The Magnetic Compass

Session Time: Two, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

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

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

ESSENTIAL QUESTIONS

1. Do aircraft instruments have to be complicated?
2. What challenges are associated with using a compass in an aircraft?

LEARNING GOALS

Students Will Know

- What a magnetic compass is and what information it can provide
- The difference between true and magnetic headings
- The types of errors associated with magnetic compasses in aircraft

Students Will Be Able To

- *Explain* magnetic compass errors. (DOK-L3)
- *Calculate* a magnetic course from a true course. (DOK-L3)
- *Predict* the behavior of a compass in various situations. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students will begin to build an understanding of why a magnetic compass behaves like it does by observing its interactions with a magnet and noting how its needle changes in response to a rolling motion of the compass, similar to that of a turning airplane.

Formative Assessment
Students will analyze compass correction cards along with information about variation in different locations. Students will also determine what magnetic heading to fly in order to achieve a specific true course. Then, students will answer several scenario-based questions.

Summative Assessment
Students will be provided several scenarios in which a compass error might occur. Students will then describe the error and explain why it occurs.

LESSON PREPARATION

MATERIALS/RESOURCES

- The Magnetic Compass Presentation
- The Magnetic Compass Student Activity 1
- The Magnetic Compass Student Activity 2
- The Magnetic Compass Student Activity 3
- The Magnetic Compass Student Activity 4
- The Magnetic Compass Teacher Notes 1
- The Magnetic Compass Teacher Notes 2
- The Magnetic Compass Teacher Notes 3
- The Magnetic Compass Teacher Notes 4

Warm-Up

- Several magnetic compasses (1 per group)
- Several handheld magnets (1 per group)

Induce Compass Errors

- Sealed magnetic compass (1 per group) (can reuse from Warm-Up)

Flight Simulation Activity

- Flight simulator with magnetic compass
- Stopwatch or timing device

LESSON SUMMARY

Lesson 1 - Gyroscopic Instruments
Lesson 2 - The Magnetic Compass

The lesson will begin with a basic discussion of how the Earth is a huge magnet containing both North and South Poles. Because the Earth is a magnet, it generates a magnetic field and lines of magnetic flux that can be sensed by various instruments, including simple magnets like those used in a compass. This magnetic field forms lines of force that run between the North and South Poles, which cause magnets within the field to align themselves with the lines of flux. Magnetic needles inside compasses follow this pattern to point to a location near the North Pole called Magnetic North, regardless of where the compass is on the planet. Compasses have been used in navigation for more than 1,000 years, and without them, global navigation in past centuries would not have been possible. Even though there are more sophisticated navigation technologies available today, the magnetic compass remains a cornerstone of all pilot training, and the compass remains required equipment in all aircraft.

The lesson continues with a discussion of how magnetic compasses work, including their components and the various types of errors found in the magnetic compass, including variation, deviation, dip errors, and acceleration errors. Students will learn how those errors can be measured, predicted, and managed.

Students will have the opportunity to calculate headings needed to compensate for compass errors. In a simulation activity, they will experience the challenges of flying with a magnetic compass as the sole means of navigation. Then they will be assessed on their understanding of compass errors and why they occur in different scenarios.

BACKGROUND

The principle behind the magnetic compass is simple. Earth act likes a giant magnet, creating a magnetic field and lines of magnetism called flux. These lines of flux run between the North Pole and South Poles. Any freewheeling, unconstrained magnet on the Earth will naturally align itself with these lines of flux. By hanging a lightweight magnet on a spindle or vertical axle and allowing it to swing freely, the magnet will point north, creating a rudimentary compass.

Because of its simplicity and reliability, the magnetic compass has been used for navigation for at least a thousand years.

Compasses used in aviation contain a rotating compass card with directional markings, two magnets, and a float. The entire assembly is suspended on a pivot and submerged in liquid, usually kerosene, to dampen movement and make the compass more readable in flight. The magnets keep the card pointed north and the aircraft pivots about it.

While the compass has proven to be a useful instrument over the centuries, it is subject to errors, especially when used in aircraft. One such error is magnetic variation. Variation occurs because the magnetic and the geographical North Poles are not in the same place, meaning that usually a correction has to be applied to arrive at a true heading. Calculations of variation change over time as the magnetic pole moves relative to the geographic pole.

Another source of error is compass deviation, caused by conflicting magnetic fields created by metal and equipment within the aircraft. The amount of compass error of each aircraft is measured, and a card is placed on the compass detailing the amount of error at various headings. Pilots use the information on that card to make the required adjustments.

Other compass errors occur because of magnetic dip and acceleration. Dip errors occur when turning, and acceleration errors result from the aircraft increasing or decreasing its speed. Pilots are trained to recognize and compensate for these errors.

MISCONCEPTIONS

It is a popular misconception that a magnetic compass will point to the geographical North Pole. In fact, the compass will point to magnetic north. Magnetic north is the point at which the northern lines of magnetic flux converge, known as the Magnetic North Pole. In most places, a correction has to be applied to the readout on the compass to arrive at the true direction. The location of the Magnetic North Pole moves over time as a result of changes inside the Earth's molten core. As a result, the correction that must be applied to a compass reading in order to find the geographical North Pole changes over a time.

DIFFERENTIATION

To support student comprehension in the **EXPLORE** section, choose a video to help explain the concept of a magnetic compass in flight. This video Magnetic Compass (Length 6:35) is one possible option. Some students may desire the auditory and visual representation in the material to aid in comprehension.

To support student comprehension in the **EVALUATION** section, create a game such as Jeopardy to help prepare students for the summative assessment. Allow student groups to choose a category with a related magnetic compass error scenario to solve, earn points and compete with other peer groups. This will allow students to learn from each other, improve metacognitive skills, and better prepare them for analyzing scenarios in the summative assessment.

LEARNING PLAN

ENGAGE

Teacher Material: **The Magnetic Compass Presentation**

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

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

Warm-Up

In this activity, students will learn how and why a magnetic compass points to magnetic north, and how the instrument behaves (deflects) during aircraft turning and banking. Divide the class into small groups of 3 to 4 students. Distribute one magnetic compass and one handheld magnet to each group. Direct students to perform the following two experiments and discuss their observations.

1. Each group will place the magnet approximately 4 feet from the compass. Now, one student will slowly move the magnet toward the compass, and the other students will note the behavior of the needle on the compass.

   Did the needle move? If so, which way? Why?
   Possible response: As the magnet gets closer to the compass, the needle on the compass should move toward the magnet. As the magnet gets closer to the compass, its magnetic field has a greater impact on the compass than the Earth's magnetic field. Since the magnetic field around the magnet is stronger, the needle on the compass will be drawn toward it. This simulates how the magnetized needle of the compass points toward a magnetic pole, such as the Earth's magnetic north pole.

   How is this compass movement useful for navigation?
   Possible response: By pointing to magnetic north, the compass gives the navigator a starting point from which to measure the direction needed to reach a desired destination.

1. Next, the students will place the magnet on a table. One student will hold the compass in their hand approximately 1 foot from the magnet, and slowly turn the compass in a rolling motion, simulating an airplane's banking motion.

   Did the needle move? If so, which way? Why?
   Possible response: The compass needle should "dip" or move away from its original position, depending on how the student turns the compass. The needle on the compass is following the Earth's lines of magnetic flux. As the orientation of the compass changes while the compass is rolling, the needle will attempt to maintain its alignment with those lines of flux. This will cause the needle to deflect away from its original position.

EXPLORE

Teacher Material: The Magnetic Compass Presentation

Slide 5: Explain that Earth itself acts like is a giant magnet, owing to the iron and other metals in its core. As with any magnet, there is a magnetic field that surrounds Earth and applies a weak magnetic force.

This force comes in the form of lines of magnetism that run between the North and South Poles. These lines of force are known as "lines of magnetic flux," and bar magnets will tend to line up with them, with one end of the magnet facing the north magnetic pole, and the other facing the south magnetic pole.

The location of the magnetic poles does not correspond exactly with the location of the geographical poles and can change over time. It is important to keep in mind that magnets align with the magnetic flux lines that run between the North and South magnetic pole locations.

Slide 6: The Chinese military may have been the first to use the magnetic compass for navigation, more than 1,000 years ago. European mariners began using the magnetic compass in the 12th century, which made possible long sea voyages out of sight of land.

Even though there are more accurate and sophisticated navigational aids today, a magnetic compass is required on all aircraft as a backup and cross check to electronic instruments.

Considering how important the compass is, it is actually quite simple in design. A solid case holds the components and allows the compass to be attached to the aircraft. A floating compass card is marked in degrees, with two magnets attached that line up with Earth's magnetic flux lines. The compass card and magnets float in a liquid, normally kerosene, that dampens movement and makes the compass easier to read in flight. A window at the front of the compass is marked with a lubber line to reference the direction the airplane is pointed.

Slide 7: The magnetic compass is subject to certain known errors.

Some of the errors, such as variation, turning and acceleration errors, are a result of the shape and location of the magnetic field surrounding the Earth on which the operation of compass relies.

Deviation comes from the installation of the compass.

The following slides discuss each of these errors in greater detail.

EXPLAIN

Teacher Materials: The Magnetic Compass Presentation, The Magnetic Compass Teacher Notes 1, The Magnetic Compass Teacher Notes 2
Student Materials: The Magnetic Compass Student Activity 1, The Magnetic Compass Student Activity 2

Slide 8: Remind students that geographical or "true" north is not in the same location as the magnetic north. When the compass points to north, it's pointing to this magnetic north location, not geographical north. The difference between true north and magnetic north is called magnetic variation, or simply variation. Note that the magnetic north pole is not a fixed point and will actually change position over time, due to magnetic changes in Earth's core.

It is important for pilots to be able to account for this variation in their flight planning. Aeronautical chart makers have made this task easier by printing lines of equal magnetic variation on sectional and other aeronautical charts, enabling pilots to see at a glance how much variation is present in the area in which they are flying. These magenta dotted lines on the charts are called "isogonic lines," and each line is labeled with its degree of variation from true north. Using these charts and their isogonic lines, pilots are able to adjust their flight planning to accommodate magnetic variation and convert true direction to magnetic direction, enabling the pilot to use the magnetic compass for direction information.

The degree of magnetic variation is not constant around the globe. In fact, the degree of magnetic variation changes substantially from west to east in the United States. For example, in Los Angeles, the difference between true north and magnetic north is 14 degrees, with that variation being referred to as "easterly." With easterly variation, pilots subtract the variation from the true (non-magnetic) direction to convert to magnetic direction, so in Los Angeles pilots would have to subtract 14 degrees from true direction to arrive at magnetic direction.

On the other side of the country in Washington, DC, pilots add 10 degrees to their true direction to convert to magnetic. This is because the magnetic variation in that part of the country is said to be "westerly," thus requiring the opposite conversion from easterly variation. In this example, pilots would have to add 10 degrees to the true direction in Washington DC to convert to magnetic direction, a value that can be used to navigate using the magnetic compass.

Teaching Tips

A helpful way to remember whether to add or subtract the magnetic variation is "East is least and West is best." In other words, add for westerly, and subtract for easterly.

Slide 9: Compass deviation is another error induced by magnetic fields, but not Earth's magnetic field. Local magnetic fields created by airplane radios and metal in the engine, propeller, and airframe can cause a compass to deviate from magnetic direction.

Fortunately, this error can be measured and compensated for by the pilot. Aircraft mechanics determine the error in each compass and then record that error on a small card attached to the compass. Pilots refer to this card, called a compass card, when flying to ensure that the desired heading is being flown.

While the amount of deviation differs depending on the aircraft's heading, it is not affected by geographical location. The amount of compass deviation is the same regardless of where the airplane is located.

Slide 10: When flight planning, pilots apply a calculation to determine what their final heading should be based on their desired direction, magnetic variation, and deviation.

This method involves specific steps that must be followed in the proper order:

1. The pilot determines the direction that must be flown to arrive at the desired destination.
2. Looking at the closest isogonic line on the aeronautical chart, the pilot adds or subtracts variation.
   a. If the variation is easterly, that variation is subtracted from the initial direction value, if the variation is westerly, it is added.
3. The pilot refers to the compass card in the aircraft to determine the amount of deviation error, then applies that in determining the heading to be steered.

Technically, there is an additional step needed in determining an actual magnetic heading, and that is calculating the correction needed for wind drift. While this is an important step, it is not covered in this lesson but will be addressed in a later course.

Let's look at an example on the next slide.

Slide 11: Let's say a pilot has determined that to fly from Washington, DC, to their destination, they must fly in a true direction of 180 degrees, or South.

They would find the magnetic variation by referring to the aeronautical chart. Finding the isogonic (variation) line closest to their route of flight, they see that the variation is 10° W, or westerly. They then add this 10° (remember, "West is best" - added) to their original required direction of 180 degrees to yield 190 degrees.

Then, they would look on their aircraft compass card to determine the deviation. The closest indication on the card to 190° is South, or 180 degrees, and they see that the deviation at 180 degrees is plus 1 degree (the difference between 181 and 180). They would then add this one degree to the 190 degrees and get a required heading of 191 degrees. This is the course to steer to get to the destination. (Once again, not accounting for wind.)

Slide 12: Recall that the lines of the Earth's magnetic flux run from north to south. The magnetic field is curved and is only parallel to the Earth's surface at the equator. As you move away from the equator, the flux lines begin to dip towards the poles. The magnetic compass aligns itself with these flux lines, but it is only capable of rotating in the horizontal plane. For this reason, certain aircraft positioning or movement causes the compass to detect this dip and create errors for which the pilot must compensate. The error created by the magnetic field dipping toward the poles is called dip error. There are two types of dip error: turning error and acceleration error.

Slide 13: Acceleration error occurs when the aircraft is on a heading of east or west and either speeds up or slows down.

Acceleration error occurs because of the inertia of the compass card. When the aircraft accelerates, the front of the compass card dips due to its inertia and causes a twisting of the card toward the north. Likewise, when the aircraft decelerates, the front of the compass card pitches up and turns towards the south. Again, acceleration error only occurs when the aircraft is on an East or West heading.

ANDS is a handy acronym that helps pilots remember which way the compass will deflect when accelerating or decelerating: Accelerate North Decelerate South.

If time allows, show this video to help students understand how compass errors occur due to acceleration.

- "Magnetic Compass Errors: Acceleration Errors" (Length 2:20)
  https://video.link/w/R72i

Slide 14: The lines of magnetic flux are only parallel to the Earth at the equator. In other locations, the flux lines dip downward toward the earth. This downward tilt of the lines of magnetic force creates dip errors when turning left or right, with the amount of error changes depending on what direction the aircraft heading is passing through.

When turning from a northerly heading, the compass will initially indicate a turn in the opposite direction, e.g., when turning right, the compass will show a turn to the left for a few seconds, then 'catch up' and start indicating a turn in the correct direction. Likewise, when turning from a southerly heading, the compass will initially show a turn in the wrong direction, but will then correct itself.

The compass will not show turns at a constant rate, but will rather speed up and slow down throughout a turn. The speed that the compass turns depends on the direction the airplane is passing through during the various points in the turn. For example, when turning from a westerly direction to the north, the compass will race ahead of the aircraft's actual heading, leading the turn. Pilots desiring to turn to a northerly heading must stop the turn before reaching the intended heading. Conversely, turning to a southerly heading, the compass will lag, turning at a slower pace than the actual turn rate. The pilot must continue the turn past the desired heading to end up with the correct heading.

UNOS is a handy memory aid. It stands for "Undershoot North, Overshoot South."

There is no dip error when turning to a heading of East or West, so pilots do not have to compensate for error when turning to these headings.

If time allows, show this video to help students understand how compass errors occur due to acceleration.

- "Magnetic Compass Errors: Turning Errors" (Length 2:18)
  https://video.link/w/8ooj

Slide 15: The magnetic compass is not always an easy instrument to read. Rough maneuvering, rapid changes in attitude, or turbulence can cause the compass card to move around rather than show a steady heading. This can make it difficult or impossible to control the heading of the aircraft using the magnetic compass alone. Once the turbulence or attitude changes stop, the compass settles down and becomes stable again.

One of the major advantages of heading indicators, whether gyroscopic or electronic, is that they are not subject to oscillations.

Slide 16: Distribute a copy of **The Magnetic Compass Student Activity 1** to each group along with the necessary materials. In this activity, students will manipulate sealed magnetic compasses to simulate acceleration errors. Additional instructions and sample student responses are provided in **The Magnetic Compass Teacher Notes 1**.

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

Formative Assessment

Distribute a copy of **The Magnetic Compass Student Activity 2** to each student. In this activity, students will analyze compass correction cards along with information about variation in different locations. Students will determine what magnetic heading to fly in order to achieve a specific true course. Then, students will answer scenario-based questions.

Correct answers are provided in **The Magnetic Compass Teacher Notes 2**.

[DOK-L3; *Formulate*]

EXTEND

Teacher Materials: The Magnetic Compass Presentation, The Magnetic Compass Teacher Notes 3
Student Material: The Magnetic Compass Student Activity 3

Slide 18: If time allows, consider doing the flight simulation activity described in **The Magnetic Compass Student Activity 3**. In this activity, students will form into groups of two and take turns flying the simulator along a prescribed route involving multiple turns with reference to the magnetic compass only. Then, students will analyze the difficult of maintaining the correct heading using the magnetic compass only. Sample student responses are provided in **The Magnetic Compass Teacher Notes 3**.

EVALUATE

Teacher Materials: The Magnetic Compass Presentation, The Magnetic Compass Teacher Notes 4
Student Material: The Magnetic Compass Student Activity 4

Slides 19-32: Quiz students on these questions from the Private Pilot Knowledge Test.

Slide 33: Conduct the **Summative Assessment**.

Summative Assessment

Distribute a copy of **The Magnetic Compass Student Activity 4** to each student. In this activity, students will answer scenario-based questions about magnetic compass errors. Correct answers are provided in **The Magnetic Compass Teacher Notes 4**.

[DOK-L2: *Predict;* DOK-L3: *Differentiate*]

Summative Assessment Scoring Rubric

- Answers show evidence of the following:
  - How a magnetic compass will respond to certain movements
  - Why magnetic errors are caused
  - The types of magnetic errors
- Student responses are complete sentences with no errors in grammar, punctuation, or spelling

- Student responses show in-depth knowledge of why compass errors occur

Points **Performance Levels**

8 All questions are answered correctly, showing a complete and accurate understanding of the types of magnetic compass errors and how they are caused
6-7 1-2 questions are answered incorrectly, showing minor gaps in understanding of the types of magnetic compass errors and how they are caused
4-5 3-4 questions are answered incorrectly, showing major gaps in understanding of the types of magnetic compass errors and how they are caused
0-3 5 or more questions are answered incorrectly, showing little understanding of this lesson's topics

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS3-5** - Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
    - Science and Engineering Practices
        - Developing and Using Models
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - PS3.C: Relationship Between Energy and Forces
    - Crosscutting Concepts
        - Cause and Effect
        - Systems and System Models

COMMON CORE STATE STANDARDS

- **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.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.
- **MP.2** - Reason abstractly and quantitatively.

REFERENCES

http://www.earthsciweek.org/classroom-activities/make-your-own-compass
https://www.youtube.com/watch?v=QiSp6pGe0w0
https://www.youtube.com/watch?v=4dDKjdj_Dvc