and the light bulb will be dark. In the water analogy, this would be like closing a valve and stopping the flow of water.

One additional point to make is that some electrical circuits in the airplane are completed through a ground connection. The circuit is completed using the metal frame of the airplane.

Distribute **Electrical Systems Student Activity 1**. Have students work in small groups to complete steps one and two of this activity by building a simple circuit with a switch and a light bulb. (The remainder of the activity will be completed later, as students learn more about aircraft electrical systems.)

EXPLAIN

Teacher Materials: Electrical Systems Presentation, Electrical Systems Teacher Notes 1, Electrical Systems Teacher Notes 2
Student Materials: Electrical Systems Student Activity 1, Electrical Systems Student Activity 2

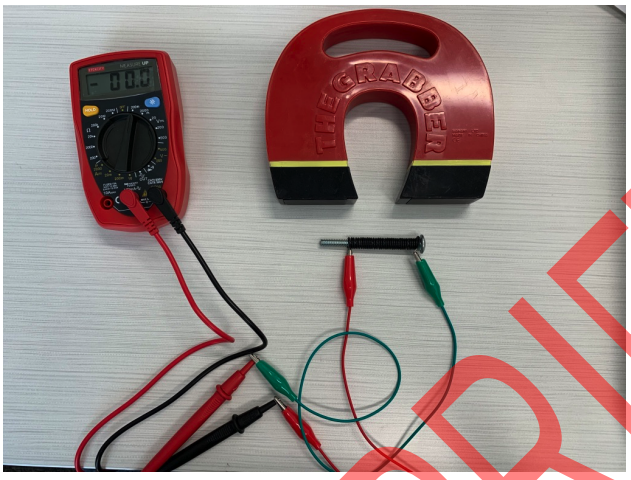
Slide 9: The simple battery-powered circuit built by students would have a major limitation if used for an airplane system. Ask students what would happen if aircraft only used a battery to power the electrical systems. The battery would eventually drain, leaving no power to continue operating the lights or any other equipment.

The typical aircraft uses quite a bit of electrical equipment including communication/navigation radios, lights, secondary control systems, engine starters, and other critical components. In order to sustain this demand well beyond

the duration of a typical battery, modern aircraft use an alternator to provide power to run the electrical components and to recharge the battery. (Some older aircraft use generators for this purpose, but these are increasingly uncommon.) Remind students about the principles they learned when studying electric motors in lesson 7C1, UAS Engines and Fuel. Alternators work similarly to the electric motors used in small UAS. The alternator creates electricity by spinning an electromagnet inside of a coil of tightly wound wire. The faster the magnets spin, the more electricity is created as the magnets force the electrons inside the wire coil to move. On an airplane, the alternator is connected to the engine by an alternator belt, which spins the electromagnet in the alternator to produce electricity.

Teaching Tips

You can build a simple generator using a coil of wire, a multimeter, a magnet, and some alligator clip leads. Set the multimeter to its most sensitive DC voltage setting and move the magnet over the coil. You will see a voltage readout on the multimeter as electricity is generated. The faster you move the magnet, the higher the voltage reading. This happens because the magnetic field is moving the free electrons in the wire.



Slide 10: On the previous slide students learned that the faster the magnets move, the more electricity the alternator or generator makes. Explain to students that one of the critical and more delicate parts of an aircraft is its avionics system which includes the communication radios and navigation units. The avionics equipment is particularly susceptible to damage from power spikes or large changes in electrical current.

Explain that the electrical power needs to be kept within safe operating parameters to avoid damaging the avionics system. This is accomplished by varying the output of the alternator with the alternator control unit. It works by sensing the needs of the electrical system and then electronically adjusting the strength of the alternator's electromagnet thereby metering the power output of the alternator within the safe operating range of the avionics equipment.

Slide 11: It is critical to monitor the flow of electricity in the system while flying. It allows the pilot to ensure that the system is operating properly, and in the case of a malfunctioning system, it provides critical information for troubleshooting. There are two common types of ammeters used in aircraft: a charge/discharge ammeter and a load meter.

A charge/discharge ammeter is a gauge that displays the flow of electricity in the system as either charging, neutral, or discharging. By showing the system's charging state, the pilot can determine whether the alternator or generator is producing sufficient power to both handle the load of electrical equipment and recharge the battery.

A load meter like the one in the picture on the slide displays the total load of power being used by the system that is being placed on the alternator or generator. As each device is turned on, the load meter displays the additional load (e. g., operating a 5 amp beacon and a 10 amp flap motor will show a 15 amp load on the system).

Have students add a load meter to their basic circuit using the directions in step 3 of **Electrical Systems Student Activity 1**.

Slide 12: Ask students to think about the way they use power strips to plug in multiple devices in a single location. Using a power strip simplifies the connection, allowing the user to plug in multiple devices without requiring multiple extension cords or wall outlets.

Explain that bus bars in an aircraft electrical system work a little like power strips. They simplify the wiring and provide a common point from which voltage can be distributed to different electrical devices within the aircraft. Bus bars are controlled by switches that allow the pilot to turn them on or off as needed for safe operation. Airplanes typically have a primary bus bar that is controlled by the master switch. The primary bus powers all the electrical equipment aside from the avionics, including the starter, flaps, landing gear, and lights. A separate avionics bus powers all of the more sensitive electrical equipment and is controlled by the avionics master switch. This allows the pilot to isolate the avionics equipment any time there is a danger of an electrical power spike, as during engine start or electrical system troubleshooting.

Have students add an avionics bus and avionics master switch to their basic circuit using the directions in step 4 of **Electrical Systems Student Activity 1**.

Slide 13: Ask students to think about a time when they had a circuit, GFCI switch, or fuse blow in their house. Most often the cause is an overloaded circuit when too many high draw electrical devices, such as hair dryers, small appliances, or space heaters, are being used at once. The same thing can happen in an airplane. To prevent fire or damage to the devices, the circuit breaker trips or the fuse blows. The overload condition can then be corrected, and the breaker can be reset or the fuse replaced.

Using the picture of the airplane circuit breaker panel on the slide, point out to students that aviation circuit breakers are typically small round push-to-reset buttons as opposed to the larger switch style circuit breakers in a house. This style of circuit breaker saves space and weight.

Slide 14: Remind students that they learned about the starter motor in a previous lesson. They may recall that the starter was an electric motor with a small gear that engaged the flywheel to turn the engine during start up.

The starter is part of the electrical system and is powered by the battery. In order for an airplane to start, the master switch must be "on" to allow power to flow from the battery. Then the pilot engages the "start" position on the ignition switch which closes the circuit from the battery to the starter motor. Once the engine starts, the starter is disengaged to avoid damaging the starter and flywheel gears. The starter requires a lot of current to be able to turn the whole engine over with such a relatively small device. This results in a significant load on the battery.

Have students create a new circuit to attach an electric "starter" motor to their electric system following the instructions in step 5 of **Electrical Systems Student Activity 1**.

Slide 15: Explain to students that devices like the starter use a lot of electrical power and require heavy duty wiring. To help minimize the length of the heavy duty wiring and its associated costs, a remote switch is used to close the high power electrical circuit for both the starter and when turning on the master switch. This remote switch is called a contactor.

The contactor is a magnetically powered switch. When the pilot moves the ignition switch to start, a low power current is sent from the ignition switch to the starter contactor where it energizes an electromagnetic coil inside the contactor. The magnetic field pulls the heavy duty switch inside the contactor to the closed position and allows the high power current from the battery to power the starter. Once the engine starts, the pilot releases the ignition switch from the start position, the contactor's internal switch opens, and power is no longer supplied to the starter motor.

Slide 16: Conduct the **Formative Assessment**.

Formative Assessment

Have students watch the following video that reviews the main features of an aircraft electrical system.

- Aircraft Systems - 08 - Electrical System (Length 4:10)
  https://video.link/w/dbCh

Then distribute **Electrical Systems Student Activity 2**. Students will use a terms list to identify and sort the appropriate electrical equipment to the avionics and primary buses. Then students will explain the function and roles of the major components of a typical aircraft electrical system. Finally, students will draw a basic electrical diagram of a primary and avionics circuit based on their experience in the class activity.

[DOK-L2; *categorize, explain;* DOK-L3; *construct*]

EXTEND

Teacher Material: Electrical Systems Presentation

Slide 17: Aircraft electrical systems are reliable and rarely suffer failures. An inoperative alternator is the most common failure in an electrical system. The alternator is turned by the engine to create electricity to power electrical equipment and charge the battery. When an alternator isn't working, all of the electrical load is carried by the battery. Alternator failures are indicated either by voltage warning lights or an ammeter showing a discharge. These indications show that the battery is carrying the electrical load.

The voltage regulator is the next most likely failure. It will produce swings in voltage which will be seen either by monitoring the voltage meter or the voltage warning light.

Slides 18-19: When the pilot notices a high or low charge in the electrical system, the first step is to see if resetting the alternator will correct the problem. The pilot turns off the avionics master switch to protect the electronics, and then turns the master switch off and back on. Cycling the master switch resets the alternator in an attempt to bring it back online. If that doesn't solve the problem of a low charge, then the battery is carrying the entire electrical load of an aircraft and will typically fail in fewer than 30 minutes. The pilot should turn off all nonessential equipment to preserve remaining power for critical uses and plan on a manual extension of the landing gear and a landing without flaps. If the failure was of excessive charge or voltage, then turning off the master switch will help protect equipment from power surges.

Slide 20: Remind students that "false" low voltage indications can also occur at low engine power settings like during taxi. This is caused when the alternator is not being spun quickly enough to meet the electrical demands of the system. A simple increase in engine RPM will correct this situation.

Slide 21: The loss of electrical power is a serious issue, but not necessarily an emergency, depending on the conditions of the flight. In visual, daylight conditions, it should be possible to land without problems. Electrical failures at night and in instrument conditions are a much more serious issue. A pilot should never hesitate to ask for help from air traffic control, or to declare an emergency.

Slide 22: The smell of burning insulation (plastic) is often the first sign of an electrical fire, and you may encounter smoke before you see flames. Any fire in flight is an emergency. In the event of an electrical fire, take the following steps:

1. Turn off the master switches.
2. Use the fire extinguisher to put out the fire if possible.
3. Land as soon as possible.

Slides 23-30: Answer a series of Private Pilot Knowledge Test questions.

EVALUATE

Teacher Materials: Electrical Systems Presentation, Electrical Systems Teacher Notes 3
Student Material: Electrical Systems Student Activity 3

Slide 31: Conduct the **Summative Assessment**.

Summative Assessment

Distribute **Electrical Systems Student Activity 3**. Students will read three in-flight scenarios based on actual pilot training and procedures. They will apply what they learned in the lesson to determine the cause of the situation and formulate a corrective action. Students will explain their reasoning.

[DOK-L2; *explain;* DOK-L3; *assess*]

Summative Assessment Scoring Rubric

- Student follows instructions
- Answers show understanding of the concepts covered in the lesson
- Answers show in-depth thinking, including analysis or synthesis of lesson objectives

Points	Performance Levels
9-10	The student accurately assesses the cause of each electrical problem based on in-class learning and provides clear and detailed explanations of the proposed corrective actions supported by evidence. The completed student activity shows clear understanding of the information presented in the lesson.
7-8	The student accurately assesses the cause of at least two of the three electrical problems based on in-class learning and provides explanations of the proposed corrective actions. The completed student activity shows understanding of the information presented in the lesson.
5-6	The student accurately assesses the cause of at least one of the three problems based on in-class learning and provides some reasoning to support the proposed corrective actions. The completed student activity shows gaps in understanding of the information presented in the lesson.
0-4	The student does not accurately assess the causes of the three problems based on in-class learning and does not provide reasoning to support the proposed corrective actions. The completed student activity shows significant gaps in understanding of the information presented in the lesson.

GOING FURTHER

Give students the opportunity to experience a simulated electrical failure. Working in pairs, students will follow the instructions on Electrical Systems Student Activity 4 to experience a variety of electrical failure modes and answer questions about their experience.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS3-5** - Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
    - Science and Engineering Practices
        - Developing and Using Models
    - Disciplinary Core Ideas
        - PS3.C: Relationship Between Energy and Forces
    - Crosscutting Concepts
        - Systems and System Models
        - Cause and Effect
- **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.

REFERENCES

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