Propellers

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. (EU 1)

A deep understanding of how an aircraft operates enables a pilot to fly the aircraft to its maximum capabilities in both normal and abnormal situations. (EU 5)

ESSENTIAL QUESTIONS

1. Are constant-speed propellers worth the extra cost and complexity?
2. Which propeller design characteristics are the most important for the pilot to know?
3. In flight, does the pilot manage the engine or the propeller?

LEARNING GOALS

Students Will Know

- The differences between fixed-pitch and constant-speed propellers
- How a constant-speed propeller system works, including the governor
- How to operate a constant-speed propeller
- The failure characteristics of a constant-speed propeller

Students Will Be Able To

- *Compare* fixed-pitch and constant-speed propellers. (DOK-L3)
- *Explain* procedures for constant-speed propeller management. (DOK-L2)
- *Apply* the concepts they've learned to simulation activities involving fixed-pitch and constant-speed propellers. (DOK-L4)

ASSESSMENT EVIDENCE

Warm-up
As a refresher, students will take a "prop quiz," competing for points as they answer questions about important terms that will be used in this lesson.

Formative Assessment
Students will be divided into two groups. One group will develop a logical argument for flying with a fixed-pitch propeller and the other group for flying with a constant-speed propeller.

Summative Assessment

Following a flight profile for an aircraft with a constant-speed propeller, students will describe how to use the propeller and throttle controls, the propeller blade pitch angle, and the appropriate instrument readings for each phase of the flight.

LESSON PREPARATION

MATERIALS/RESOURCES

- Propellers Presentation
- Propellers Student Activity 1
- Propellers Student Activity 2
- Propellers Student Activity 3
- Propellers Teacher Notes 1
- Propellers Teacher Notes 2
- Propellers Teacher Notes 3

Recommended Student Reading

- **Pilot's Handbook of Aeronautical Knowledge**
  Chapter Seven, Aircraft Systems, pages 7-4 to 7-7 (Propeller section) 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
Lesson 4 - The Power Cycle: Combustion and Exhaust
Lesson 5 - Turbochargers and Superchargers

This two-session lesson will begin with a "prop quiz," a review of what students learned about propellers from the previous semester during the thrust lesson. Students will be using the terms from the quiz throughout this lesson on propeller systems.

The lesson goes on to cover the details of the systems that drive both fixed-pitch and constant-speed propellers. These systems are covered as an overview at first, and then each type of propeller is examined in greater depth. As the lesson progresses, students will conduct two simulation activities. Students will complete a formative assessment by developing logical arguments for flying with either a fixed-pitch propeller or a constant-speed propeller.

Finally, students will follow a flight profile for an aircraft with a constant-speed propeller and describe how to use the propeller and throttle controls, the propeller blade pitch angle for various phases of flight, and the appropriate instrument readings for each phase of the flight.

BACKGROUND

Propeller systems can be categorized into the fixed-pitch and variable-pitch varieties. Pilots must understand the intricacies and variations in their aircraft engine systems and how these factors drive the propeller. Pilots must also understand the potential inefficiencies and failures of both fixed-pitch and variable-pitch propeller systems. Though the fixed-pitch propeller is lighter, less expensive, and easier to maintain, the variable-pitch propeller is more efficient. A constant-speed propeller is the most common type of variable-pitch propeller. The type of propeller selected depends on the type of flying a particular aircraft will do. For example, fixed-pitch propellers may utilize either a climb or cruise propeller, based on the aircraft's intended purpose.

Constant-speed propellers require the pilot to manage both the propeller and the engine. Pilots use a propeller control lever to control the tachometer/RPMs, and the throttle to control the manifold pressure. Unlike fixed-pitch propellers, constant-speed propellers are subject to overspeed, underspeed, and feathering conditions, each of which is explained throughout the lesson.

MISCONCEPTIONS

Propellers look simple, and students may believe they fully covered the topic in the thrust lesson in Unit 4, which included information on how propellers produce thrust. But they likely do not understand the complex systems that drive propellers, the variety of propellers available, or the advantages and drawbacks of different types. If some students have trouble understanding the mechanics that drive these systems, enlarging the provided diagrams and walking through the operation of each step, one at a time, will help enhance understanding and retention.

DIFFERENTIATION

To provide students with additional support in the **ENGAGE** section of the lesson, provide students a word bank of options to choose from when answering the questions in the "prop" quiz. The idea behind the quiz is to activate students' prior knowledge so that they can feel confident moving forward in the lesson. Providing students with a word bank can help students who struggle to regain confidence and improve motivation.

Instead of having students work individually to complete the Formative Assessment in the **EXPLORE** section of the lesson, turn the assessment into a class discussion. Draw a Venn diagram on the board and have a student volunteer write down the class's answers. This visual representation can help students better understand the differences between the two types of propeller systems.

LEARNING PLAN

ENGAGE

Teacher Material: Propellers Presentation

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

Slides 4-17: Conduct the **Warm-Up**.

Warm-Up

Students will complete a "prop quiz." This game reviews what students learned about propellers from the previous semester during the lesson on thrust. There are a total of six questions, some with multiple answers, about important terms that will be used in this lesson.

Students should compete as individuals, writing down the answer to each question as it is asked in the presentation. Then, students should exchange their answers with a partner to score their work. Each correct answer is worth 1 point, but an incorrect answer subtracts 1 point. Up to 10 points are possible. The student with the most points at the end of the game wins.

Slides 4-10 present the questions. Slides 11-16 present the answers in the same order.

[DOK-L1; *define, recall*]

EXPLORE

Teacher Materials: Propellers Presentation, Propellers Teacher Notes 1
Student Material: Propellers Student Activity 1

Slide 18: There are two main categories of propeller system: fixed-pitch and variable-pitch. As the name suggests, fixed-pitch propellers have fixed blade angles that cannot be changed. The propeller is usually a single piece of material.

This system is most efficient at a very specific airspeed and engine RPM. Consequently, individual blades have pitches that are less than ideal for takeoff, climb, cruise, descent, or landing; instead the blades are designed with pitches that balance for all phases of flight.

Fixed-pitch propellers are generally simpler, cheaper, and lighter than constant-speed propellers. And they require less maintenance.

Questions

What kinds of aircraft do you think would utilize a fixed-pitch propeller system?
A fixed-pitch system is best for aircraft that prioritize decreased weight, cheaper cost, and simplicity of design. These include smaller, lightweight, general aviation aircraft such as trainers and common recreational aircraft.

Slides 19-20: In general, a fixed-pitch propeller is considered either a climb propeller or a cruise propeller. Each type provides a compromise between speed and power. The aircraft's intended mission drives the manufacturer's decision as to which type of propeller to install.

The climb propeller has a lower pitch; therefore, it creates less drag, which allows for higher RPMs and a greater horsepower output. This delivers greater takeoff and climb performance, but is less efficient for long-range cruising. Hence the name "climb prop."

In contrast, the cruise propeller is designed at a higher pitch, which induces more drag and results in lower RPMs and lower horsepower output. This diminishes takeoff and climb performance, but enables increased efficiency during long-range cruising.

Both types of propellers are typically mounted to shafts that are an extension of the engine crankshaft; consequently, the crankshaft's RPM matches the propeller's RPM. However, on some engines, the propeller is mounted on a shaft that is then geared to the engine crankshaft. Due to the gearing in between, the propeller's RPMs would vary from the engine's RPMs.

Questions

What types of general aviation aircraft would likely utilize a climb propeller, and which would likely utilize a cruise propeller?
Aircraft that need good takeoff and climb performance or that are not used primarily for cross-country travel would use climb propellers. These include airplanes used for backcountry flying, seaplanes, aircraft based at high-elevation airports, and training aircraft. Aircraft that are used primarily for cross-country travel, such as light twins and single-engine aircraft with four to six seats, would be more likely to use cruise propellers.

Slide 21: In fixed-pitch propeller aircraft, the tachometer indicates engine power. Because the propeller is typically mounted to an extension of the crankshaft, the RPMs for the engine and propeller are the same. The green arc on a tachometer denotes the maximum continuous operating RPMs. In some cases, the tachometer may have additional markings that reflect engine and propeller limits.

In aircraft with a fixed-pitch propeller, RPMs are regulated by the throttle, which controls how much fuel-air mixture flows to the engine. (The mixture control, not the throttle, controls how much fuel is in that mixture.) The higher the tachometer reading, the higher the power output of the engine, assuming altitude remains constant. When altitude changes, the tachometer reading changes accordingly, since air density decreases as altitude increases. Therefore, 2,000 RPMs at 5,000 feet produce less horsepower than 2,000 RPMs at sea level. So as altitude changes, the throttle must be increased or decreased to maintain a constant RPM.

Questions

How does a tachometer in a car work? How is it similar to an aircraft? How is it different?
Both instruments show engine RPM. Since a car doesn't have a propeller, however, the tachometer measures the speed at which the crankshaft is turning to send power to the wheels. You don't shift gears in aircraft, but you can in a car to avoid red-lining into hazardous engine RPMs.

Slide 22: Conduct the flight simulation activity.

Simulator Extension Powered by Redbird

Conduct **Propellers Student Activity 1**. Using a simulator, each student will take off, climb, and cruise in an aircraft with a fixed-pitch propeller. Instructions and possible responses are found on **Propellers Teacher Notes 1**.

Teaching Tips

Pause here to have a brief discussion about why running an engine at maximum RPMs is seldom desirable. For cruising, a long-range angle of attack, resulting from a set pitch and power setting, ensures the best range for aerodynamic efficiency and fuel conservation. Even during takeoff and climbout, takeoff-rated thrust (which is still short of maximum) is only recommended for a minimal amount of time: i.e., until obstacles are cleared or the required climb gradient is met. Max thrust puts a strain on the engine(s) (shown as red line RPMs), which can cause damage and potential failure, and should only be considered for crash avoidance—for instance, when losing one or more engines at low altitude or heavy weight.

Slide 23: For a variable-pitch propeller, the angle of the propeller blades can be changed by rotating the blades at the hub. This changes their angle of attack, or pitch. In the first variable-pitch propellers, pitch could be changed with the engine off but not during flight. These became known as ground-adjustable propellers.

The first variable-pitch propeller systems provided only two pitch settings: low and high. Today, most variable-pitch propeller systems are capable of a range of pitch settings.

Though the fixed-pitch propeller is lighter, less expensive, and easier to maintain, the variable-pitch propeller is more efficient.

Slide 24: The most common type of variable-pitch propeller today is a constant-speed propeller. A constant-speed propeller allows the pilot to set a low pitch (high RPM) for takeoff, and a higher pitch (low RPM) for cruise, using a propeller control knob or lever next the throttle. The system then works to maintain that RPM.

Slide 25: The propeller governor is what makes the constant-speed propeller work. The governor takes in oil under pressure from the engine, usually about 50 to 70 pounds per square inch, and boosts it to 300 psi. That pressure is sent to the back side of the propeller, where its job is to push on a plunger that moves gears. The gears change the propeller blade angle. The plunger's position is limited by a "speeder spring" that, in turn, is controlled by the pilot. When the plunger gets to a setting chosen by the pilot, oil is released back to the engine and the plunger maintains its position, keeping rpm constant at that setting.

Show students this video to reinforce what they've learned more about how the governor utilizes the aircraft's oil system to adjust the pitch of the propeller.

- "Constant Speed Prop Basics" (Length 2:38)
  http://video.link/w/q00g

The high and low pitch stops define the propeller's constant-speed range. This is the range of possible blade angles for a constant-speed propeller. So a constant engine RPM will be maintained as long as the propeller blade angle is within the constant-speed range (not against either pitch stop). If the propeller blades contact a pitch stop, engine RPMs will either increase or decrease depending on how airspeed and propeller loads change.

Slide 26: Complete the **Formative Assessment**. This will complete the first session of this lesson.

Formative Assessment

Divide the class into two groups. One group will make the argument for flying with a fixed-pitch propeller. The second group will make the argument for flying with a constant-speed propeller. Have students work together to develop a logical argument for their type of propeller, then select one person from each group to serve as a spokesperson. Allow each side one rebuttal. The group that makes the best argument wins.

Responses in defense of the fixed-pitch propeller should include that it is simple, lightweight, easy to maintain, less expensive, and does not require special management by the pilot. Responses in defense of the constant-speed propeller should include that it maximizes engine power and efficiency for any stage of flight and is adaptable for whatever type of mission the pilot chooses to fly.

[DOK-L3; *develop a logical argument*]

EXPLAIN

Teacher Material: Propellers Presentation

Slide 27: The last session discussed the relationship between RPMs and blade angles. For an aircraft with a constant-speed propeller, a pilot controls power and RPM separately. The throttle controls power and the propeller control sets the RPM. In constant-speed propeller aircraft, power is indicated on the manifold pressure gauge. This gauge measures the absolute pressure of the fuel-air mixture inside the intake manifold. At a constant RPM and altitude, the amount of power produced is determined by the fuel-air mixture delivered to the combustion chamber.

As the throttle is increased, more fuel and air flows to the engine and the manifold pressure increases. When the engine is not running, the manifold pressure gauge should indicate the ambient air pressure (29.92 "Hg on a standard day at sea level). When the engine is started, the manifold pressure indication decreases to less than ambient pressure (i.e., idle at 12 "Hg). If an engine failure or power loss occurs, the manifold pressure gauge will show an increase to match the outside ambient air pressure.

The manifold pressure gauge is color-coded to indicate the engine's operating range. The green arc shows the normal operating range.

Questions

What reading will the manifold pressure gauge give when the engine is off? Why?
The gauge will show ambient air pressure if the engine is off. Because the engine is not producing power, the pressure inside and outside the engine are equal.

Slide 28: The pilot must understand how to operate both the throttle and the propeller control on a constant-speed propeller aircraft. While the throttle controls power output measured in inches of mercury displayed on the manifold pressure gauge, the propeller control regulates engine and propeller RPMs, reflected on the tachometer.

High RPMs and a low blade pitch provides the best takeoff and climb performance. Lower RPMs and a higher blade pitch provides the most efficient cruise performance.

Questions

Why does a pilot need to monitor both the RPMs and the manifold pressure?
Because these measurements are for two different parts of the system, both of which are critical to engine performance. While the RPMs gauge the engine/propeller performance, the manifold pressure considers the strain that the engine is under to produce the force required. That's why both gauges have a green band (normal operating range) and a red line.

Slide 29: To avoid engine stress, increase the mixture and RPM before adding power. Reduce power in the reverse order—reduce power, reduce RPM, then set the mixture.

1. When decreasing power, reduce manifold pressure first, then reduce RPM.
2. When increasing power, increase RPM first, then increase manifold pressure.
3. Note that it's important to minimize operating time at maximum RPM and manifold pressure and to avoid operating at low RPM and high manifold pressure.

Failure to follow these steps may cause engine damage, fatigue, and excessive wear. Emphasize to students that a pilot should always avoid combinations of high manifold pressure and low RPM because it can overstress the engine, just as we can overstress our legs by trying to pedal a bike in high gear up a hill.

Slide 30: If the engine stops or the propeller governor loses oil pressure as with a failure of the pump or seals, the springs in the governor will push the blades to a pitch stop. Failure modes have been considered by engineers in the design of constant-speed propellers and engines:

- If the system fails in a single-engine aircraft, a spring automatically pushes the blades to a flat pitch, which maintains a high RPM and enables the aircraft to keep flying until it can land as soon as practical. This is true for the majority of single-engine propeller-driven aircraft, but some exceptions exist.
- If the system fails in a multi-engine aircraft, the blades "feather"that is, they turn sideways and align with the airflow, which minimizes drag. The engine no longer produces thrust, and the pilot utilizes the remaining engine(s) to reach a suitable landing airfield. This is true for the majority of multi-engine propeller-driven aircraft, but some exceptions exist.

Teaching Tips

If time allows, conduct an activity that will help students visualize how variable-pitch propellers operate. Provide students with a high-powered standing fan and a handheld folding fan.

Stand before the standing fan and set to high power. Fully open the handheld fan and hold it in the path of air. Adjust the fan to simulate blade pitch angle during takeoff. Remind students that during takeoff, the blades are at a low pitch angle. Then instruct students to adjust the fan to simulate the blade twist during cruise. Remind them that at this lower RPM setting, the propeller blades are at a higher pitch angle. Finally, instruct students to simulate feathering in the event of a failure mode.

Ask students:

1. How much resistance did you feel during "takeoff"? During "level off"?
2. How much did "feathering" the fan affect resistance?

EXTEND

Teacher Materials: Propellers Presentation, Propellers Teacher Notes 2
Student Material: Propellers Student Activity 2

Slide 31: Conduct the flight simulation activity.

Simulator Extension Powered by Redbird

Conduct **Propellers Student Activity 2**. Using the simulator, student will take off, climb, and cruise while managing a constant-speed propeller. They will use their observations to answer questions. Instructions and possible responses are provided in **Propellers Teacher Notes 2**.

EVALUATE

Teacher Materials: Propellers Presentation, Propellers Teacher Notes 3
Student Material: Propellers Student Activity 3

Slides 32-37: Quiz students on questions from the Private Pilot Knowledge Test.

Slide 38: Conduct the **Summative Assessment**.

Summative Assessment

Students will imagine they are making a flight in an aircraft with a constant-speed propeller. Following the flight profile in **Propellers Student Activity 3**, they will describe how to use the propeller and throttle controls, the propeller blade pitch angle, and the appropriate instrument readings for each phases of the flight. They will then analyze their own aviation needs and select the right kind of propeller for the missions they plan to fly. Sample answers are provided in **Propellers Teacher Notes 3**.

[DOK-L4, *analyze;* DOK-L1, *label;* DOK-L2, *interpret*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Explanations show evidence of each of the following:
    - Accurate and detailed description of how to manipulate the throttle and propeller controls
    - Thoughtful analysis of how these actions affect aircraft performance and propeller blade pitch
    - Accurate and persuasive supporting evidence for their choice of propeller type
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives
- Correct spelling and grammar

Points **Performance Levels**

9-10 The student accurately describes the correct throttle and propeller control settings for each phase of flight, including the order in which the controls are manipulated. The student correctly describes the manifold pressure and tachometer readings, and accurately describes the propeller blade pitch for each phase of flight. The student provides a logical and thorough argument for their choice of propeller that accurately reflects the type of flying they propose to do and the characteristics of the propeller they have selected.

7-8 The student adequately describes the throttle and propeller control settings for each phase of flight, including the order in which the controls are manipulated. The student provides adequate information about manifold pressure and tachometer readings, and describes the propeller blade pitch for each phase of flight. The student provides reasonable argument for their choice of propeller and includes information about the type of flying they propose to do and the characteristics of the propeller they have selected.

5-6 The student does not correctly describe the throttle and propeller control settings for each phase of flight, or does not accurately describe the order in which the controls are manipulated. The student incorrectly describes the manifold pressure and tachometer readings, and does not accurately describe the propeller blade pitch for each phase of flight. The student provides an inadequate argument for their choice of propeller that does not accurately reflect the type of flying they propose to do and the characteristics of the propeller they have selected.

0-4 The student does not describe the throttle and propeller control settings for each phase of flight, or the order in which the controls are manipulated. The student does not provide information about manifold pressure and tachometer readings, or the propeller blade pitch for each phase of flight. The student does not provide an argument for their choice of propeller.

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.
- **W.9-10.1.D** - Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.
- **W.9-10.2.D** - Use precise language and domain-specific vocabulary to manage the complexity of the topic.

- **W.9-10.4** - Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **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.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/09_phak_ch7.pdf
http://www.boldmethod.com/learn-to-fly/aircraft-systems/how-a-constant-speed-prop-works/
http://hartzellprop.com/whats-the-difference-between-a-fixed-pitch-and-variable-pitch-propeller/