



# Turbochargers and Superchargers



Session Time: One, 50-minute session

## DESIRED RESULTS

### ESSENTIAL UNDERSTANDINGS

Innovations in aviation are driven by the desire to make aircraft safer, more capable, and more efficient. (EU2)

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. (EU3)

### ESSENTIAL QUESTIONS

1. What limits an airplane's ability to fly higher?
2. How does technology affect those limits?

### LEARNING GOALS

#### Students Will Know

- Engines depend on air pressure to produce power.
- As airplanes climb and air pressure decreases, the ability of an engine to produce power also decreases.
- Superchargers and turbochargers increase the air pressure in the induction system, allowing engines to produce more power at higher altitudes

#### Students Will Be Able To

- *Describe* forced induction systems. (DOK-L2)
- *Differentiate* between turbochargers and superchargers. (DOK-L3)
- *Explain* the benefits and operational considerations in terms of what they've learned about engines throughout this unit. (DOK-L3)
- *Assess* whether forced induction or normally aspirated engines would be the most effective specific scenarios. (DOK-L3)

## ASSESSMENT EVIDENCE

#### Warm-up

Students watch a video on the use of forced induction in automobiles, then discuss why the same principles could be useful in aircraft.

#### Formative Assessment

Students will write and deliver a brief sales pitch to persuade pilots that they should purchase a forced induction engine.

#### Summative Assessment

Students will label diagrams of different forced induction systems, making note of the airflow. Students will also explain the advantages and disadvantages of each type of forced induction system.

### MATERIALS/RESOURCES

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- [Turbochargers and Superchargers Presentation](#)
- [Turbochargers and Superchargers Student Activity 1](#)
- [Turbochargers and Superchargers Student Activity 2](#)
- [Turbochargers and Superchargers Teacher Notes](#)
- [Turbochargers and Superchargers Teaching Aid](#)

#### Air for Ignition Demonstration

- Lighter
- Candle that can stand on its own (votive, tea light, or pillar candles work well)
- Clear glass container large enough to completely cover the candle without touching the wick (A glass, jar, or vase will work well)
- Tongs or a hot pad that will allow the glass container to be placed over the candle and removed without burning the demonstrator
- Safety goggles

#### Recommended Student Reading

- **Pilot's Handbook of Aeronautical Knowledge**  
Chapter Seven, Aircraft Systems, pages 7-12 to 7-15 [https://www.faa.gov/regulations\\_policies/handbooks\\_manuals/aviation/phak/media/09\\_phak\\_ch7.pdf](https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/09_phak_ch7.pdf)

### LESSON SUMMARY

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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 lesson begins with an overview of the theory that makes turbochargers and superchargers work—forced induction. Students will learn about the problems turbochargers and superchargers are designed to solve and make the connection between this common automobile technology and its use in aircraft.

Students will refresh their understanding of the effects of altitude on air pressure and density, and watch a simple demonstration of the importance of oxygen for ignition using a candle and a glass container. Students will observe how forced induction can strengthen the flame. Students will learn about the concept of an aircraft service ceiling and how the use of a turbocharger or supercharger can provide increased power and allow an aircraft to fly higher.

Students will then use what they've learned to write a short sales pitch to persuade pilots to purchase a forced induction engine.

Students will then examine the mechanics of turbochargers in greater depth, learning about components of the system as well as the operational considerations and limitations. Next, students will look at superchargers, including their components. Finally, students will consider the differences between the two systems and the advantages and disadvantages of each.

### BACKGROUND

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The concept of forced induction is neither new nor complicated. In fact, using a bellows to fan a flame is a simple form of forced induction. Even in aviation, the idea has been around for a long time. Superchargers were common in World

War II military aircraft. However, unlike today’s systems, early superchargers placed a high workload on the pilot who had to actively manage the system at every stage of flight.

In modern aircraft, two types of forced induction systems are in common use, turbochargers and superchargers. Both systems compress air, which is then forced into the engine to provide greater air density (and therefore more oxygen) for combustion.

As altitude increases and air density decreases, less and less oxygen is available for combustion, reducing the engine’s ability to produce power. In a normally aspirated engine (one without a forced induction system), it is impossible for manifold pressure to exceed ambient air pressure. So as the aircraft climbs higher, the pressure in the engine decreases. Eventually, the engine can no longer produce enough power for the aircraft to climb at a prescribed rate, typically 100 feet per minute. This point is known as the service ceiling of the aircraft. The point beyond which the aircraft can no longer maintain altitude is known as the absolute ceiling.

By compressing air to provide more oxygen in the same volume of space (for example, the volume within an engine cylinder), forced induction systems provide higher manifold pressures, making it possible for the engine to continue producing power at relatively higher altitudes. This system improves efficiency and power output at any altitude, providing increased true airspeeds and higher service ceilings than normally aspirated engines can achieve.

The key difference between turbochargers and superchargers lies in the power source for compression. A supercharger relies on an engine-driven air pump or compressor, while a turbocharger gets its power from exhaust gases that are routed through a turbine, which in turn spins the compressor.

Turbochargers are more efficient, but also suffer from a lag between the time the throttle is applied and the time the turbine spools up to deliver compressed air. Superchargers are less efficient but do not suffer from this same lag.

An aircraft with either of these systems has a manifold pressure gauge, which must be carefully observed in flight for safety. High RPMs and hot temperatures associated with forced induction systems—especially turbochargers—mean pilots must closely monitor these systems, continuously checking manifold pressure, oil pressure, and oil temperature.

## MISCONCEPTIONS

Students may think of turbochargers and superchargers mainly as components used to “boost” engine performance in a car or truck. Students may have preconceived notions from auto racing or from movies or television. They are unlikely to realize that these components have been used in aircraft since World War II and are commonplace in modern aircraft.

## DIFFERENTIATION

To support student comprehension in the **EXPLORE** and **EXPLAIN** sections, provide a graphic organizer such as a Know /Want-to-Know/Learned (KWL) for students to complete regarding the information on superchargers and turbochargers. This will allow students to better understand the structure of new information on forced induction and also connect working and long-term memories.

## LEARNING PLAN

### ENGAGE

**Teacher Material:** [Turbochargers and Superchargers Presentation](#)

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

**Slides 4-5:** Conduct the **Warm-Up**.

### Warm-Up

Show students a video introducing the concept of forced induction and why it is used in many cars.

“Forced Induction - System Principles” (Length 2:10)

<http://video.link/w/rGUf>

In the video, students will learn that turbochargers used on automobiles help increase the amount of air and therefore oxygen available to help burn fuel in the combustion stroke and that at higher RPMs the reduced time between strokes can make it difficult for a normally aspirated engine to bring in enough air to fill the cylinder ahead of combustion.

After students watch the video, lead a brief class discussion asking the following questions:

- What problems do turbochargers used on cars help solve?
- How might these same problems apply to aircraft?
- What advantages would a turbocharged aircraft have over an aircraft with a normally aspirated (non-turbocharged or supercharged) engine?

[DOK-L3 Hypothesize; DOK-L3 Compare]

## EXPLORE

**Teacher Materials:** [Turbochargers and Superchargers Presentation](#), [Turbochargers and Superchargers Teaching Aid](#)

**Student Material:** [Turbochargers and Superchargers Student Activity 1](#)

**Slide 6:** There are two main types of forced induction systems used in aircraft: turbochargers and superchargers. Both bring compressed air into the engine, helping increase the efficiency of combustion and delivering more horsepower and higher true airspeeds. Forced induction systems are effective at any altitude--but their benefits are most notable at high altitudes where air is less dense.

**Slide 7:** All internal combustion engines need air to operate. More specifically, they need oxygen in order to burn fuel. Remind students that as altitude increases, atmospheric pressure decreases at the rate of about 1” Hg per every 1,000 feet. As the density of the air decreases, the same volume of air (such as the volume of air that fits inside an engine cylinder) holds fewer molecules. That means there are fewer molecules of oxygen to support combustion, which reduces engine efficiency and power output.

**Slide 8:** Conduct a simple demonstration to reinforce what students already understand about the role of air in ignition and combustion and show them how a very primitive form of forced induction (blowing onto a flame to increase the available oxygen) affects ignition. Step-by-step instructions are provided in **Turbochargers and Superchargers Teaching Aid**.

**Slide 9:** Just as lack of air made it difficult or impossible for the flame to keep burning in the demonstration, insufficient air makes it difficult or impossible for an engine to effectively burn fuel. As a normally aspirated aircraft climbs, the air density continues to decrease until it reaches a point where the manifold pressure is insufficient to give the airplane’s engine enough power to climb at a specified rate (usually greater than 100 feet-per-minute). This is known as the airplane’s *service ceiling*. (Remind students that manifold pressure is the pressure inside the engine’s induction system. In a normally aspirated engine, it is not possible to have manifold pressure that is greater than the outside air pressure.) The *absolute ceiling* is the altitude above which an aircraft can no longer sustain level flight.

If the engine’s induction air can be pressurized so that more oxygen is contained in the same volume of air, the airplane will be able to operate at:

- Higher altitudes

- Higher true airspeeds

**Slide 10:** Complete the **Formative Assessment**.

### Formative Assessment

Provide each student with a copy of **Turbochargers and Superchargers Student Activity 1**. Working individually, students will imagine they are aircraft salespeople and create a brief “elevator” sales pitch to persuade pilots that they should purchase an aircraft with a forced induction system. If time permits, have students deliver their sales pitch to the class.

*Possible student response: Get better performance from takeoff through landing with a turbocharged or supercharged engine. By delivering compressed air to the combustion chamber, our forced induction systems will give increased airspeeds, more efficient performance, and a higher service ceiling. You'll be able to fly faster and higher than ever before.*

[DOK-L3 Formulate; DOK-L2 Explain]

**Slide 11:** Turbochargers are the most efficient method of increasing horsepower. A turbocharger uses the engine's exhaust gases to drive a turbine that compresses the exhaust air. This compression process heats the air, which must then pass through an intercooler to cool it down, further increasing the air density. The cooled and compressed air is then routed into the engine through the carburetor or fuel injection system. Its increased density provides the “boost” needed to increase engine power output.

Play video describing the function while showing animation of a turbocharger:

- “How a Turbocharger Works!” (Length 3:42)  
<http://video.link/w/xyEf>

After watching the video, review the diagram on the slide with students, emphasizing the path air follows through the system.

## EXPLAIN

**Teacher Material:** [Turbochargers and Superchargers Presentation](#)

**Slides 12-13:** As the video showed, the turbocharger components consist of the:

1. Wastegate: An adjustable butterfly valve used to control the amount of exhaust gases flowing over the turbine. So when the valve is closed, almost all of the exhaust gases flow over the turbine. When it's open, the exhaust gases bypass the turbine and flow out through the exhaust system. Being able to limit the amount of gas flowing through the turbine helps prevent an “overboost” condition, which can damage the engine.
2. Turbine: Connected to the impeller by a drive shaft and driven by exhaust gases from the engine. The amount of air compression is controlled by using varying amounts of exhaust gases flowing over the turbine.
3. Compressor: Houses an impeller (fan) that is turned at a high rate of speed by a drive shaft connected to the turbine. As induction air is drawn across the impeller blades, the air is accelerated, which draws large volumes of air into the compressor housing. This produces high-pressure, high density air that is delivered to the engine

4. Intercooler: A heat exchanger. Since compression causes the induction air temperature to rise, the intercooler uses outside air to cool the hot, compressed air before it enters the fuel metering device, which reduces the risk of detonation in the cylinders.

**Slide 14:** Most modern turbocharged aircraft have an automatically actuated wastegate that maintains the desired manifold pressure based on throttle setting. But some turbocharged systems use a manual wastegate control wherein the manifold pressure must be closely monitored. If left in a high power setting while descending from altitude, the manifold pressure could exceed the engine's limitation. This is known as overboost, which could lead to severe detonation or structural failure.

Even with an automatic wastegate system, overboost conditions can still occur, such as when applying takeoff power while the oil temperature is below its normal operating range. This is possible because cold oil may not flow out of the wastegate actuator quickly enough to prevent the overboost condition.

Since turbochargers can spin in excess of 80,000 RPM, they produce extremely high temperatures. Therefore, engine oil must be constantly supplied to lubricate and cool the components, the pilot must monitor the oil supply and temperature. If the oil supply fails, the components could rapidly overheat, seize up, or even experience structural failure.

**Slide 15:** As the airplane climbs, the wastegate incrementally closes in order to maintain the maximum allowable manifold pressure. When the aircraft reaches the engine's critical altitude, the wastegate should be fully closed. Above this altitude, the engine will experience decreased power just as a normally aspirated aircraft engine would. Below the critical altitude, decreases in power may be a sign of system trouble and may require maintenance. A pilot's crosscheck and vigilance in this matter is extremely important.

**Slide 16:** The supercharger is an engine-driven air pump or compressor. Outside air is pulled into the compressor, where an impeller (fan) speeds up and compresses the air. The supercharger is placed between the fuel metering device (carburetor) and intake manifold.

Like a turbocharger, a supercharger has a critical altitude beyond which it can no longer compress air sufficiently to maintain maximum power. Unlike a turbocharger, a supercharger puts an additional load on the engine because it is used to power the compressor.

## EXTEND

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**Teacher Material:** [Turbochargers and Superchargers Presentation](#)

**Slide 17:** The video, "Supercharger vs Turbocharger", <http://video.link/w/sGUf> (Length 1:45) provides a simple overview of the differences between turbochargers and superchargers. Review the advantages and drawbacks of each type of forced induction system with students. Superchargers respond instantly to throttle input, but are less efficient than turbochargers. However, turbochargers can experience lag as they must wait for the exhaust gas to pass over the turbine and drive the induction fan. Superchargers put an additional load on the engine because it powers the compressor, while turbochargers do not. Both systems produce considerable heat, though the high RPMs of the turbocharger create more extreme conditions. Pilots must monitor manifold pressure and oil temperature and pressure carefully to prevent detonation and engine damage.

## EVALUATE

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**Teacher Materials:** [Turbochargers and Superchargers Presentation](#), [Turbochargers and Superchargers Teacher Notes](#)

**Student Material:** [Turbochargers and Superchargers Student Activity 2](#)

**Slide 18:** Conduct the **Summative Assessment**.

### Summative Assessment

Using **Turbochargers and Superchargers Student Activity 2**, students will label the key components of a turbocharger diagram and show the flow of air through the system. They will also answer questions about the function and benefits of each system. Answers and instructions are available in **Turbochargers and Superchargers Teacher Notes**.

#### Summative Assessment Scoring Rubric

- Follows assignment instructions
- Explanations show evidence of each of the following:
  - Accurate and detailed description of the turbocharger components and operation
  - Accurate assessment of aviation fleet scenarios with explanations that show clear understanding of where a forced induction engine system would be most appropriate
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives
- Correct spelling and grammar

| Points | Performance Levels |
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| 9-10 | All answers were complete and accurate; scenario answers demonstrated strong evidence of a complete understanding of forced induction systems. |
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| 7-8 | Accurate and detailed answers, shows strong evidence of understanding forced induction systems; few errors |
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| 5-6 | Most answers were complete, but lacked accuracy or detail that show strong evidence of lesson objectives |
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| 0-4 | Numerous incorrect or incomplete answers, little to no evidence of meeting lesson objectives |
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[DOK-L1 Define; DOK-L3 Assess]

## GOING FURTHER

During World War II, radial engines were often equipped with single stage, two-speed superchargers, sometimes called turbosurperchargers. The pilot controlled the lever which powered the low blower and high blower.

- Low blower: used for takeoff and operations at lower altitudes - known as a ground-boosted engine
- High blower: engaged at a certain altitude to provide power as the airplane climbs

This Army Air Forces training video provides insight into how these aircraft operated. (Length 10:20)

<http://video.link/w/tGUf>

After watching the video, have students write two to three paragraphs explaining the value of supercharged aircraft to the war effort and discussing operational considerations and risks associated with the use of early supercharged aircraft like the one in the training film.

## STANDARDS ALIGNMENT

## NGSS STANDARDS

### Three-dimensional Learning

- **HS-PS3-2** - Develop and use models to illustrate that energy at the microscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).
  - Science and Engineering Practices
    - Developing and Using Models
  - Disciplinary Core Ideas
    - PS3.A Definitions of Energy
  - Crosscutting Concepts
    - Energy and Matter

## 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](https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/09_phak_ch7.pdf)  
<https://www.aopa.org/training-and-safety/students/solo/special/turbochargers>