Airspeed Indicator

Session Time: Two, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

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

Safe and efficient aviation operations require that pilots use math, science, and technology. (EU3)

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. (EU4)

ESSENTIAL QUESTIONS

1. How does an airspeed indicator work?
2. Which airspeeds are critical for a pilot to know?

LEARNING GOALS

Students Will Know

- Functions of an airspeed indicator
- Different types of airspeed
- Airspeed limitations used to operate light aircraft safely

Students Will Be Able To

- *Describe* the components and operation of an airspeed indicator. (DOK-L2)
- *Interpret* the standard markings on an airspeed indicator. (DOK-L4)

ASSESSMENT EVIDENCE

Warm-up
Students will blow balloons up and answer questions about how the principle of inflating a balloon relates to the speed of an aircraft.

Formative Assessment
Students will describe the components and operation of an airspeed indicator. They will also define the various types of airspeed.

Summative Assessment
Using an airspeed indicator, students will analyze the markings/colors on an airspeed indicator and demonstrate what they have learned about important airspeeds.

LESSON PREPARATION

MATERIALS/RESOURCES

- Airspeed Indicator Presentation
- Airspeed Indicator Student Activity 1
- Airspeed Indicator Student Activity 2
- Airspeed Indicator Student Activity 3
- Airspeed Indicator Teacher Notes 1
- Airspeed Indicator Teacher Notes 2
- Airspeed Indicator Teacher Notes 3

Balloon Warm-Up Demonstration

- One (1) latex balloon per student

Flight Simulation Activity

- Flight simulation equipment

Recommended Student Reading

- **Pilot's Handbook of Aeronautical Knowledge**
  Chapter Eight, Flight Instruments, pages 8-8 through 8-10 https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/10_phak_ch8.pdf

LESSON SUMMARY

Lesson 1: Altimeter and VSI
Lesson 2: Airspeed Indicator
Lesson 3: Pitot-Static Failures

In this two-session lesson, students will learn what an airspeed indicator is, how it works, and how its measurements are used to calculate different kinds of airspeeds and determine safe airspeeds for various maneuvers.

Students will begin the lesson by blowing balloons up and answering questions about how the principle of inflating a balloon relates to the speed of an aircraft. Students will then learn that an airspeed indicator is a very sensitive differential gauge that uses dynamic and static pressure to determine airspeed. Students will learn about the four main types of airspeed: indicated (the number revealed), calibrated, true, and groundspeed. Students will then learn about the various markings on the dial, which tell pilots when it is safe to perform various maneuvers or operations during flight.

Students will complete a flight simulation activity in which they evaluate the utility and importance of the airspeed indicator. During a summative assessment, students will analyze the markings/colors on an airspeed indicator and demonstrate what they have learned about important airspeeds.

BACKGROUND

The airspeed indicator is an indispensable cockpit instrument. It's one of the few required by regulations to be operational on all types of flights, which demonstrates its significant role in keeping us flying safely. A quick glance at an airspeed indicator can tell pilots much about the current state of the aircraft.

The airspeed indicator is the only pitot-static instrument that used both dynamic and static pressure to operate. It is a scale that measures the difference between the static pressure from the static ports, and the total pressure (dynamic + static) from the pitot tube.

Airspeed is marked on the face of the instrument in either miles per hour (mph), nautical miles per hour (knots), or both. There are a variety of airspeeds that pilots need to know. Indicated airspeed (IAS) is read directly from the face of the airspeed indicator. Calibrated airspeed (CAS) is indicated airspeed corrected for installation and instrument errors (such as the effect of unusual angles of attack on the pitot-static system). True airspeed (TAS) is calibrated airspeed corrected for non-standard temperature and pressure. Finally, groundspeed is the speed of the aircraft relative to the ground. It is true airspeed adjusted for winds.

The different airspeeds that either limit or result in specific aircraft performance are known as V speeds—V for velocity. V speeds are important or useful to the operation of all aircraft. V speeds are derived from data obtained by aircraft manufacturers during flight testing. A good pilot selects a specific, appropriate airspeed for every flight operation and knows how to achieve it. Limiting speeds such as maximum flap and gear extension speeds, never-exceed speed, and minimum controllable airspeed, will help a pilot avoid structural damage. On the low side of the airspeed indicator, pilots want to avoid stalls.

MISCONCEPTIONS

Students may assume that an airspeed indicator measures the actual speed of the aircraft as it moves over the ground. In fact, the pitot tube measures total or ram air pressure to provide the speed indication. This should not be confused with velocity of the air moving into the tube. The air doesn't flow past the airspeed indicator. Instead, it pushes on a diaphragm, and the difference between the static pressure from the static port, and the ram air pressure from the pitot tube results in the airspeed indication.

DIFFERENTIATION

To support student memory and recall in the **EXPLORE** section of the lesson plan, have students create a graphic organizer. First, have them fold a piece of paper into four squares and write each of the following terms in one of the squares: Indicated (IAS), Calibrated (CAS), True (TAS), and Groundspeed (GS). On the back side of the paper, have students write each of the following terms in one of the squares: white arc, green arc, yellow arc, and red line. Encourage students to jot down notes and questions as they learn about these terms during the lesson.

LEARNING PLAN

ENGAGE

Teacher Material: Airspeed Indicator Presentation

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

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

Warm-Up

During this warm-up, students will think about how the principle of inflating a balloon relates to the speed of an aircraft.

Provide a medium to large latex balloon to each student. Ask them to blow the balloons up and observe that the rate at which the balloons inflate depends on the rate at which air enters the balloons. Ask them to think about the following questions:

Do you think you could you use a balloon to tell how fast an airplane is going?
Students may surmise that if dynamic pressure (a concept they learned about in the previous lesson) was

introduced at the opening of the balloon, it would inflate. The rate at which the balloon inflates would be an indication of the speed at which the air is travelling.

How would the rate at which the balloon inflates relate to the actual speed of the airplane?
The faster the airplane is traveling, the faster the balloon would inflate.

What part of the airplane mimics the opening of the balloon?
Students may recognize that the opening of the balloon, which captures the dynamic pressure from their breath, is similar to the pitot tube, which captures ram air pressure as the airplane moves through the air.

[DOK-L2; *make observations]*

EXPLORE

Teacher Material: Airspeed Indicator Presentation

Slide 5: The airspeed indicator is an indispensable cockpit instrument. It's one of the few required by regulations to be operational on all types of flights, which demonstrates its significant role in keeping us flying safely. A quick glance at an airspeed indicator can tell pilots much about the current state of the aircraft.

An airspeed indicator is a very sensitive differential pressure gauge. It measures the difference between dynamic and static pressure around the aircraft, and translates this measure into a number that indicates airspeed. The airspeed indicator utilizes both dynamic and static pressure.

Remind students they learned about dynamic, static, and total pressure in the previous lesson, and quiz them now to confirm they remember. Have students complete a Think-Pair-Share before you reveal the correct definitions on the next slide.

Questions

Can you recall the difference between static, dynamic and total pressure?

Static or "ambient" pressure is the pressure from still air. It is the pressure of a fluid on a body when the body is at rest relative to the fluid - in this case, the fluid is air. With static pressure, air presses equally in all directions. It is always present on an aircraft, whether it is at rest or in motion.

Dynamic pressure is the pressure of the air that results only from its motion. Because static pressure from still air is always present, it cannot be separated to directly measure only dynamic pressure. Instead, the difference between the total pressure and the static pressure is used to find dynamic pressure.
Total Pressure - Static Pressure = Dynamic Pressure.

Total or "ram" pressure is the pressure from moving air as it is brought to a stop. Everyone has put their arm out of the car window while driving on a nice day and felt the pressure against their hand. The pressure against the hand, where the moving air is stopping against the skin, is total pressure. The pressure behind the hand, where the air is still, is static pressure.
Static Pressure + Dynamic Pressure = Total Pressure

Slide 6: Static pressure is the pressure from still air. It is always present whether at rest or in motion. Dynamic pressure is pressure as a result of motion. It is the difference between total and static pressure. When an object is moving, the pressure of the moving air as it is brought to a stop is known as total or "ram" pressure. Total pressure is dynamic pressure plus static pressure.

When the aircraft is sitting on the ground, in still air, there is no motion and so the static and ram pressures are equal; there is no dynamic pressure; and consequently, the airspeed indicator will show airspeed as zero. As the aircraft moves faster, the dynamic pressureand thus the airspeedincreases.

Slides 7-8: The airspeed indicator, is essentially a scale that measures the difference between the static pressure from the static port, and the total pressure (dynamic plus static) from the pitot tube. The static pressures cancel each other out, and what's left is dynamic pressure.

The airspeed indicator is the only flight instrument that uses the pitot tube. It takes the total air pressure that enters the front of the pitot tube and directs it to the back of the instrument. There, it meets a closed disk or diaphragm that sits inside the back of the case. The instrument case is sealed, except for a small hole that is directly connected to the static port.

As the total air pressure pushes against the diaphragm, the diaphragm expands. A gear or series of gears are attached to a diaphragm, which is then attached to a needle that indicates on the face of the instrument. As the pressure increases (more speed means more pressure), the diaphragm expands and the needle moves to higher numbers around the dial, showing that the aircraft is moving at higher airspeeds.

Teaching Tips

For a more hands-on approach for teaching the mechanisms of an airspeed indicator, consider purchasing one or more used airspeed indicators (around $10 on eBay). In class, disassemble and dissect the inner workings of the airspeed indicator, so that students can get a better understanding of how the diaphragm, gears, and needle function together.

EXPLAIN

Teacher Materials: Airspeed Indicator Presentation, Airspeed Indicator Teacher Notes 1
Student Material: Airspeed Indicator Student Activity 1

Slide 9: Airspeed is the velocity of an airplane relative to the air mass through which it is flying. The dial of an airspeed indicator displays dynamic pressure in knots (kts) or miles per hour (mph). Some airspeed indicators, particularly for jet aircraft, measure Mach number: the ratio of aircraft speed to the speed of sound in air.

Just as there are several types of altitudes, there are also several types of airspeeds. The following slides provide more detail about each type of airspeed.

- Indicated airspeed (IAS): the number read off the dial
- Calibrated airspeed (CAS): IAS corrected for instrument and installation errors
- True airspeed (TAS): indicated airspeed that's been corrected for temperature and barometric pressure variations from standard sea level conditions
- Groundspeed (GS): true airspeed adjusted for wind (actual speed of the aircraft as it moves over the ground)

Slide 10: Indicated airspeed (IAS) is the number read directly from the airspeed indicator dial. It is uncorrected for variations in atmospheric density and temperature, and installation and instrument error. Indicated airspeed is an indication of airflow over the wings. Manufacturers use IAS to determine aircraft performance; the takeoff, landing, and stall speeds listed in the Pilot's Operating Handbook for a particular aircraft are typically indicated airspeeds (which should be adjusted for gross weight, density altitude, and environmental conditions).

Slide 11: Calibrated airspeed (CAS) is the indicated airspeed corrected for installation error and instrument error. In some aircraft, for example, the design of the fuselage or wings requires the pitot system to be placed in a way that changes the dynamic pressure entering the pitot tube. Airspeed indicator errors can also be caused by the instrument's proximity to other instruments or sources of heat and by changes in air flow caused by certain flap and gear settings.

The errors that affect IAS are usually most pronounced at low airspeeds; most of the time, IAS and CAS are very close. At certain airspeeds and flap settings, however, the difference between IAS and CAS may be several knots. The airspeed calibration chart in the Pilot's Operating Handbook shows the difference between calibrated airspeed and indicated airspeed at different flap settings and speeds.

Slide 12: True airspeed (TAS) is the calibrated airspeed corrected for temperature and barometric pressure variations from standard sea level conditions—15 degrees Celsius and a barometric pressure (altimeter setting) of 29.92 inHg.

Because the air is less dense at higher altitudes, dynamic air pressure is lower for a given airspeed (hot air is also less dense than cold air; thus, hotter air produces lower dynamic pressure). Remember, the airspeed indicator does not directly measure airspeed: it measures the difference between dynamic and static pressure, so as dynamic pressure decreases, indicated airspeed (the number shown on the airspeed indicator dial) and calibrated airspeed (IAS adjusted for various errors) will likewise decrease, even if the airplane is not actually slowing down. In other words, the airplane must fly faster in less dense air to cause the same pressure difference between dynamic pressure and static pressure. Therefore, if flying the same IAS, TAS will increase with altitude. If flying the same TAS, IAS will decrease with altitude.

True airspeed is calculated from calibrated airspeed using a manual or electronic flight computer; it can also be estimated by adding 2 percent of the calibrated airspeed for every 1,000 feet of altitude. (For example, suppose that CAS at 10,000 feet is 100 knots. To estimate TAS, add 2 knots, or 2 percent of 100 knots, for every 1,000 feet: TAS would be approximately 120 knots.) Pilots use true airspeed to create and file a flight plan.

Slides 13-14: Groundspeed (GS) is true airspeed adjusted for wind. It is the actual speed of the aircraft as it moves over the ground.

Groundspeed increases with a tail wind (i.e., a wind from behind that pushes the aircraft forward) and decreases with a headwind (i.e., a wind from ahead that opposes the aircraft). Pilots use groundspeed to determine how long it will take to reach a destination and how long their fuel will last.

Questions

Ask the students what is the groundspeed of an aerobatic airplane flying straight up?
An airplane flying completely vertically would have zero groundspeed since it is not traveling across the ground, it is flying perpendicular to the ground.

Questions

On slide 14, ask students to make the following calculations:

Determine the groundspeed for an airplane with a TAS of 120 knots in a 30-knot headwind.
The airplane has a groundspeed of 90 knots. 120 - 30 = 90 knots

Determine the groundspeed for an airplane with a TAS of 120 knots with an 18-knot tailwind.
The airplane has a groundspeed of 138 knots. 120 + 18 = 138 knots

Slide 15: Complete the **Formative Assessment.** This will likely conclude the first session.

Formative Assessment

Provide each student with a copy of **Airspeed Indicator Student Activity 1.** In this activity, students will describe the components and operation of an airspeed indicator. They will also define the various types of airspeed. Either individually or in pairs, students should answer each question.

Correct responses are provided in **Airspeed Indicator Teacher Notes 1**.

[DOK-L2; *describe, explain*]

Slide 16: The different airspeeds that either limit or result in specific aircraft performance are known as V speeds—V for velocity. V speeds are important or useful to the operation of all aircraft. V speeds are derived from data obtained by aircraft manufacturers during flight testing.

For airplanes with a maximum gross weight of less than 12,500 pounds and certificated after 1945, the FAA requires that some of the most important V speeds are color-coded on the airspeed indicator. This enables pilots to quickly determine how their aircraft velocity conforms to certain airspeed limitations, and whether they are at a safe speed for their current phase of flight or need to either increase or decrease their speed.

The numbers on the airspeed indicator increase as the needle moves clockwise around the dial. The dial also includes several colored arcs and lines, which indicate speeds or speed ranges in which an aircraft may safely fly under certain conditions.

Additionally, some important airspeeds are *not* marked on the airspeed indicator (the dial isn't large enough to show every important airspeed); instead, they are identified on placards in the cockpit or in the Pilot's Operating Handbook.

The next few slides will describe the most-important airspeed markings and address each of the color-coded ranges.

Slide 17: The white arc denotes the speeds at which the aircraft can be flown with its flaps fully extended.

The "bottom" end of the white arc, or the lowest speed in the white arc, denotes V_{SO}. V_{SO} is the power-off (engine at idle) stall speed at the maximum landing weight in the landing configuration (gear and flaps down). V_{SO} is an important speed to monitor, especially when landing.

The "top" end of the white arc, or the highest speed in the white arc, denotes $V_{FE.}$ $V_{FE.}$ represents the maximum speed at which the airplane can be flown with its flaps fully extended. Flying at speeds greater than V_{FE} with full flaps can result in damage, perhaps to the point of losing one or both flaps.

Questions

Ask the students to look at the airspeed indicator on the slide and observe the speeds or speed range for $V_{SO,}$ $V_{FE,}$ and the white arc.

V_{SO} - 40 knots
V_{FE} - 85 knots
White arc - 40 - 85 knots

Slide 18: The green arc spans the aircraft's normal operating range, where most flying takes place. Notice that it partly overlaps with the white arc. It starts with V_{S1} at the "bottom" of the green arc. V_{S1} is the velocity at which the airplane will stall at maximum takeoff weight, with power off (power at idle) and in the "clean" configuration (flaps up and gear up, if retractable).

The green arc terminates at V_{NO}, the maximum normal operating velocity or maximum structural cruising speed. This speed shouldn't be exceeded except when flying in smooth air. Flying above V_{NO} in turbulent conditions may cause damage to an aircraft. The formula for calculating V_{NO} is somewhat complex, but one of the formula's factors is the airplane's ability to withstand a specified vertical gust (30 feet per second for airplanes certificated before August 1969 and 50 feet per second after this date) and not exceed its maximum load limit.

Questions

Ask the students to look at the airspeed indicator on the slide and observe the speeds or speed range for V_{S1}, V_{NO}, and the green arc.

V_{S1} - 48 knots
V_{NO} - 130 knots
Green arc - 48 - 130 knots

Slide 19: The yellow arc represents the "caution" range. An aircraft should fly at these speeds only in smooth air (i.e., no turbulence).

V_{NO} is at the "bottom" of the yellow arc.

The "top" of the yellow arc terminates at the red line - or V_{NE}. V_{NE} is the never exceed speed. It represents the maximum operating speed. Exceeding this airspeed is prohibited because doing so may damage the aircraft to the point of structural failure.

Questions

Ask the students to look at the airspeed indicator on the slide and observe the speeds or speed range for V_{NE} and the yellow arc.

V_{NE} - 163 knots
Yellow arc - 130 - 163 knots

Slides 20-21: Other important airspeed indications are not found on the dial; instead, they may appear on placards in the cockpit or in the Pilot's Operating Handbook.

Ask students to recall the definition of maneuvering speed. Students first learned about maneuvering speed in unit 5 during the lesson on Load Limits in Aircraft Design.

Questions

Can you recall the definition of maneuvering speed? Why is it important?
Maneuvering speed is the speed at which a pilot can fully deflect one control surface (elevator, ailerons, or rudder) in smooth air without risking structural damage to the aircraft. Pilots use this speed to perform normal maneuvers without overstressing the aircraft.

V_A - Design maneuvering speed
Maneuvering speed is determined by the aircraft manufacturer as part of the design and testing process. Pilots use maneuvering speed to perform normal maneuvers without overstressing the aircraft. When encountering moderate or greater turbulence, pilots will slow to maneuvering speed. In severe turbulence, they may slow to well below maneuvering speed.

Remind students that they were able to use a Vg diagram to find an aircraft's maneuvering speed. This is the speed that pilots use to perform a normal maneuver without overstressing the aircraft. For this particular aircraft, the V_A shown is about 135 mph, and any loads must be less than about 4.4 Gs. Excessive speed and Gs risks structural damage. In other words, the maneuvering speed is how fast the aircraft can go to pull Gs equal to the load limit factor.

Maneuvering speed varies with the weight of the aircraft. The published maneuvering speed found in the Pilot's Operating Handbook is maneuvering speed at maximum gross weight for the aircraft. At lower weights, the maneuvering speed is lower.

Slide 22: Other important airspeeds include:

V_{LO} - Landing gear operating speed
Maximum speed for extending or retracting an aircraft's landing gear.

V_{LE} - Landing gear extended speed
Maximum speed for safely flying with the landing gear extended.

V_X - Best angle-of-climb speed
At this airspeed, an aircraft will gain the greatest amount of altitude over a given distance; it is typically used on short-field takeoffs to clear an obstacle.

V_Y - Best rate-of-climb speed
At this airspeed, an aircraft will gain the greatest amount of altitude over a given period of time; this is often used as the climb speed for a normal takeoff.

Slide 23: The airspeed indicator is an important instrument that should be carefully checked prior to flight. When an airplane is sitting still on the ground, the airspeed indicator should read zero, unless there is a strong wind blowing into the pitot tube. During the takeoff roll, the pilot should check the airspeed indicator to ensure it shows an appropriate increase in airspeed.

EXTEND

Teacher Materials: Airspeed Indicator Presentation, Airspeed Indicator Teacher Notes 2
Student Material: Airspeed Indicator Student Activity 2

Slide 24: In this simulation activity, students will use a flight simulator to evaluate the utility of the airspeed indicator. Students will experience take off, climb, level off, and configuration changes first using the airspeed indicator. They will then repeat the same steps as if the airspeed indicator is inoperative. Students will make observations regarding flying with and without this critical instrument and answer questions related to its importance for safety.

Provide students with **Airspeed Indicator Student Activity 2.** Either individually or in pairs (depending on the number of available simulators), students should work through the simulation. Sample responses to analysis questions are provided in **Airspeed Indicator Teacher Notes 2**.

EVALUATE

Teacher Materials: Airspeed Indicator Presentation, Airspeed Indicator Teacher Notes 3
Student Material: Airspeed Indicator Student Activity 3

Slides 25-30: Quiz students on questions from the Private Pilot Knowledge Test.

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

Summative Assessment

Working individually, students will demonstrate what they have learned about airspeed indicator markings and important speeds.

Provide each student with a copy of **Airspeed Indicator Student Activity 3** and Instruct them to refer to the image of the airspeed indicator on the activity sheet to answer the questions.

Correct answers are provided in **Airspeed Indicator Teacher Notes 3**.

[DOK-L2; *interpret; explain*]

Summative Assessment Scoring Rubric

Follows assignment instructions

Student work shows

Ability to interpret the standard markings on an airspeed indicator.

An understanding of the same airspeeds represented by these markings.

Contributions show understanding of course of the concepts covered in the lesson.

Contributions show in-depth thinking including analysis or synthesis of lesson objectives.

Points	Performance Levels
9-10	The student answers the questions correctly showing a full understanding of how to read an airspeed indicator.
7-8	The student answers the questions correctly but explanations reveal minor gaps in understanding of how to read an airspeed indicator.
5-6	The student answers some the questions correctly with unsupported explanations.
0-4	The student is unable to answer most of questions with little or no explanations. Student work shows many gaps in understanding of the lesson objectives.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS3-2** - Develop and use models to illustrate that energy at the macroscopic 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
- **HS-ETS1-4** - Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.
  - Science and Engineering Practices
    - Using Mathematics and Computational Thinking
  - Disciplinary Core Ideas
    - ETS1.B: Developing Possible Solutions
  - Crosscutting Concepts
    - Systems and System Models

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

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