Turbine Engines

Session Time: Two, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The principles of aerodynamics allow an aircraft to fly, yet those same principles limit its ultimate performance and capabilities. (EU2)

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

Safe and efficient aviation operations require that pilots use math, science, and technology. (EU4)

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

ESSENTIAL QUESTIONS

1. How is the type of propulsion system for a specific aircraft determined?
2. How do turbine engines produce more power than reciprocating engines?
3. Are there limits to how much power a turbine engine can produce?

LEARNING GOALS

Students Will Know

- How a turbine engine works
- The different types of turbine engines
- How to manage and monitor a turbine engine using common cockpit gauges
- Some technological differences between turbine and reciprocating engines and know how to apply those differences to flying techniques

Students Will Be Able To

- *Differentiate* between turbojet, turbofan, and turboprop engines. (DOK-L3)
- *Summarize* the five stages of jet engine operation. (DOK-L2)
- *Compare* the power cycle of a reciprocating engine to a turbine engine. (DOK-L3)
- *Distinguish* operating differences between a turbine engine and a reciprocating engine. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
A vocabulary quiz show game will help refresh students' memories about important terms that will be used in this lesson.

Formative Assessment

Working individually, students write a paragraph to describe how the power cycle of a reciprocating engine differs from the “power cycle” of a turbine engine.

Summative Assessment
In pairs, students will write five oral examination questions and answers that pertain to turbine engines and the information learned throughout this lesson. Once the questions are written, students will be paired with someone new, and take turns asking and answering each other's questions.

LESSON PREPARATION

MATERIALS/RESOURCES

- Turbine Engines Presentation
- Turbine Engines Student Activity
- Turbine Engines Teacher Notes
- Turbine Engines Teaching Aid

LESSON SUMMARY

Lesson 1 - Turbine Engines

This two-session lesson will begin with a review of turbine-related terms that students already learned during the previous semester. They will be using these terms throughout this lesson on turbine engines.

In a class discussion, students will review a brief history of turbine engine development and discuss why they were developed and the impact they had on aviation. Students will then review the five stages of a jet engine. As a formative assessments, students will write a paragraph to describe how the power cycle of a reciprocating engine differs from the “power cycle” of a turbine engine.

To finish the first session, students will use the Internet to complete research and determine the similarities and differences between a turbojet, turbofan, and turboprop engine.

Students will then learn about the engine indications that are unique to turbine engines, including engine pressure ratio (EPR), N_1 and N_2, exhaust gas temperature, and torquemeter. They will also cover some of the technological differences between turbine and reciprocating engines and how pilots apply those differences to their flying techniques.

Finally, students will pair up and write five oral examination questions and answers that pertain to turbine engines and the information learned throughout this lesson. Once the questions are written, students will be paired up with someone new, and take turns asking and answering each others’ questions.

BACKGROUND

Students learned about the basics of how a jet engine works during the lesson on thrust last semester. Jet engines operate according to Newton's third law of motion, which states that every force acting on a body produces an equal and opposite force.

Jet engines were developed to get around the limitations of propellers. Instead of moving large amounts of air at low speeds as a propeller does, jet engines move relatively small amounts of air at very high speeds. The jet engine works by drawing in some of the air through which the aircraft is moving, compressing it, combining it with fuel and heating it, and finally ejecting the ensuing gas with such force that the plane is propelled forward. The power produced by such engines is expressed in terms of pounds of thrust.

A jet engine has five stages: Intake, Compression, Combustion, Turbine, and Exhaust.

- Air enters the engine at the intake through suction created by the engine itself.
- This air then passes through a compressor. The compressor section is made up of several stages, each with a set of blades rotating at very high speed. Each stage of the compressor increases the pressure of the air.
- Combustion takes place Inside the combustor where the air is injected with fuel and ignited, creating a contained explosion. Due to the energy released at ignition, the air is pushed through a turbine component and then through the exhaust.
- The turbine component is a series of fans with rotating blades, similar to the compressor section. The high-energy air forces the turbine blades to rotate. A shaft connects the turbine and compressor sections, allowing the turbine to drive the compressor section.
- Next, the high-energy air leaves the engine through the exhaust at high speed. The air moving rearward at high speed propels the engine (and attached aircraft) forward due to Newton's Third Law.

Although the stages rely on simple physics, the high speed, temperature, and pressure put extreme demands on the engine components, especially the fan, compressor, and turbine blades.

A turbojet and a turbofan operate on the same principles, the difference being that a turbofan engine drives a much larger inlet fan, which produces a large percentage of the thrust that the engine is delivering. Much of the additional air going through the fan isn't taken into the engine itself to be combusted, but flows outside the core of the engine. This is called "bypass air," since it is bypassing the interior of the engine. Students should see that the fan is treating the bypass air much as a propeller would, thus delivering some of the advantages of a propeller, such as available thrust at low speed and greater fuel efficiency, to a jet engine. These advantages lead to better acceleration, a shorter takeoff roll, and improved climb performance.

The jet engine, like many technological innovations, took a long time to progress from concept to design to execution. The first attempts to transcend the traditional piston engine were actually modifications of that engine, both heavy and complex. Frank Whittle received an English patent for the jet engine in 1930. Although testing on Whittle's engine began in 1937, it did not fly successfully until 1941. Similar but entirely separate work had begun in Germany in 1935 with a jet engine patent issued to Hans von Ohain. Four years later, the Germans conducted the first entirely jet-powered flight in history.

MISCONCEPTIONS

Even though jet engines are more powerful than reciprocating engines, students may not realize that the acceleration of a jet engine from idle to full power is much slower than the acceleration of a piston engine from idle to full power. This is because in a propeller-driven airplane, a constant speed propeller keeps the engine turning at a constant r.p.m. and power is changed by varying manifold pressure. This means that acceleration of a piston from idle to full power is relatively rapid.

DIFFERENTIATION

Modify the Think-Pair-Share exercise at the beginning of the **EXPLORE** section to include a writing component. This provides teachers with the opportunity to determine if there are problems in comprehension. Before students pair and share their answer, ask them to first write down their answer to the question "Why was there a need to develop aircraft engines that would increase the speed and distance of aircraft?"

LEARNING PLAN

ENGAGE

Teacher Materials: Turbine Engines Presentation, Turbine Engines Teaching Aid

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

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

Warm-Up

A vocabulary quiz show game will help refresh students' memories about important terms that will be used in this lesson.

Divide the class into two evenly-sized groups. Each group selects one student to be the "buzzer." This student will "buzz in" by raising their hand when the group knows the definition of a term.

Refer students to the "Turbine Quiz Show" board on slide 5. Determine which team will select the first category and point value. The teacher should refer to **Turbine Engines Teaching Aid** to read the term associated with the chosen category and point value. Allow the teams to confer on the definition of the term before the "buzzer" raises their hand. The first group to buzz in provides a definition. If the definition is correct, that team has earned the points for that term.

If the definition is inadequate, the other team has a chance to confer and provide a better definition.

The first team that offers the correct definition wins the points and is allowed to choose the next term. Keep a running total of points earned for each team on the board. Once all the terms have been defined, the team with the most cumulative points is the winner.

Be sure to reiterate the correct definition clearly each time.

[DOK-L1; *define, recall*]

EXPLORE

Teacher Material: Turbine Engines Presentation

Slide 6: Students will recall that most early aircraft were powered by gas or diesel reciprocating engines. Reciprocating gasoline engines dominated aviation into the 1940s, but as World War II progressed, there was a need to go faster. Likewise, gas reciprocating engine technology had reached its limit. Engines had become big with lots of cylinders (e.g. Pratt & Whitney produced the R 4630 Wasp engine with 28 cylinders), and complex. This presented many maintenance issues. In addition, the reciprocating engine with a propeller was limited in how fast it could go because of the limitations imposed by propellers.

Slide 7: Sir Frank Whittle from Great Britain and Dr. Hans von Ohain from Germany are recognized as being the co-inventors of the jet engine, even though each worked separately and knew nothing of the other's work.

Whittle was the first to register a patent for the turbojet engine, in 1930, but von Ohain is considered the designer of the first operational turbojet engine (on the Heinkel He 178 airplane). Von Ohain's jet was the first to fly, in 1939. Whittle's jet took off for the first time in 1941.

Slide 8: The turbine engine turned out to be a new technology that offered simplicity, lower maintenance, massive power, and high speed. Initially, jet engines were simple and powerful but consumed huge amounts of gas. In time however, they became much more fuel efficient.

Slide 9: Using Think-Pair-Share, ask students why there was a need to develop engines that would increase the speed and distance of aircraft and why the invention of the jet engine was such a great turning point for aviation.

Questions

Why was there a need to develop engines that would increase the distance and speed of aircraft?
Possible responses: To make travel for people and products faster and more efficient; to connect the world; to get a warfighting advantage.

Why was the invention of the jet engine such a great turning point for aviation?
Possible responses: Airplanes became much more practical for both civil and military uses due to their increased speed and range; non-stop transoceanic flights became possible which became both a threat and an opportunity for the military, which had to figure out how to fly high speed bombers around the world, as well as defend against enemy bombers; for the first time, international travel became easy and affordable for common people; a new category of overnight international trade was born moving perishable and high value cargo; airplanes also became less complex, easier and cheaper to maintain and operate.

EXPLAIN

Teacher Materials: Turbine Engines Presentation, Turbine Engines Teacher Notes
Student Material: Turbine Engines Student Activity

Slide 10: A jet engine is contained within a cowling, an external casing, open to the oncoming air, that serves as an air intake, provides drag reduction, cools the engine by directing airflow, and permits inspection and repair of the interior components.

Attached to each engine is a pylon, a metal arm that joins the engine to the body or wing of the airplane. Through pumps and feed tubes in the pylons, fuel is relayed from wing tanks to the engine, and the electrical and hydraulic power generated by the engine is then routed back to the aircraft through wires and hoses/pipes also contained in the pylons.

Slide 11: Ask students if they can recall the five stages of a jet engine. The next five slides reveal each stage and provide a brief description.

Slides 12-16: A jet engine has five stages: Intake, Compression, Combustion, Turbine, and Exhaust.

Intake - Air enters the engine at the intake through suction created by the engine itself.

Compression - This air then passes through a compressor. The compressor section is made up of several stages, each with a set of blades rotating at very high speed. Each stage of the compressor increases the pressure of the air. To accelerate the progress of the air through the engine, the compressor is fitted with blades that rotate like simple household fans. In the incredibly brief time it takes air to reach the inner end of a typical compressor, it has been squeezed into a space 20 times smaller than the intake aperture.

Combustion - Expanding as it leaves the high-pressure compressor, the air enters the combustor, an interior engine cylinder where the air is injected with fuel and ignited, creating a contained explosion. Due to the energy released at ignition, the air is pushed through a turbine component and then through the exhaust.

Turbine - The turbine component is a series of fans with rotating blades, similar to the compressor section. Its job is to extract enough energy from the hot gases leaving the combustor to power the compressor shaft. The high-energy air forces the turbine blades to rotate. A shaft connects the turbine and compressor sections, allowing the turbine to drive the compressor section.

Exhaust - Finally, the high-energy air leaves the engine through the exhaust at high speed. The air moving rearward at high speed propels the engine (and attached aircraft) forward due to Newton's Third Law.

Slide 17: Conduct the **Formative Assessment**.

Formative Assessment

Working individually, ask students to write a paragraph describing how the power cycle of a reciprocating engine differs from the "power cycle" (or combustion stage) of a turbine engine. Prompt them to think about whether or not each engine produces thrust on its own as a result of what happens during the power cycle or combustion stage.

Collect and grade each students' work. If time allows, ask students to share their answers with the class.

[DOK-L3; *compare*]

Questions

How does the power cycle of a reciprocating engine differ from the "power cycle" of a turbine engine?
A piston engine cannot produce thrust on its own. Once the fuel-air mixture is ignited in a reciprocating engine, the hot expanding gases force the piston away from the cylinder head. Piston force and the subsequent reciprocating motion are converted to rotational motion through the connecting rods and crankshaft, which provides power to a spinning propeller. The spinning propeller produces thrust, resulting in a forward force.

On the other hand, jets produce thrust on their own by igniting a compressed fuel air mixture, which rapidly expands, propelling the aircraft forward.

In addition, a reciprocating engine produces power at discrete moments as each cylinder is ignited, whereas a jet engine produces steady power through a continuous combustion process.

Slide 18: The basic gas turbine engine can be used in a variety of ways. Each has its advantages and disadvantages. During this next activity, students will use the Internet to complete research and determine the similarities and differences between a turbojet, turbofan and turboprop engine.

Provide students with copies of **Turbine Engines Student Activity**. This may be assigned as homework and will complete the first session of the lesson. Teachers may want to review the answers to the questions during the beginning of the second session of the lesson.

EXTEND

Teacher Material: Turbine Engines Presentation

Slide 19: Have students predict which engine instruments might be common to both reciprocating and turbine engines. These include oil pressure, oil temperature, engine speed, and fuel flow.

Slide 20: Students will learn about the engine indications that are unique to turbine engines, including engine pressure ratio (EPR), N_1 and N_2, exhaust gas temperature, and torquemeter.

Slide 21: On some turbine engines, thrust is indicated by the EPR gauge. Essentially, it indicates the power output of a turbine engine. Engine pressure ratio can be thought of as being equivalent to the manifold pressure gauge on a reciprocating engine.

EPR is the difference between turbine discharge pressure and engine inlet pressure. EPR is an indication of what the engine has done with the air it has scooped in. Probes collect data at the inlet and at the exhaust. An EPR setting of 1.498 (reference engine display below) means that the discharge pressure relative to the inlet pressure is 1.498 to 1.

Slide 22: Turbofan engines with two spools or separate shafts, high pressure and low pressure spools, are generally referred to as N_1 and N_2, with each having its own indicator.

On most turbofan engines, N_1 is the primary indication of thrust. N_1 represents the rotational speed of the low pressure compressor. N_1 is presented on the indication gauge as a percentage of design RPM. The N_1 turbine stage is connected to the N_1 low pressure compressor through a low pressure compressor drive shaft.

N_2 represents the rotational speed of the high pressure compressor. The N_2 turbine stage is connected to the N_2 high pressure compressor through a high pressure compressor drive shaft.

Slide 23: The temperature of turbine gases must be closely monitored by the pilot because exceeding temperature limits (even for a very short period of time) can result in serious damage to the turbine blades and exhaust section components.

Turbine gas temperatures can be measured at different locations within the engine and have different names according to the location of the probes.

The most important of these is exhaust gas temperature (EGT). A limiting factor of a turbine engine is the temperature of the exhaust gases as they enter the tailpipe, after passing through the turbine. An EGT gauge provides pilots a way to monitor the temperature of the exhaust gases.

Slide 24: On turboprop engines, torque is used to measure power output (unlike turbojet or turbofan engines where EPR or N_1 is used to measure power output).

In a turboprop, thrust is set using the torquemeter, which measures the torque (in foot-pounds) being applied to the propeller shaft (turned by the gas generator). Torque is the twisting force applied to a turboprop's propeller drive shaft.

Slide 25: Although the principles of aerodynamics are the same, a pilot flying a turbine airplane must consider the technological differences between turbine and reciprocating engines and apply those differences to their flying techniques.

One considerable difference between a reciprocating and turbine engine is the time it takes for the engine to accelerate. In a propeller-driven airplane, a constant speed propeller keeps the engine turning at a constant r.p.m. and power is changed by varying manifold pressure. This means that acceleration of a piston from idle to full power is relatively rapid (about 3-4 seconds). The acceleration of a jet engine is usually much slower. Jet engines are most efficient at high r.p.m. .

When going from idle r.p.m. to high r.p.m., engine acceleration is initially very slow, but then changes to very fast after about 78 percent r.p.m. is reached. Although engine acceleration is nearly instantaneous after 78 percent r.p.m., the acceleration from idle to full power may take as long as 8 seconds. A rapid change in power application from idle to full power could overfuel the engine and cause a flameout in which the fire in the engine unintentionally goes out.

Questions

Ask students if they can think of same phases of flight when this operational difference is very important to consider.

Students may recognize that slow engine acceleration would be an important consideration during a go-around or balked landing situation when an airplane is close to the ground and needs to accelerate and climb quickly because a landing is unsafe. This may be due to a vehicle or animal being on the runway, a rapid switch in wind, etc.

For this reason, many pilots operate at a relatively high thrust setting on final approach to landing or at any other time when immediate power may be needed.

Slides 26-27: During the last semester, students learned that propellers produce thrust by accelerating a large mass of air rearwards, which then passes over the wing and past the empennage and tail section. On a propeller-driven airplane, the total lift developed is a sum of the lift created by the surface area in and out of the propeller slipstream. By increasing or decreasing power, the slipstream is increased or decreased and the total lift changes without changing airspeed.

In a situation where a propeller-driven airplane is too low or slow (like on an approach), a quick application of power remedies the situation quickly. Students just learned this on the last slide. In addition to increasing lift at a constant airspeed, the speed at which the airplane will stall with power on is reduced.

Because of extremely hot exhaust, turbine engines are mounted so that the exhaust does not pass over the wings. While a turbine also produces thrust by accelerating a mass of air rearward, this air doesn't pass over the wings so there is no lift bonus at increased power (such as the lift bonus produced as a result of propeller slipstream). In addition, the power-on stall speed is not reduced by an increase in power at a constant airspeed.

There are three ways in which a turbine pilot is disadvantaged as compared to a piston pilot when it comes to slipstream.

- It is not possible to produce increased lift instantly by simply adding power
- It is not possible to lower the power-on stall speed by simply adding power
- There is much slower acceleration response to an addition of power

Questions

Ask students what this means for a piston pilot and a turbine pilot on an approach to landing?
The answer is that the piston pilot has more room for error because a quick addition of power will salvage a situation where the pilot is too low or too slow. Students should also conclude that a stabilized approach in a jet should be flown fully configured for landing (lots of drag) and at higher power settings. This allows for a more immediate response from the engine since it is already operating at a higher r.p.m.

EVALUATE

Teacher Material: Turbine Engines Presentation

Slide 28: Conduct the **Summative Assessment**.

Summative Assessment

To fly a high-performance turbine airplane a pilot must take an oral exam administered by an FAA examiner. To pass, the pilot must answer a majority of the questions asked by the examiner.

The questions may be related to operations, systems, operating limitations, regulations, and/or scenarios in which the candidate would describe what might be happening with the airplane and what they might do to diagnose or correct a scenario.

In this summative assessment, students will pair up and write five oral examination questions and answers that pertain to turbine engines and the information learned throughout this lesson. Once the questions are written, students should be paired with someone new, and take turns asking and answering each other's questions.

Examples of questions include

- Explain the main difference and advantage of a turbofan over turbojet engine.
- Name the major components of a gas turbine engine.
- Describe the five stages of gas turbine engine operation.
- What is the purpose of a compressor? What drives the compressor?
- What are some engine instruments that a pilot would use to set power and monitor a turbine engine?
- What is bypass air?

Teachers may choose to show students this video of a mock oral examination.

- "Private Pilot Oral Exam" (Length 2:46)
  https://video.link/w/ZMXg

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Questions and answers show evidence of the following:
  - Knowledge of turbine engine key components and their operation
  - Explanation of differences between reciprocating and turbine engines
  - Knowledge of how to monitor the health of a turbine engine
  - Differences between different types of turbine engines
- Questions and answers show understanding of the concepts covered in the lesson
- Questions and answers show in-depth thinking including analysis or synthesis of lesson objectives

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

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.grc.nasa.gov/WWW/K-12/airplane/shortp.html
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