Electric Aircraft

Session Time: Two, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Appreciate the rich, global history of aviation/aerospace and the historical factors that necessitated rapid industry development and expansion. (EU1)

Aspire to the highest level of technical proficiency as it relates to flight operations and engineering processes. (EU4)

Develop an uncompromising safety mindset, understanding that growth and development in the aviation/aerospace industry must always be accompanied by responsive safety initiatives. (EU5)

ESSENTIAL QUESTIONS

1. Will it be possible to develop an electric aircraft big and powerful enough to fulfill meaningful functions?
2. Are clean sources of energy a viable way to power aircraft?

LEARNING GOALS

Students Will Know

- The benefits of electric aircraft
- The challenges of building practical electric aircraft

Students Will Be Able To

- *Draw conclusions* regarding the future of electric aircraft based on knowledge gained about the challenges and opportunities for electric flight. (DOK-L3)
- *Explain* the most significant hurdles for electric aircraft development. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Use a “popcorn” or another teaching method to have students call out various types of vehicles that rely only on electricity for power. Use guiding questions to help students realize differences between electric-powered and gas-powered vehicles.

Formative Assessment
Students will answer driving questions about three electric aircraft in various stages of development.

Summative Assessment
Students will summarize their thoughts on what it will take to make electric aircraft commercially viable and give an opinion on the future of electric flight.

LESSON PREPARATION

MATERIALS/RESOURCES

- Electric Aircraft Presentation
- Electric Aircraft Student Activity **(GOING FURTHER)**
- Electric Aircraft Teaching Aid **(GOING FURTHER)**

Build-Your-Own-Battery Activity (per team) (GOING FURTHER)

- 7-10 test leads with alligator clips
- 4-6 lemons
- Small electric motor with propeller
- One AA battery
- Small LED light
- 4-6 galvanized nails/screws
- 4-6 pieces of bare copper wire (about 2 inches long)
- Ruler
- 2-3 rubber bands
- 4-6 drinking straws or small dowels
- Safety glasses
- Multimeter (shared among the class)
- Wire cutters/strippers (shared among the class)
- Digital scale (shared among the class)

LESSON SUMMARY

Lesson 1 – Supersonic Aircraft
Lesson 2 – Autonomous Aircraft
Lesson 3 – Electric Aircraft

This two-session lesson will begin by asking students to brainstorm various types of vehicles that rely only on electricity for power. Guiding questions will help students realize differences between electric-powered and gas-powered vehicles.

During a class discussion, students will apply information about the development and introduction of electric cars (something they might be familiar with) to the development of electric aircraft. The presentation also will explore the benefits of electric aircraft technology.

Students will study three electric aircraft in various stages of development and learn about the most significant hurdle facing development of electric aircraft, which is developing lightweight, powerful, and environmentally responsible batteries.

Finally, students will summarize their thoughts on what it will take to make electric aircraft commercially viable and give an opinion on the future of electric flight.

BACKGROUND

Today's aircraft have two big problems: They are noisy, and they burn a lot of fuel. NASA, the FAA, and private industry are conducting significant research in the area of electric aircraft, with the goal of dramatically decreasing the noise and emissions of future aircraft.

An aircraft is considered electric when it is powered by electric motors. The electricity may come from various places, including batteries and solar cells. The electricity drives the propellers on airplanes or the rotors on helicopters.

In order for electric flight to become mainstream, improved batteries are necessary. Other industries have replaced traditional lead-acid batteries with lithium-ion batteries, which now power most of our laptops, phones, and electric cars. For aviation purposes, the next generation of batteries needs to deliver a tremendous amount of power while simultaneously being smaller, safer, and lighter than current aircraft batteries.

If time allows for the “Going Further” activity, refresh students on basic concepts and terms about electricity. As a refresher, voltage indicates how much electrical pressure is available from a battery. The electrons won’t flow without pressure (voltage). Current is the amount of electricity that is flowing and is measured in amperes. In order to have electricity, current (amperes) must flow. The current won’t flow without force (voltage).

Think of water flowing through a pipe. The amount of water flowing through the pipe is current, and the water pressure is voltage.

The activity uses two types of electrical circuits – series circuits and parallel circuits. A series circuit is created by using wire to connect different ends of two or more batteries. This means connecting the positive (+) end of one battery to the negative (-) end of the other battery. Wires from the remaining positive and negative terminals will connect directly to the positive and negative terminals of your motor or LED (light-emitting diode, or small light). Using series circuits increases voltage. The increase can be calculated by adding the voltages of the connected batteries. For example, if you connect a 1.5-volt battery to another 1.5-volt battery in a series circuit, you will be able to light a 3-volt bulb.

When wiring a parallel circuit with two or more batteries, connect the positive (+) end of one battery to the positive end of the other battery. Also connect the negative (-) ends of the batteries together.

Two additional wires are used to connect the positive and negative ends of one of the batteries to the motor or LED. Students will not be able to light the 3-volt battery with the parallel circuit because the voltage will remain at 1.5 volts, but the batteries will last longer and they will get more current (amperes) from the batteries. Diagrams throughout the student activity illustrate series and parallel circuits.

MISCONCEPTIONS

Students may think that because electric cars are becoming mainstream, airplanes are close to follow. In fact, a practical, all-electric airliner is decades away.

LEARNING PLAN

ENGAGE

Teacher Material: Electric Aircraft Presentation

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

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

Warm-Up

Using a “popcorn” strategy, invite students to call out various types of vehicles that only rely upon electricity for power. Write down student responses on the board.

Use student ideas and guiding questions to conduct a class discussion about the characteristics of vehicles that use electricity as their only source of power. Ask students how these vehicles differ from gas-powered vehicles (specifically aircraft).

[DOK 2; *relate*, DOK 1; *list*]

Questions

Vehicles that rely solely on electricity include:
Electric cars, electric trains, go-karts, personal transporters (Segways), electric golf carts, electric bicycles, electric motorcycles, scooters, etc.

What are some characteristics of vehicles that rely solely on electricity for power?
They let off no emissions (and less pollution); they often can carry only one person or just a few people; they must be plugged in and recharged often; some electric trains must be connected to electrified rails or overhead lines; they often times don't go very fast due to having little power, are slow to accelerate, etc.

How do they differ from gas-powered vehicles and airplanes?
Gas engines emit pollutants; large gas engines have higher thrust-to-weight ratio (can produce a lot of thrust and power); more thrust means the vehicles can carry more weight and more people or cargo; they are easy and fast to refuel, etc.

EXPLORE

Teacher Material: Electric Aircraft Presentation

Slide 5: Begin by asking students to name several electric car brands or models. Several major car brands now have fully electric cars. These include all Tesla cars, the Nissan Leaf, the Chevrolet Bolt, and the Volkswagen e-Golf.

Students may not be able to differentiate between electric and hybrid. The primary difference is that the hybrid car derives some of its power from a conventional gasoline engine. A true electric car gets all of its power from electrical sources and thereby is a completely non-polluting, zero-emission vehicle.

Slide 6: Ask students why they think electric cars are becoming so popular. Solicit their ideas and then review some of the reasons using the next slide.

Slide 7: Students may surmise that electric cars are becoming increasingly popular because more people are environmentally conscious, owners save money on gas and maintenance, and they are quieter. Students also may recognize that owners like to take advantage of federal and state tax credits, drivers can use HOV lanes, and technology advancements have given electric cars longer range.

Ask students why nearly silent cars might be a problem. They may determine that sound helps people be aware of cars, which provides a safety factor.

Slide 8: Several challenges still face electric cars and their development. Electric car manufacturers know that consumers are worried about how far they can travel in electric cars before the batteries run out. In a gas-powered car, running low on gas is not that concerning; drivers can just pull into a gas station and fill up in about five minutes. Charging an electric car isn't quite so simple. Most production electric cars can only go about 100 miles on a single charge. And, unless drivers have access to a specialized charging station (which are currently in short supply), getting a full charge takes around 9 hours. While most people drive less than 40 miles a day and could easily charge their electric cars overnight, electric cars still aren't useful for long road trips.

Charging stations are another challenge. While some charging stations are available to the public (like in mall parking lots), most charging still needs to be done at home, in a garage. That means that people who live in shared housing or use street parking likely will have the hardest time charging their cars.

Battery technology is expensive, and because batteries in electric cars need to be able to hold massive amounts of charge to make the cars practical for most drivers, they have to be built using expensive materials. Because electric cars cost a lot to build, they also cost more than comparable gasoline cars to buy.

EXPLAIN

Teacher Material: Electric Aircraft Presentation

Slide 9: Now that students understand the benefits of electric cars and the challenges to their development, they will apply that learning to the development of electric airplanes.

Begin the discussion by explaining to students that the concept of using electric motors to power airplane systems dates back at least to World War II, when the B-29 Superfortress bomber used electric motors to power its gun turrets. Since then, other airplanes have replaced the ducts and hoses of hydraulic and pneumatic systems with electrical power to control such things as flight controls and brakes. That can save significant weight and reduce fuel burn.

In the first semester, students learned about fly-by-wire systems, which serve as a replacement to heavy, mechanical cable flight controls.

Using electrical power to actually propel airplanes, however, is a more complicated challenge. Like electric cars, the benefits of electric airplanes are widely recognized, and many companies are working on their development.

Slide 10: Before reviewing the potential benefits of electric airplanes, ask students to work in small groups and brainstorm a list of at least three benefits. They should draw from what they just learned in the discussion about electric cars. After giving students about five minutes to make their lists, solicit their answers, and write them on the board.

The next three slides will outline the benefits using three categories: environment, cost of operation, and ease of operation.

Slide 11: Students learned in the first lesson in this unit that as the fastest-growing form of transportation, aviation's impact on the environment will continue to grow. Currently, aviation is responsible for about 2 percent of the world's human-induced carbon-dioxide emissions, but that percentage is expected to grow as aviation meets the needs of a growing world economy and expanding world population.

Electric airplane engines would greatly reduce aviation's impact on the environment by cutting both emissions and noise. Aircraft engines produce emissions that are similar to other emissions resulting from fossil-fuel combustion. Noise emissions are created in part as a result of engine combustion. Unlike combustion engines, electric aircraft engines produce little to no noise.

Slide 12: It is believed that an airplane with electric engines will be less expensive to operate. First, with only one moving part (the shaft that drives the propeller or rotor blades), they will be easier to maintain. In comparison, a combustion piston engine has hundreds of moving parts, all subject to movement and vibration. A heavy, vibrating engine must have a strong, substantial mount and structure around it. An electric aircraft with minimal vibration can have a lighter structure, and its components will last longer because they are subject to much less vibration. In addition, less vibration produces less noise and provides a more comfortable flight for pilots and passengers.

Electric engines are also free from the regular replacement of components like spark plugs and oil filters, and they don't require the replenishment of fluids such as gasoline and oil.

Slide 13: The operation of an electric engine is much simpler than a combustion engine, which can involve adjustments for the amount of fuel going into the engine, the mixture of fuel to air, carburetor heat, and more. All of these adjustments depend on the altitude of the airplane, phase of flight, external temperature, and more. Multiple factors must be considered in order to fly a combustion engine properly and most efficiently.

Unlike internal combustion engines, electric engines don't require air to produce power, so they can maintain full power even at high altitudes or in high temperatures where the air is thin. There is a marked difference in the ease with which electric engines are operated.

Furthermore, unlike internal combustion engines, with requirements for cooling air, combustion air intake, fuel lines, and a provision for exhaust gases, electric engines can be mounted in airframes in different ways. An electric motor can be placed anywhere on the aircraft.

Slide 14: Explain to students that electric aircraft engines are primarily powered by either batteries or through solar energy.

Batteries are the most common energy source for electric aircraft engines due to their relatively high capacity. Batteries were the earliest source of electricity, first powering airships in the 19th century. These early batteries were very heavy, and not until the arrival of technologies such as nickel-cadmium (NiCad) rechargeable types in the second half of the twentieth century did batteries become a practicable power source. Modern lithium-ion batteries remain a popular power source today, although they still have limited life between charges and require recharging on the ground.

A solar cell converts sunlight directly into electricity, either for direct power or temporary storage. The power output of solar cells is small, even when many are connected together, which limits their use. They are also expensive. However, their use of freely available sunlight makes them attractive for high-altitude, long-endurance airplanes. For endurance flights, a backup storage system supplies power during the hours of darkness and recharges during the day.

This will complete the first session of this lesson.

EXTEND

Teacher Material: [Electric Aircraft Presentation]

Slides 15-20: Conduct the **Formative Assessment**.

Formative Assessment

Students will learn about several electric aircraft models that are being developed and tested. After they review a slide and watch a video about each, students will answer driving questions about the challenges to their development and potential future viability.

After all the questions have been answered, ask students to share their answers.

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

Aircraft 1 – *Solar Impulse*
Solar Impulse was the first aircraft to fly around the world on solar power. It used no fuel. The flight took 25 days, 500 flying hours, and five months to complete. The upper wing surface was covered in solar cells. Energy used for night flying was stored in lithium polymer batteries. The mass of the batteries accounted for about 25 percent of the aircraft's total weight! The aircraft had a single seat, and each pilot flew long hours and for several days at a time with very little sleep.

- "Solar Impulse – Flying Without Fuel" (Length 4:12)
  http://video.link/w/cMQd

Aircraft 2 – Eviation *Alice* Commuter
Eviation is developing an all-electric commuter airplane that is designed to seat nine passengers and fly up to 650 miles at a cruise speed of 240 knots (276 miles per hour) on one battery charge. It will have three propellers – one pusher propeller on the tail and one propeller at each wingtip to reduce drag and improve efficiency. The company estimates that it will be flying in commercial service in 2021.

- "Eviation Aircraft on the BBC Talking Business" (Length 4:01)
  http://video.link/w/wACf

Aircraft 3 – Pipistrel *Alpha Electro*
Pipistrel's *Alpha Electro* aircraft has a liquid-cooled, 60-kilowatt electric motor. The motor is powered by six air-cooled, lithium-ion batteries arranged in two packs – one pack installed just forward of the firewall

and the other behind the pilot's seat. Each battery weighs 45 pounds, for a total battery weight of 270 pounds. This airplane is best-suited for flying around the traffic patterns. Its battery endurance is approximately one hour, which leaves pilots with a 30-minute reserve. The propeller is designed to regenerate electrical power when it's windmilling, or at lower power settings. Essentially, the propeller acts as a sort of wind turbine, capable of partially recharging the batteries in flight. Pipistrel engineers say that for six trips around the pattern, you get an extra circuit for "free."

- "Pipistrel Alpa Electro" (Length 3:05)
  http://video.link/w/fMQd

Questions

Aircraft 1 – *Solar Impulse* was not designed for use in commercial service; however, what advancements did the team make that can be applied to viable electric aircraft in the future?

The team discovered more effective ways to store solar power and built a high-density battery storage system to store energy for night-flying; they were able to make the aircraft very light yet strong (they used carbon fiber and determined how to reduce weight in order to make room for the batteries).

Aircraft 2 – Why could Eviation's *Alice* airplane be one of the first all-electric aircraft viable for commercial passenger service?

It can carry up to six passengers at speeds more than 250 miles per hour on a single battery charge. The simplicity of electric aircraft bring down operating costs, and the aircraft are easy and cost-effective to maintain. This makes it very economical for commercial operators.

Aircraft 3 – Do you think this aircraft could be the flight trainer of the future?
Some students may believe that it could be because it's much cheaper to operate, which would bring down the cost of learning how to fly, and it's practical because students wouldn't need to go very far when learning how to fly. This airplane goes as far as you need it to. Other students may believe that one hour of flight time just isn't enough or that the airplane isn't versatile enough because its range is too short.

Slide 21: Lead a class discussion about the most significant hurdle facing development of electric aircraft, which is developing lightweight, powerful, and environmentally responsible batteries.

Explain to students that 1,000 pounds of jet fuel provides about 14 times more energy than a 1,000-pound battery. The jet fuel capacity of a Boeing 787 Dreamliner is about 223,000 pounds. The estimated weight of a battery pack with equivalent energy would be millions of pounds.

Slide 22: For electric airplanes to be practical, batteries must be able to store more energy than an internal combustion engine. If engineers cannot solve this issue, then the maximum speed and weight for all electric aircraft will remain so low as to be impractical.

Teaching Tips

If time allows, have students do a hands-on activity where they determine whether it is practical for lemons to power a small motor with a propeller. Students will first construct a lemon battery and attempt to power an LED light bulb. Once they have a functioning lemon battery, they will attempt to build a battery large enough to power a small motor and propeller. They must determine whether the battery they build is a practical solution.

More information about this activity is in the **GOING FURTHER** section.

EVALUATE

Teacher Material: Electric Aircraft Presentation

Slide 24: Conduct the **Summative Assessment**.

Summative Assessment

Students will summarize their thoughts on what it will take to make electric aircraft commercially viable and give an opinion on the future of electric flight.

Ask students to write several paragraphs in which they answer the following questions:

1. What advancements must be made before a fully electric aircraft becomes a practical means of flight?
2. Do you think that fully electric aircraft capable of long-range flight will be a reality in the near future? Why or why not?
3. If small electric aircraft become affordable, will they be as popular as electric cars?

Collect student responses for grading.

[DOK L2; *infer, predict*]

Summative Assessment Scoring Rubric

Follows assignment instructions

Written response includes:

- Clear and accurate explanation of the challenges facing the development of electric aircraft, which may include batteries that are more powerful and lighter in weight, the need for additional ways to reduce the total weight of aircraft to account for batteries, methods to recharge batteries faster, or a system to replace batteries quickly and easily.
- Opinions on the future of long-range electric flight and small electric cars are clearly structured and show in-depth thinking and analysis.

Correct spelling and grammar

Points	**Performance Levels**
9-10	Consistently demonstrates criteria
7-8	Usually demonstrates criteria
5-6	Sometimes demonstrates criteria
0-4	Rarely to never demonstrates criteria

GOING FURTHER

Students have learned that one of the challenges with electric vehicles is developing lightweight, powerful, and environmentally responsible batteries. The weight is even more critical when dealing with aircraft because any additional weight will require additional power from the electric motors. In this small-group activity, students will determine whether it is practical for lemons to power a small motor with a propeller. Provide students with copies of Electric Aircraft Student Activity. The Electric Aircraft Teaching Aid provides the same step-by-step instructions as students will see in the activity, along with answers to the questions.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-ETS1-1** – Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
    - 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
        - Systems and System Models
        - Influence of Science, Engineering, and Technology on Society and the Natural World
- **HS-ETS1-2** – Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
    - Science and Engineering Practices
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.C: Optimizing the Design Solution
    - Crosscutting Concepts
        - None
- **HS-ETS1-3** – Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
    - Science and Engineering Practices
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas

        - ETS1.B: Developing Possible Solutions
    - Crosscutting Concepts
        - Influence of Science, Engineering, and Technology on Society and the Natural World

COMMON CORE STATE STANDARDS

- **RL.9-10.2** – Determine a theme or central idea of a text and analyze in detail its development over the course of the text, including how it emerges and is shaped and refined by specific details; provide an objective summary of the text.
- **RL.9-10.4** – Determine the meaning of words and phrases as they are used in the text, including figurative and connotative meanings; analyze the cumulative impact of specific word choices on meaning and tone (e.g., how the language evokes a sense of time and place; how it sets a formal or informal tone).
- **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.9-10.3** – Follow precisely a complex, multistep procedure when carrying out experiments, taking measurements, performing technical tasks, or attending to special cases or exceptions defined in the text.
- **RST.9-10.4** – Determine the meaning of symbols, key terms and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.
- **WHST.9-10.2** – Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
- **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

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