VOR and GPS Navigation

Session Time: Four, 50-minute session(s)

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Comprehensive preflight planning is an integral (and regulatory) component of safety for all flights.

Advances in navigation technology have allowed pilots to navigate from point-to-point with greater precision and accuracy than pilotage and dead reckoning alone can provide.

ESSENTIAL QUESTIONS

1. How do electronic navigation tools such as VOR and GPS allow pilots to navigate more effectively than using pilotage or dead reckoning?

LEARNING GOALS

Students Will Know

- How GPS is used in VFR flight.
- What factors affect the navigational integrity of GPS and VOR.
- What types of VHF Omnidirectional Range navigation stations a pilot may encounter.
- How to determine an aircraft's position relative to a VOR station.
- How to navigate to a VOR station.
- How to read a typical cockpit VOR indicator

Students Will Be Able To

- *Recall* how to determine whether or not a GPS signal is usable. [DOK-L1]
- *Construct* diagrams indicating an aircraft's position relative to a VOR station. [DOK-L2]
- *Apply the concepts* of electronic navigation to propose solutions to navigation scenarios. [DOK-L4]

ASSESSMENT EVIDENCE

Warm-up
In groups, students will brainstorm a list of methods for pilot navigation. They will then discuss the relative accuracy and complexity of each method as a class.

Formative Assessment
In pairs, students will recall core concepts of VOR navigation and apply these concepts to a real-world scenario.

Summative Assessment

Individually, students will recall key information about VOR and GPS navigation and apply that knowledge to scenarios involving navigation and malfunctions.

LESSON PREPARATION

MATERIALS/RESOURCES

- VOR and GPS Navigation Presentation
- VOR and GPS Navigation Student Activity 1
- VOR and GPS Navigation Student Activity 2
- VOR and GPS Navigation Student Activity 3
- VOR and GPS Navigation Student Activity 4
- VOR and GPS Navigation Teacher Notes 1
- VOR and GPS Navigation Teacher Notes 2
- VOR and GPS Navigation Teacher Notes 3
- VOR and GPS Navigation Teacher Notes 4
- **VFR Sectional Chart (any area is suitable, but one covering the local area is preferable)**
- **Chart Supplement**
- **Protractor**
- **Pencil, ruler indicating centimeters**

LESSON SUMMARY

Lesson 1: Plotting Your Course
Lesson 2: Helpful Documents
Lesson 3: VOR and GPS Navigation

The lesson will begin with a warm-up in which students will brainstorm methods of navigation pilots can use. That will segue into a discussion of VORs and their use in VFR navigation. Students will demonstrate their understanding of VORs in a formative assessment in which students will recall key concepts and apply them to a real-world scenario.

During the next part of the lesson, students will understand the fundamental concepts of the GPS navigation system and its application to VFR navigation.

Finally, students will work in pairs to apply the VOR and GPS navigation concepts to various scenarios involving displays, charts, and limitations. Students will demonstrate their understanding of navigation principles in an individual summative assessment in which they will recall fundamental concepts and apply them to practical situations.

BACKGROUND

There are several electronic navigation systems that can aid a pilot during VFR navigation. VOR navigation is based on a network of ground stations using VHF radio signals to transmit location information and a receiver on board an aircraft. The VOR receiver in the aircraft, in conjunction with a visual indicator, allows pilots to determine their azimuth from any VOR station. Some VOR stations and aircraft are equipped with distance measuring equipment (DME) that allows a pilot to determine the aircraft's distance from the ground station.

The system of VORs is decades old but continues to be a reliable means of navigation; however, GPS is becoming more common. In comparison to the VOR system, GPS is more precise and allows pilots to see their current location—as well as their desired flight path—on a moving map, greatly simplifying navigation and increasing pilots' situational awareness. Other data contained in the GPS, including details about airports and special use airspace nearby, puts more information at a pilots' fingertips than ever before.

GPS and VOR supplement pilotage and dead reckoning navigation. VFR pilots should always begin with a clearly planned route of flight with visually identifiable checkpoints. VORs may malfunction or be shut down for maintenance, and GPS signals may be interrupted for military exercises or national security reasons, so having a hard copy of the planned route of flight is important.

An excellent overview of VORs and GPS for the purposes of this lesson can be found in this Embry-Riddle video:

- Navigation Systems" (Length 23:11)
  https://video.link/w/QRE0

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/watch?v=6E_4jhFalXE&feature=youtu.be&t=561

The video provides background information for the teacher; however, it may be valuable to have the class watch as a review at the end of this lesson. This may be assigned for homework if not viewed in class.

MISCONCEPTIONS

Students may think the signals for the Global Positioning System (GPS) come from towers or other ground-based sources. However, GPS is based on a constellation of satellites orbiting Earth.

GPS devices on board aircraft are capable of providing pilots with information other than the aircraft's position. Databases in GPS devices give pilots access to a wide range of useful data which often includes a moving map display, airport details, important communication frequencies, flight planning tools, and sunset/sunrise times.

Despite the ubiquity of GPS in our everyday lives, not all aircraft are equipped with GPS devices, so it is important to remember that pilots must be familiar with a variety of navigation techniques aside from GPS use.

Because students are unlikely to have encountered VORs prior to this lesson, they may not have any misconceptions about them at this time.

DIFFERENTIATION

To support student comprehension of VOR, if time permits, allow students to watch additional clips from instructional videos. A few examples include: VORs Made Simple for the Written Test (YouTube Link) and VOR Navigation Explained (easy) by Captain Joe (YouTube Link).

To support student comprehension in the EXPLAIN section, perform a demonstration of the HSI simulator prior to engaging in the optional enrichment activity. If time does not permit a full student activity, just perform the demonstration. See Pilot's Handbook of Aeronautical Knowledge page 16-24 and the simulator. Provide the link to students for practice at home.

LEARNING PLAN

ENGAGE

Teacher Material: VOR and GPS Navigation Presentation

Session 1

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

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

Warm-Up

Divide the class into two groups. Have each group brainstorm a list of methods a pilot can use to navigate from one location to another. Include a description of each method.

For example, one navigation method is pilotage, defined as referencing the ground and flying from one landmark to another.

Once complete, have the class come together and compare lists.

Potential responses include:

Pilotage: referencing the ground and flying from one landmark to another

Dead reckoning: flying a fixed heading for a set time

Radar vectors (from air traffic controllers): following the headings provided by ATC

VOR: Tuning the receiver, determining the current location, and then flying to the next location

GPS: Entering a location and following guidance to the next location

Note: Though VORs have been mentioned in previous lessons, students may not yet understand their capability. That will be discussed later in this lesson.

As a class, discuss:

Which method requires the most technology? Which requires the least?

Potential response: GPS likely requires the most technology, while pilotage requires the least.

As a class, try to organize the list from most accurate (most likely to get a pilot to their destination correctly) to least accurate.

Responses may vary depending on the justification. A sample list may look like this:

GPS

VOR

ATC vectors

Dead reckoning

Pilotage

Which method requires the most work on the part of the pilot? Which one is the easiest?

Responses may vary. Generally, dead reckoning or VORs probably require more work than the other methods of navigation. Radar vectors from ATC may be the easiest, since the pilot just has to listen and comply, but GPS is the easiest system to use without outside assistance, assuming the particular device is user-friendly.

EXPLORE

Teacher Materials: VOR and GPS Navigation Presentation, VOR and GPS Navigation Teacher Notes 1
Student Materials: VOR and GPS Navigation Student Activity 1, **VFR Sectional Chart, Chart Supplement**

Slide 5: There are two common types of electronic navigation aids (navaids) available to pilots: VORs and GPS. Of these navigation methods, VORs are likely the most foreign to nonpilots because, unlike GPS, VORs are specific to aviation.

Divide the class into small groups and distribute **VOR and GPS Navigation Student Activity 1**. Students will identify the information about VORs on a VFR sectional chart. Sample responses are available in **VOR and GPS Navigation Teacher Notes 1**.

Questions

Where could you find more information about VORs?

The Chart Supplement lists VORs alphabetically by name in the same section as the airports.

A variety of nongovernmental commercial sources offer pilots access to databases that include information related to VORs.

Slide 6: The Chart Supplement contains many details on VOR ground stations. The upper image on the slide is a Chart Supplement excerpt, and the lower image is a copy of the legend from the Chart Supplement. As shown on the legend, for each VOR, the Chart Supplement displays the

- Name
- Latitude and longitude coordinates
- Direction from nearest town or airport
- Elevation and magnetic variation
- Names of charts where it can be found
- Class: terminal (T), low altitude (L), and high altitude (H)
- Unusable areas
- RCO ("Remote Communications Outlet", to be discussed later)

EXPLAIN

Teacher Materials: VOR and GPS Navigation Presentation, VOR and GPS Navigation Teacher Notes 2
Student Material: VOR and GPS Navigation Student Activity 2

Slide 7: VOR stands for very high frequency (VHF) omnidirectional range. These ground-based navigational aids (navaids) transmit in all directions (omnidirectional) on a VHF frequency band of 108.0 to 117.95 MHz. Transmissions from the station are called radials and are numbered 001 through 360, correlating with degrees from magnetic north. Think of the VOR as the center of a bicycle wheel and the spokes as the radials. Pilots can use equipment in the aircraft to tune in a particular VOR, identify which radial they are on, and fly to or from the VOR station.

Watch the following Embry-Riddle video for an introduction to the VOR:

- "Navigation Systems" (Length 0:58)
  https://video.link/w/0wC0

For teachers unable to view SafeYouTube links, the video may also be found here: https://www.youtube.com/embed/6E_4jhFalXE?start=561&end=619

Slide 8: The symbols students found in the EXPLORE activity (Student Activity 1) represent three VORs that pilots may encounter and use. Note that when a VOR is located on the grounds of an airport, a white dot symbolizes the location of the VOR.

VORs are frequently paired with other navaids (navigation aids). A VOR/DME is a VOR combined with distance measuring equipment (DME) which broadcasts a signal that will give a distance reading to the VOR/DME station, if the aircraft has a DME radio on board. (DME operates in the UHF band, requiring a radio on board the aircraft separate from a VOR receiver.)

Similarly, some VORs are paired with tactical navigation stations (TACANs), which are a military navaid that combines the features of a VOR and DME on UHF frequencies. If an aircraft is DME equipped, they can use the DME portion of the VORTAC.

Slide 9: VOR symbols are surrounded by a compass rose that is oriented toward magnetic north. Since pilots rely upon magnetic headings in flight, VORs are lined up with magnetic north.

Slide 10: Each VOR ground station has a three-letter identifier, and it is transmitted in Morse Code on the VOR's frequency. Pilots don't need to know Morse Code, however, as the relevant "dot dash" code for the VOR is printed on the sectional chart next to the identifier. Some VORs have a voice recording speaking the identifier. Pilots who are relying on a VOR should verify its identifier. This ensures the correct VOR is being received.

Sometimes a VOR is out of service for maintenance. In these cases, it will either have a "test" identifier (the letters T-E-S-T in Morse Code) or have its identifier removed to warn pilots that it should not be used for navigation.

Some aircraft have advanced VOR receivers that can automatically identify the VOR station and display the correct three-letter identifier on a screen in the aircraft.

To hear an example of a VOR's Morse Code identifier, play this video:

- "SMO VOR Morse code identification" (Length 0:30)
  https://video.link/w/B160

For teachers unable to view SafeYouTube links, the video may also be found here: https://www.youtube.com/watch?v=i6bxH7e4Vb0

Slide 11: The range of a VOR signal is dependent on its signal strength and line-of-sight. The signal strength is based on VOR class. VOR classes include terminal (T), low (L), and high (H).

Line-of-sight principles apply to VOR signals in the same way they apply to communications signals. Terrain or obstacles can block signals, so flying at high altitudes typically results in the best reception of VOR signals.

The range of reliable reception varies depending on the altitude of the receiving aircraft. A terminal VOR has a usable range of approximately 25 NM, low VORs have usable ranges of approximately 40 NM, and high VORs have usable ranges of approximately 130 NM when the receiving aircraft is above 18,000 feet. Line-of-sight means that once there is no longer a direct line of view to the VOR (for example, it is hidden behind a hill or is beyond the horizon at altitude), the signal cannot be received. Occasionally there are known issues with a VOR being unusable between certain radials or distances, and those zones will be noted in the Chart Supplement for the VOR. These capabilities and limitations are similar to the VHF radios most General Aviation aircraft use, since they both operate in the same basic band of frequencies. However, a VOR signal can be much weaker than a communications transmission and still be usable, so VORs generally have a higher range than comparable voice radios.

Slide 12: VOR transmitters are considered to be accurate to 31 degree. While the strength of reception decreases with distance from the VOR station, accuracy of the transmission does not decrease. However, 1 degree is 1 mile wide at 60 miles away from the VOR, and 2 miles wide at 120 miles away from the VOR.

How does a pilot know if the VOR equipment in the aircraft is working properly? Pilots may check the accuracy of the equipment with VOR tests. There are three types: a VOR test facility (VOT), a ground check, and an airborne check. Airborne and ground check points consist of certified radials that should be received at specific points on the airport surface or over specific landmarks while airborne in the immediate vicinity of the airport.

Slide 13: Pilots receive VOR signals using a navigation or "nav" radio. Often, the nav radio is paired with a communication radio. Nav radios vary in complexity from basic electro-mechanical displays to electronic cockpit touchscreen displays. Often, a GPS receiver in an aircraft also has a nav radio built in. The pilot selects the frequency for the VOR in the appropriate nav window, identifies the VOR by listening to the Morse Code identifier, and should then proceeds to monitor the course deviation indicator (CDI) which displays the navigation information from the selected VOR.

Slide 14: There are three main types of VOR displays pilots may see: the course deviation indicator (CDI), horizontal situation indicator (HSI), or radio magnetic indicator (RMI). The CDI is the most common in training aircraft and will be discussed here. The others should be reviewed if flying aircraft equipped with those displays.

A CDI is composed of an omnibearing selector (OBS, or course selector), CDI needle, TO/FROM indicators, and an unreliable signal flag. Should there be a problem with the VOR signal, or if the aircraft fails to receive the tuned VOR signal, the VOR receiver will display a flag as an alert.

The OBS is a knob that allows the pilot to select the desired course or radial for display on the CDI. Rotating the OBS selects a radial FROM the VOR or course TO the VOR. If the pilot rotates the OBS until the needle is centered and FROM is displayed in the TO/FROM window, the radial displayed in the OBS window is the one on which the aircraft is located relative to the VOR.

The OBS knob rotates a compass ring that surrounds the CDI. Often, this is called the "OBS ring." Note that there is a mark at the top of the CDI called the course index. This is where a heading to or from the station may be read.

Slide 15: VOR antennas are usually mounted near the top of an aircraft's vertical stabilizer. The antenna consists of two straight components mounted in a horizontal plane.

Slide 16: Watch the following Embry-Riddle video for a description of the VOR indicator:

- "Navigation Systems" (Length 0:33)
  https://video.link/w/vqC0

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/embed/6E_4jhFalXE?start=620&end=653

Teaching Tips

The following slides allow students to see how a CDI behaves when the aircraft is in various positions relative to a VOR. Two common (and free) VOR simulators give the teacher an opportunity to demonstrate how the CDI behaves depending on aircraft position.

A Flash-based VOR simulator is available at the Luiz Monteiro Aviation Education website: http://www.luizmonteiro.com/Learning_VOR_Sim.aspx

The FlyGo IFR Trainer is a free app available at the Apple App Store: https://apps.apple.com/us/app/flygo-ifr-trainer-all-in-1/id896679194#?platform=ipad

Nav Trainer Pro for Pilots is an Android app available at the Google Play Store: https://play.google.com/store/apps/details?id=com.pilotscafe.apps.navtrainer&hl=en_USAt the time of publication, the app was available for $8.99.

Slide 17: An aircraft's position relative to the VOR station can be thought of being in one of four quadrants. Once a particular radial is selected and centered using the OBS knob on the CDI, there is a region where the TO flag will show on the CDI and a region where the FROM flag will show on the CDI. Additionally, if the aircraft is to the left of the selected radial, the CDI needle will point to the right, indicating the pilot should fly to the right to join the selected course. Conversely, if the aircraft is to the right of the selected radial, the CDI needle will point to the left, indicating the pilot should fly to the left to join the selected course.

When an aircraft passes from the TO to the FROM area (and vice versa), the TO/FROM indicator may flip back-and-forth or the nav warning flag may appear briefly. The same indication would occur when flying directly over the VOR station.

Slide 18: When a pilot selects a VOR station on the nav radio and twists the OBS knob until the CDI needle is centered with a FROM indicator, they know on which radial the aircraft is at that moment. The heading of the aircraft does not matter.

If you were standing in the middle of aisle 15 at the supermarket, it wouldn't matter if you faced the front of the store, the back of the store, or the shelves to your left or right. You are still in aisle 15.

Teaching Tips

This is a good opportunity to introduce the online VOR simulator. Simply placing the aircraft in different positions and selecting different radials and aircraft headings will begin to give students an idea of how the CDI behaves depending upon aircraft position.

To emphasize that the CDI simply shows the radial on which the aircraft is located, use the VOR simulator to place the aircraft on a particular radial. Freeze the motion of the aircraft. Then change only the aircraft's heading. You are rotating the aircraft in one location, so the CDI will remain centered as the aircraft's heading is changed.

Slide 19: If a pilot has decided to use a VOR as a waypoint along a route of flight, then the pilot will want to fly to that VOR before flying on to the next checkpoint on the navigation log. How does a pilot fly directly to a VOR? Here are the steps to follow:

1. Tune the nav radio to the VOR's frequency.
2. Positively identify the VOR station by listening to the Morse Code identifier.
3. Turn the OBS knob until there is a TO indicator showing on the CDI.
4. Continue turning the OBS knob until the CDI needle is centered.
5. Read the magnetic heading direction to the station at the course index (top of the CDI)
6. Turn the aircraft to fly the same heading that is indicated at the course index on the CDI.
7.

In a no-wind condition, this allows the aircraft to fly directly to the station.

Watch this video clip about flying to a VOR:

- "Ep. 71: How to Use a VOR in an Airplane" (Length 3:41)
  https://video.link/w/KNE0

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/embed/Fk_hnws0Tw8?start=29&end=250

It is important to remember that in this example, the pilot is flying a heading of 030° to the station; however, the aircraft is actually on the 210° radial. This is known as the reciprocal radial from what is indicated on the course index.

Slide 20: As the aircraft nears the VOR, the CDI needle reacts more rapidly because the radials are narrowing close to the station. Flying close to the VOR, the needle may fluctuate rapidly. Flying over the VOR, the TO/FROM indicator will flip and the nav flag may show momentarily. The pilot should simply maintain heading, and the needle should return to a center position and the TO/FROM indicator will show a FROM indication.

Slide 21: Flying from a VOR station is easy if the pilot plans to continue in the same direction as when they were flying to the station. After station passage, the pilot simply maintains the same heading and continues outbound. In the example on the slide, the pilot was flying to the station on a heading of 030°. Once past the station, the pilot continues on a 030° heading to fly outbound from the station on the 030° radial.

If a pilot needs to fly outbound from the VOR on a different radial, they would fly over the VOR then turn to the heading that matches the desired outbound radial. Next, the pilot would turn the OBS knob until the desired radial was indicated at the course index. As the pilot flew from the station, they would alter course left or right as indicated by the CDI needle. Once the CDI needle is centered, the pilot would fly the heading that matches the outbound radial.

Slide 22: When there is no wind (or a direct headwind or tailwind), a pilot can fly along a VOR radial by matching the aircraft heading with the course to or radial from the VOR station. If there is any crosswind component, then the aircraft will drift off course. A wind correction angle must be established using bracketing.

This is the same technique a pilot would use if navigating by pilotage or dead reckoning. The difference is that with VOR navigation, the pilot principally uses the CDI to determine if the aircraft is on course or not rather than landmarks. For example, when the CDI needle moves left, then the desired course or radial is to the left. The pilot flies to the left to intercept the course then returns to the original heading or alters heading to establish a wind correction angle that allows the aircraft to remain on course.

Slide 23: While pilots may use any radial from a VOR to navigate, the FAA has established certain radials as "highways in the sky." These airways are labeled with a V and a number (for example, V4, V21). They are called "Victor Airways" since they depend on VORs and "victor" is used to represent the letter V in the phonetic alphabet.

Victor airways are readily identified on sectional charts by light blue lines emanating from VOR compass roses. Look for a radial that defines the airway (216° in the slide), the identifier (V 553 in the slide), and a distance between the two VORs that are the endpoints of that segment of the airway (101 NM in the slide).

Slide 24: If a pilot simply needs to find their relative location to a known VOR, then the pilot can quickly determine where the aircraft is from the VOR. To determine their location relative to a VOR, pilots tune the frequency, identify the Morse Code of the VOR, and then turn the OBS dial until the CDI centers with a "FROM" indication. At that point, they know on which radial from that VOR they are located.

- "Ep. 71: How to Use a VOR in an Airplane" (Length 1:19)
  https://video.link/w/kRE0

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/embed/Fk_hnws0Tw8?start=316&end=395

This method tells the pilots which azimuth they are on, but it does not tell them how far away from the VOR they are. The pilot may then choose to draw a line on their sectional chart representing the radial on which the aircraft is located and look for geographic features on the sectional chart to further refine their location.

Slide 25: If a pilot wants more precision in determining their position, the pilot could use triangulation with two VOR stations. This means that the pilot will determine their location by performing the previous procedure with two VORs. The intersection of those two radials is the aircraft's location.

Slide 26: Watch the following Embry-Riddle video for a discussion of how a pilot uses VORs to determine location:

- "Navigation Systems" (Length 1:17) https://video.link/w/VoOz

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/6E_4jhFaIXE?start=843&end=920

Teaching Tips

For a demonstration, enrichment activity, or practice activity, consider having the students access the VOR simulator at Luiz Monteiro Aviation Education: http://www.luizmonteiro.com/Learning_VOR_Sim.aspxNote that Flash is required for the simulator to run properly.

The simulator may be useful to students as they determine the answers to the scenarios on slides 27 and 28.

Slides 27-30: Divide the class into small groups. Slide 27 presents two aircraft scenarios (A and B) in relation to a VOR, for which students should draw what the VOR CDI display would look like to the pilot based on the presented position of the aircraft and indicated radial. There is also one CDI display scenario (#3 on Slide 29), for which students should draw the relationship between the VOR and the aircraft.

Students should include these important elements in their diagrams: the CDI's course index with the correct degree reading, the position of the needle, and the position of the TO/FROM indicator.

Slides 31 and 32: Two additional VOR features that pilots may use include voice capability and distance measuring equipment.

Slide 31: Because they operate in the same band as VHF voice radios, VORs can sometimes be used for voice communication. In some cases, Flight Service can transmit over the VOR frequency, making it a remote communications outlet (RCO). Pilots can configure their VOR receivers to listen to transmissions from Flight Service on the VOR's frequency.

On the slide, a pilot who wants to communicate with Altoona Flight Service to obtain weather updates could tune their communication radio to 122.1 MHz and the nav radio to 113.9 MHz. The pilot would speak to Flight Service using the communication radio. To hear what Flight Service says, the pilot would turn up the volume of the nav radio to hear Flight Service on the VOR frequency.

Slide 32: VOR/DME or VORTAC stations broadcast a UHF signal that allows a pilot to determine the aircraft's distance from the VOR. This can be done when the aircraft is equipped with distance measuring equipment (DME). A DME receiver in the aircraft will also have a display that allows the pilot to read the aircraft's distance from the selected VOR. Aircraft with DME often have a distance display built into the nav radio, so that when a pilot enters a VOR frequency, the DME is automatically tuned to the appropriate frequency and shows the distance to the selected station. If the DME receiver is separate from the nav radio, the pilot must enter the correct VOR frequency separately.

DME measures what is known as the slant-range distance. This is the actual distance between the aircraft and the station. Slant-range distance will always be slightly greater than the flight-planned distance to a DME station, because it also includes the aircraft's height above the station—the DME display in an aircraft 6,000 feet directly above a DME transmitter will read one nautical mile.

Slide 33: Complete the **Formative Assessment**.

Formative Assessment

Divide the class into pairs and distribute **VOR and GPS Navigation Student Activity 2**. Students will recall and apply key concepts of navigation with reference to VORs. Sample responses are available in **VOR and GPS Navigation Teacher Notes 2**.

[DOK-L1; *recall,* DOK-L2; *construct*]

Slide 34: The Global Positioning System (GPS) is familiar to many people because it is ubiquitous in cars and smartphones. GPS navigation is becoming more popular in aircraft as well. In addition, the FAA has decided not to repair or replace many VORs as they age and start to break down, in part because of the cost involved and in part because pilots are increasingly favoring GPS over VORs.

GPS is a space-based navigation system that uses signals from multiple satellites to determine a precise location in latitude, longitude, altitude, and time. The full constellation is 32 satellites, with a minimum of 24 necessary to operate the system continuously. The GPS constellation is controlled by a Master Control Station at Schriever Air Force Base in Colorado. The control station assesses the altitude, position, speed, and health of the satellites, and then uploads that assessment back to the satellites for transmission to GPS users.

Like VORs, GPS signals are line-of-sight and can be blocked by terrain or buildings. A GPS receiver needs to track at least four satellites to determine an accurate three-dimensional (3D) location using trilateration. Trilateration differs from triangulation in that it only uses distances, not angles. GPS determines location by measuring distances from multiple points (satellites). The intersection of these distance measurements is where the GPS user is located.

Since GPS is a space-based system, there are no GPS-related navaid symbols on the sectional.

Slide 35: Watch the following Embry-Riddle video for a discussion of how GPS receivers use satellites and trilateration to determine a precise location:

- "Navigation Systems" (Length 4:53)
  https://video.link/w/JpOz

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/6E_4jhFalXE?start=1659&end=1709

Slide 36: GPS can accurately determine latitude and longitude, and it can provide an altitude, but will the altitude be the same as that displayed on the altimeter? In most cases, no. While a GPS can provide an altitude figure, it is strictly based on distances, while the altimeter displays an altitude based on the current air pressure. The FAA defines this non-barometric altitude as "geometric" altitude (see AC 20-163). Because it is not corrected for local pressure conditions, it will provide a different reading than a static system and may reduce aircraft separation if it is used instead of the pressure-sensing altimeter used by other aircraft. It is possible that manufacturers could produce a GPS that integrates with other systems to provide a more refined altitude display. Pilots should be aware of the capabilities of their system prior to using it. The altitude limitations of a particular GPS should be described in the manufacturer's documentation. For example, the Pilot's Guide for Garmin's GNS 430 has a warning that says "GPS altitude should never be used for vertical navigation. Always use pressure altitude displayed by pressure altimeters in the aircraft" (p. iv).

Slide 37: GPS provides more consistently accurate position data than a VOR. While VOR position ambiguity increases with distance from the station, GPS is accurate to less than 10 meters anywhere a sufficient GPS signal can be received.

While GPS is inherently accurate, there are times when aviators need more precision than 10 meters. As a result, the GPS constellation is enhanced with a Wide Area Augmentation System (WAAS). Several ground stations, whose locations are known with great accuracy, receive GPS signals and analyze the error between their known, accurate location and what the GPS signals are telling them. They calculate the necessary correction and redistribute it into the GPS satellite network. GPS receivers equipped for WAAS read and apply the correction, resulting in an error of less than 3 meters.

Slide 38: Aviation GPS receivers vary from advanced installations in aircraft to handheld GPS displays that are very similar to those used in cars. In recent years, tablets or smartphones with GPS-enabled apps like ForeFlight and Garmin Pilot have become popular VFR GPS navigation aids. While the term GPS refers to an entire navigation system, pilots are generally referring to their GPS display unit when they discuss "the GPS" for their flight.

Slide 39: Most GPS devices have the ability to display many different parameters such as groundspeed, ground track, the desired track to the next waypoint, ETA, ETE, and distance. Pilots need to be cautious of becoming distracted from the primary responsibility of looking outside and flying the aircraft. The complexity of many GPS units often means that pilots spend too much time looking at the GPS and not enough time looking outside.

Some GPS navigation systems add a CDI to the display which acts very much like the CDI for a VOR, except that the CDI needle represents the offset from the desired GPS track to the next waypoint. In some aircraft, what looks like a VOR CDI can receive a signal from either the VOR or GPS. Pilots need to be aware of which navigation device is actually providing the guidance in the display. Typically, there is an indicator to show the navigation input source.

Slide 40: Most GPS units contain large databases of waypoints, which include airports, airspace boundaries, navaids, obstructions, and other information relevant to a pilot like runway lengths, communication frequencies, and sunset /sunrise times.

When selecting an airport, most GPS units will require the full four-letter identifier of the airport to avoid confusion. For example, if pilots want to fly to the airport in St. Joseph, Missouri, they'll need to input KSTJ. If they input only STJ, the GPS will direct them to the St. Joseph VOR, which is actually 15 miles to the north of the airport. Smaller public airports that use numbers in their identifiers use only three characters (for example, 0N0 is Roosterville Airport in Missouri).

GPS units have the ability to update this database to keep it current in conjunction with the FAA's revision cycle. Verifying database currency prior to use is not a requirement for VFR flight; however, pilots should be aware of the status of their database and the limitations or issues of an expired database.

GPS displays range from simple to elaborate, but there are common features among most GPS displays in aircraft:

The in-aircraft information presented to the pilot varies from a simple display to flight directors providing flight path guidance. Simple displays can show the aircraft location overlaid on a sectional chart moving map; pilots can input a destination or route, and the pilots will see a magenta line for the route, which they can follow to their destination.

Teaching Tips

Manufacturers often offer free online training apps for their GPS units. You or your students may wish to investigate GPS functions by selecting a GPS simulator from this website: https://www.flightschoollist.com/aviation-gps-simulators.php

Slide 41: Most GPS units feature a "Nearest" button which enables pilots to quickly obtain a list of the airports closest to their present position which is a useful function in the event of an emergency.

Slide 42: Just like a VOR can have a maintenance issue, the system of GPS satellites sometimes undergoes maintenance or planned outages for military training purposes.

Poor or no GPS signal indications may be the result of satellite problems, an insufficient number of satellites in view of the receiver, solar flares, or US government GPS jamming exercises.

The GPS system uses Receiver Autonomous Integrity Monitoring (RAIM) to determine if any satellites are providing bad information. At a minimum, RAIM requires five satellites to assess the integrity of GPS signals. RAIM needs six satellites to actually isolate and remove the bad signal from the GPS unit's position calculations.

There are no RAIM requirements for VFR flight using GPS, and many VFR-only GPS devices are not even equipped to display RAIM information. Pilots should be aware of the limitations of their system and the corrective actions, if necessary. When conditions are known to exist that will affect the GPS system (maintenance, jamming, solar activity, etc.), NOTAMs will be published to identify the known outages.

Slide 43: GPS is an excellent tool, but beware of these common pitfalls: looking at the display too much, flying too close to airspace boundaries, and pilot error—be careful entering airport or navaid identifiers.

GPS can greatly increase the situational awareness and safety of flight. However, because the amount of information that GPS can provide is so great and so detailed, it presents an opportunity distraction. Pilots can be tempted to spend too much time looking at the GPS display and trying its many functions instead of flying VFR, which requires that they "see and avoid" other aircraft by looking out the window. This is complicated further by some GPS units that display traffic data, which can tempt pilots to "find" traffic on the display rather than by looking outside. In addition, because of the precision of the display, pilots may be tempted to fly very close to airspace boundaries, which could lead to unintentional incursions or conflicts with other aircraft who may not be relying on GPS for deconfliction. Finally, like every form of technology and automation, the greatest source of error is operator error. Unlike a car GPS that takes only a point of origin and destination, pilots often input all of the waypoints they will use during a flight. Pilots should continually monitor and verify that the display reflects a reasonable output based on their inputs. Inadvertently typing HNL instead of HLN will result in the pilot flying toward Honolulu, Hawaii, instead of Helena, Montana.

EXTEND

Teacher Materials: VOR and GPS Navigation Presentation, VOR and GPS Navigation Teacher Notes 3
Student Materials: VOR and GPS Navigation Student Activity 3, **Compass**

Slide 44: Before distributing **Student Activity 3**, ask the question below and field student responses. Then divide the class into pairs and distribute **VOR and GPS Navigation Student Activity 3**. Students will work together to understand and apply the concepts of GPS navigation. Sample responses are available in **VOR and GPS Navigation Teacher Notes 3**.

Questions

What can a GPS device in an aircraft provide for a pilot?

Potential responses:

Accurate position

Moving map: situational awareness

Ability to fly directly to a specified point

Airport information

Nearest airport button (useful for emergencies)

Flight plan route storage

User waypoint creation

Checklists

Airspace alerts

Reminders/timers

Sunrise/Sunset times

EVALUATE

Teacher Materials: VOR and GPS Navigation Presentation, VOR and GPS Navigation Teacher Notes 4
Student Material: VOR and GPS Navigation Student Activity 4

Slides 45-66: Complete the practice Private Pilot Knowledge Questions.

Teaching Tips

To remember the 180° OBS setting with a TO indication on the CDI at a VOT station (PPL Question 9 on Slide 51), it may help to remember that Cessna makes an aircraft called the 182 ("180" and "TO").

Watch the video below from FLY8MA for a VOR review and helpful technique for determining aircraft position from a VOR. This is a common question on the FAA Private Pilot Knowledge Test.

- "VORs Made Simple For The Written Test | Pass Your FAA Exam" (Length 6:03)
  https://video.link/w/0aH0

  For teachers unable to access Safe YouTube links, the video is also available here:
  https://www.youtube.com/watch?v=swAOdvyqNVY

Slide 67: Conduct the **Summative Assessment**.

Summative Assessment

Distribute **VOR and GPS Navigation Student Activity 4**. In this summative assessment, students will recall information about VORs, evaluate a VOR display, and demonstrate an understanding of the core concepts of GPS navigation. Sample responses are available in **VOR and GPS Navigation Teacher Notes 4**.

[DOK-L4; *apply concepts*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Postings show evidence of one or more of the following:

  - Correct recall of VOR and GPS concepts, capabilities, and limitations.
  - Reasonable application of VOR and GPS navigation to scenarios
  - Evidence and explanation of the above that demonstrate understanding of the material
- Contributions show understanding of the concepts covered in the lesson
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 Demonstrates a clear understanding of all VOR and GPS concepts, capabilities, and limitations, and reasonably applies them to navigation scenarios, with appropriate explanations.

7-8 Correctly understands most VOR and GPS concepts, capabilities, and limitations, with some errors, and generally reasonably applies them to scenarios, with some incomplete analysis or errors.

5-6 Understands some VOR and GPS concepts, capabilities, and limitations, with errors, or generally reasonably applies them to scenarios but lacks adequate explanation.

0-4 Provides few, if any, correct ideas about VOR and GPS concepts, capabilities, and limitations, and/or poorly applies them to scenarios with inadequate explanation.

GOING FURTHER

Slide 68: For a realistic presentation of a GPS display, consider using a GPS device simulator available from manufacturers. For example, Garmin makes free simulators available at https://www8.garmin.com/include/SimulatorPopup.html.

For exposure to dynamic VOR displays, set up a flight simulator to fly toward a VOR and have students explore the displays (and the overhead view of their actual location) as they fly toward, away from, and around the VOR.

STANDARDS ALIGNMENT

COMMON CORE STATE STANDARDS

- **RST.11-12.2** - Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
- **RST.11-12.4** - 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 11-12 texts and topics*.
- **WHST.11-12.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.
- **WHST.11-12.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
- **WHST.11-12.9** - Draw evidence from informational texts to support analysis, reflection, and research

PRIVATE PILOT

VI. Navigation

Task B. Navigation Systems and Radar Services

- Knowledge The applicant demonstrates understanding of:
    - **PA.VI.B.K1** Ground-based navigation (orientation, course determination, equipment, tests, and regulations).
    - **PA.VI.B.K2** Satellite-based navigation (e.g., equipment, regulations, database considerations, and limitations of satellite navigation).
- Risk Management The applicant demonstrates the ability to identify, assess and mitigate risks, encompassing:
    - **PA.VI.B.R1** Failure to manage automated navigation and autoflight systems.
    - **PA.VI.B.R2** Distractions, loss of situational awareness, or improper task management.
    - **PA.VI.B.R3** Limitations of the navigation system in use.
    - **PA.VI.B.R4** Loss of a navigation signal.
- Skills The applicant demonstrates the ability to:
    - **PA.VI.B.S1** Use an airborne electronic navigation system.
    - **PA.VI.B.S2** Determine the airplane's position using the navigation system.
    - **PA.VI.B.S3** Intercept and track a given course, radial, or bearing, as appropriate.
    - **PA.VI.B.S4** Recognize and describe the indication of station or waypoint passage, if appropriate.
    - **PA.VI.B.S5** Recognize signal loss or interference and take appropriate action, if applicable.

REFERENCES

Garmin GNS 430 Pilot's Guide and Reference, page iv, available at https://static.garmin.com/pumac/GNS430_PilotsGuide.pdf

Advisory Circular 20-163, Displaying Geometric Altitude Relative to Mean Sea Level, 9 July 2009.

Aeronautical Information Manual (AIM) section 1-1-3 and 1-1-4

"WAAS – How It Works" FAA, available at https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/waas/howitworks/.

https://www.aopa.org/news-and-media/all-news/2018/may/23/vor-shutdown-update

"Navigation Systems"
https://youtu.be/6E_4jhFalXE

"Ep. 70: VOR Basics–What They are and How They Work"
https://www.youtube.com/watch?v=38D03xtbxn0

"Ep. 71: How to Use a VOR in an Airplane–Flying Navigation"
https://www.youtube.com/watch?v=Fk_hnws0Tw8&t=226s

"VORs Made Simple for the Written Test"
https://www.youtube.com/watch?v=swAOdvyqNVY