Electronic Flight Displays

Session Time: One, 50-Minute Session

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Innovations in aviation are driven by the desire to make aircraft safer, more capable, and more efficient. (EU 3)

Safe and efficient aviation operations require that pilots use math, science, and technology. (EU 4)

ESSENTIAL QUESTIONS

1. Is digital better than analog?

LEARNING GOALS

Students Will Know

- The types of instrumentation represented on electronic flight displays
- The appearance and operation of those instruments

Students Will Be Able To

- *Compare* the appearance and functionality of analog and electronic flight instruments. (DOK-L3)
- *Analyze* electronic flight display readings to determine the attitude, airspeed, and heading of an aircraft in flight. (DOK-L4)

ASSESSMENT EVIDENCE

Warm-up
Students will watch a short video on the development of electronic flight displays in airline operations. Students will then be asked to reflect on why airlines and others have switched from analog to electronic displays.

Formative Assessment
Students will watch two videos: one showing a primary flight display (PFD) in action during takeoff and one showing analog instruments during takeoff. Students should pause each video at the indicated times and answer each question. Finally, they will compare the appearance and functionality of analog and electronic flight instruments.

Summative Assessment
Students will analyze electronic flight display readings to determine the attitude, airspeed, and heading of an aircraft in flight.

LESSON PREPARATION

MATERIALS/RESOURCES

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- Electronic Flight Displays Presentation
- Electronic Flight Displays Student Activity 1
- Electronic Flight Displays Student Activity 2 **(optional)**
- Electronic Flight Displays Student Activity 3
- Electronic Flight Displays Teacher Notes 1
- Electronic Flight Displays Teacher Notes 2 **(optional)**
- Electronic Flight Displays Teacher Notes 3

Flight Simulation Activity: Electronic Flight Displays Student Activity 2 (optional)

- Flight simulator capable of displaying both analog and electronic flight instruments
- Clock, timer, or stopwatch

LESSON SUMMARY

The lesson begins with a video about the adoption of electronic flight instrumentation by the airlines. Following the video, students will discuss with a partner their answers to questions about why they think the airlines and other devices changed from analog displays to electronic ones.

During the next part of the lesson, the various types of electronic flight displays (EFDs) will be discussed, including primary flight displays (PFD) and multi-function displays (MFD). The risk of over-reliance on EFD will be emphasized, as will the importance of maintaining a continual visual scan of the entire instrument panel, especially when flying in conditions with little or no visual reference to the outside.

The lesson will continue with an explanation of how EFDs work without gyroscopes, using instead sophisticated solid-state laser and other sensor-based systems to provide attitude information to the instruments. EFD reliability and failure resistance will also be discussed as important advantages over analog attitude instrumentation.

The function and operation of each individual instrument will then be detailed, including the airspeed tape, attitude indicator, altimeter, vertical speed indicator, heading indicator, slip/skid indicator, turn rate indicator, and tachometer. The Air Data Computer (ADC) and its importance to the electronic flight display system, along with an explanation of the trend vector capability of EFD, will complete the instructional portion of the lesson.

Students will be assessed on their ability to compare digital and analog displays as well as to analyze the readings on an electronic flight display.

If time allows, students can complete a flight simulation activity using analog and electronic instrument displays.

BACKGROUND

Until recently, flight instruments were powered by mechanical forces. The airspeed indicator, altimeter, and vertical speed indicator have been traditionally powered by air pressure. The attitude indicator, turn coordinator, and heading indicator have historically depended on gyroscopes, and the inclinometer has been a simple ball in a glass tube.

Most of these instruments used round dials, using needles or symbolic airplanes to depict information. Such representations using a continuously changing physical quantity are known as analog.

All that started to change in the 1980's as airlines began adopting screen displays in the place of analog instruments. The first systems used cathode ray tubes (CRT) for the displays. These cathode ray tubes, similar to old televisions (though much smaller) would soon give way to electronic flight display (EFD) technology using LCD screens similar to computer monitors. Digital EFDs use sensors, lasers, and other electronic technology to replace the electromechanical gyros of round dial instruments.

Electronic flight displays are also known as "glass cockpits" because the instrument panel consists of a series of flat panel glass displays. EFDs come in a variety of configurations, many including primary flight displays (PFD) and multi-function displays (MFD). PFDs normally replace the round dial instruments and include presentations for roll, pitch, turn

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rate, airspeed, direction, and altitude. MFDs typically display a GPS-driven moving map as well as electronic displays for important engine information, such as oil pressure and temperature.

Advantages of EFDs over round dial systems include better accuracy, improved reliability, the concentration of more information on a single screen, better display of aircraft location, and reduced pilot workload. Most aircraft manufactured over the past two decades came with electronic systems as standard equipment along with a handful of backup analog instruments.

Although EFDs are a positive development in aircraft instrumentation, they do have the drawback of complex interfaces. In contrast to analog instruments which are mostly standard from one airplane to another, EFDs from different manufacturers have varying interfaces and operating principles, requiring pilots familiarize themselves with the particular EFD they are flying.

MISCONCEPTIONS

High tech cockpits with sophisticated displays might give the impression that today's aircraft are significantly different from those of the recent past. While navigation, systems monitoring, and pilot interfaces have been greatly improved, aircraft fly using the same principles and at about the same speeds they have for decades. "Fly the airplane" is a mantra that still works well in the age of computers.

DIFFERENTIATION

To support student memory and recall in the **EXPLORE** section of the lesson plan, have students create a graphic organizer. To create the organizer, have students fold a sheet of paper into two columns. In the first column, they should write down the instruments found on the electronic flight displays. In the second column, they should write any notes, sketches, or questions they have about the instrument. You may want to allow struggling students to use these notes while completing the summative assessment.

To encourage student engagement and motivation in the **EXPLAIN** section of the lesson plan (formative assessment), have students complete the activity with a partner (this could also be done in small groups). One partner watches the first video and answers the questions while the second partner watches the second video and answers the questions. Then the partners switch papers and watch the video they hadn't watched yet, verifying the answers their partner came up with. If the partners disagree on any of the answers, they may need to rewatch the portion of the video again together to verify the correct answer. Once all partners have come to a consensus on the answers, conduct a class discussion to review the correct answers related to both videos.

LEARNING PLAN

ENGAGE

Teacher Material: [Electronic Flight Displays Presentation]

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

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

Warm-Up

Watch the following short video together as a class. Then have students divide into pairs and discuss the questions. Allow students to share their ideas with the class.

- "Boeing: Flipping the Switch to a Glass Flight Deck" (Length 1:37) https://video.link/w/kWlh

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Then, direct students to divide into pairs and discuss the following questions:

- Why do you think the airlines switched to electronic displays?
  Possible response: Better visual representation of aircraft attitude, more reliability, less maintenance, lighter, easier for pilots, centralized location of information, and more accurate navigation capability.

- Are electronic displays easier to read and interpret than the older analog instruments, or harder? Why?
  There is no right or wrong response to this question. Many pilots who were originally trained on the round analog gauges still find those to be easier to use and interpret. Most new pilots who train with electronic displays prefer them.

- Can you think of any electronic devices outside of aviation that used to have analog displays that now use electronic displays?
  Possible response includes: Many devices in the home that use electricity for power now use an electronic display rather than an analog display. Examples include digital clocks, stoves, refrigerators, electric blankets, and printers. Many modern cars also have electronic displays.

[DOK-L2; *Predict*]

EXPLORE

Teacher Material: Electronic Flight Displays Presentation

Slide 5: The term *electronic flight display* or EFD refers to the newest generation of cockpit instruments that use LCD flat screens instead of round analog gauges to display aircraft orientation and other information critical to safe flight.

EFDs provide the pilot with all the information previously displayed by analog gauges, plus other information not previously available. EFDs display airspeed, altitude, rate of climb, rate of turn, direction, navigation, and engine monitoring information to the pilot. Many systems are also capable of displaying traffic, terrain, and weather on large, color screens, greatly enhancing situational awareness, reducing pilot workload, and improving safety.

Practically all new aircraft: military, airliners, and general aviation, are delivered with EFDs. Existing aircraft too, especially in general aviation, are being retrofitted with electronic displays as their cost, reliability, and capabilities make them viable alternatives to analog instruments. Modified regulations allowing for simplified approvals are also facilitating the change as regulators recognize the enhanced safety that electronic systems provide.

When equipped with EFDs, an aircraft is said to have a “glass cockpit,” in reference to the flat glass screens that now make up the instrument panel.

Slide 6: Fully configured electronic flight display systems include two categories of displays–primary flight displays and multi-function displays.

The **primary flight display** (PFD) is a flat glass system that combines all the primary flight instruments into one screen, including the airspeed indicator, altimeter, vertical speed indicator, turn coordinator, attitude indicator, and heading indicator. The PFD may also include navigational information, such as course deviation indicators that assist the pilot in maintaining an accurate track over the ground. Many PFDs also include communication and navigation radios.

The other category is the **multi-function display** (MFD): another large screen that normally displays a GPS-driven moving map, real-time weather and traffic information, fuel management gauges, and even aircraft checklists. Many MFDs also include the primary flight instruments for added redundancy and safety.

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Most PFDs and MFDs have at least a limited capacity to display the information normally displayed on the other screen in case one screen fails in flight. This built-in ability to share information between screens adds greater safety through redundancy.

Slide 7: Electronic flight displays provide several benefits to pilots and several advantages over older analog systems.

- While analog attitude instruments depend on gyroscopes to provide an attitude reference, electronic flight instruments eliminate those gyros and replace them with a series of solid-state lasers and gyros.
    - These components are much more reliable and require less maintenance than gyroscopic instruments.
- Another advantage of EFDs over analog systems is the consolidation of multiple instruments in a single display. This feature, along with the moving map of the MFD, enables the pilot to fly a more precise course and reduces workload. Pilots especially appreciate the large map display which pinpoints their position and provides for better situational awareness.
- The electronic flight display provides a more intuitive picture to the pilot and forms a more cohesive instrument system than was previously available with analog gauges.
- However, even with the improved visual references and situational awareness afforded to pilots with EFDs, it is still important that pilots maintain constant vigilance while flying. It is very easy to get drawn into relying on the instruments and “flying” the instrument panel rather than the airplane. Pilots must maintain a consistent scan and crosscheck of all the instruments, and maintain a constant lookout outside the aircraft for possible traffic and terrain.

EFDs are valuable tools, but do not replace the pilot.

The following slides will discuss the various instruments on an electronic flight display.

EXPLAIN

Teacher Materials: Electronic Flight Displays Presentation, Electronic Flight Displays Teacher Notes 1
Student Material: Electronic Flight Displays Student Activity 1

Slide 8: An EFD system is comprised of different components.

The attitude indicator, heading indicator, turn instruments, and the slip and skid indicator are controlled by the AHRS (Attitude and Heading Reference System). The AHRS (commonly pronounced as A-hars) is the brains of the system.

The AHRS contains solid state accelerometers and gyros that detect changes in attitude which are processed and sent to the display screens.

The AHRS also sends signals to the autopilot to make course, speed, or altitude changes as directed by the pilot or navigation system.

The AHRS and other components of EFDs are modular units, easily removed and replaced in the event of failure. This ease of repair greatly reduces downtime, enabling aircraft to be returned to service quickly.

Slide 9: The attitude indication found on electronic flight displays is much larger than that found on analog attitude indicators. For example, the horizon line often extends the entire width of the screen; and the symbolic airplane, roll and pitch markings are also much larger. As a result of this larger size, the attitude indicator on EFDs is easier to read and follow.

Like the analog attitude indicator, the first three roll markings on the EFD are provided in 10-degree increments left and right; the markings on each side represent 10-degrees, 20-degrees, and 30-degrees respectively. The fourth marking on each side represents 45-degrees, with the fifth and final markings representing 60-degrees. The pitch markings are in 5-degree increments up and down.

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Unlike the analog attitude indicator, the EFD attitude indicator does not use a gyroscope for attitude information. Instead, the EFD gets attitude information from the onboard AHRS (Attitude Heading Reference System) and its various sensors that detect movement and motion. This system uses no moving parts, is far less prone to failure than gyros, and provides a much more reliable instrument for the pilot.

Slide 10: The heading indicator on an EFD is located below the attitude indicator. The heading indicator is configured like a horizontal situation indicator (HSI). Recall from a previous lesson that the horizontal situation indicator provides the pilot with the aircraft’s heading as well as the electronic navigation course deviation indicator (CDI) that shows the aircraft's position relative to the desired course.

The aircraft's heading is displayed in a window at the top of the indicator. A heading bug enables the pilot to preset a heading, either as a reminder to the pilot of a heading to turn to or as an instruction to the autopilot to turn to that heading.

The heading indicator used in EFDs does not use a gyroscope for positional reference, but rather receives its information from a magnetometer and AHRS. The magnetometer sends signals to the aircraft's AHRS which processes those signals and sends instructions to the heading indicator. Because the heading indicator gets its information from the AHRS, unlike the analog heading indicator, it does not have to be reset periodically to the magnetic compass to maintain accuracy.

Slide 11: The turn rate indication feature of the EFD is often found on the heading indicator. White marks on the arc of the indicator call out standard rate and half standard rate turns. Recall that standard rate turns are 3 degrees per second, so half standard rate would be 1.5 degrees per second.

When the aircraft is turning, a colored arc appears around the top of the heading indicator. This arc is called the turn rate vector and indicates what the heading will be in 6 seconds if the pilot maintains a constant rate.

Like the other attitude instruments, the EFD turn indicator does not depend on a gyroscope for attitude information, but relies on the AHRS to process data from sensors and send instructions to the indicator.

Slide 12: The slip and skid uses either a small horizontal bar beneath the roll pointer or a graphical depiction of a ball to show an out of balance condition.

The slip and skid indicator in the EFD works like the inclinometer in an analog display. When an unbalanced condition creates centrifugal force, the horizontal bar deflects in the direction of that force, just like the ball deflects in an inclinometer. The pilot uses the slip and skid indicator to maintain coordinated flight by applying rudder pressure in the direction of deflection.

The slip and skid indicator does not detect an uncoordinated condition directly. Instead, sensors and accelerometers detect lateral forces and send information to the AHRS for processing before being sent to the slip and skid indicator.

Slide 13: The air data computer (ADC) controls three of the instruments in the EFD: the airspeed indicator, altimeter, and vertical speed indicator. It receives static air pressure from external ports, measures that pressure, computes the correct altitude, then sends the information to the altimeter tape for display on the EFD. Similarly, in controlling the airspeed indicator, the ADC receives inputs of static pressure, ram pressure, and temperature, and then uses those data points to calculate both indicated and true airspeeds.

The ADC and AHRS also send signals to the autopilot to make course, speed, or altitude changes as directed by the pilot or navigation system.

Like the AHRS, the ADC is a modular unit, easily removed and replaced in the event of failure. This ease of repair greatly reduces downtime, and enables aircraft to be returned to service quickly with a minimum of delay.

Slide 14: Airspeed indication on an EFD comes in the form of a vertical airspeed tape rather than a round dial. The tape is located on the left side of the display screen and may appear on either the PFD or both the PFD and MFD for redundancy.

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Unlike an analog airspeed indicator, the airspeed indication on an EFD is not the direct result of ram pressure moving the gauge. Instead, with the EFD airspeed tape, the ram pressure from the pitot tube is fed to the ADC which processes incoming pressure and temperature data to convert the data into an electronic signal readable by the EFD.

Airspeed changes are shown as a scrolling tape, with the tape moving downward as airspeed increases and upward as speed decreases. Indicated airspeed is shown in the center of the vertical tape, with true airspeed appearing at the bottom. Exact locations of the various readings on the airspeed tape may vary from manufacturer to manufacturer, so pilots are cautioned to become familiar with their display before flying the aircraft.

Slide 15: Certain important airspeeds may be displayed using "bugs," or reminder markings on the face of the instrument. Of special interest to pilots are V-speeds, and several are commonly found on airspeed tapes:

- Vr the speed at which the pilot should rotate the aircraft during takeoff
- Vx, best angle of climb speed
- Vy, best rate of climb speed
- Other V-speeds may be included by the manufacturer or configured by the user

Recall that the analog airspeed indicator includes three colored arcs around the outside rim of the face of the instrument. These colored arcs represent airspeed ranges used for various phases of flight. Color coding is also displayed on the airspeed tape of an EFD.

- The white arc represents the flap operating range.
- The green arc shows the normal operating range.
- The yellow arc is the caution range.
- The red line the never exceed speed.

On some tapes, red markings may appear at both the lower and upper ends of the airspeed range, representing both minimum and maximum speeds with the same red coloring.

Slide 16: The altimeter on an electronic flight display is found on the right side of the screen and comes in the form of a scrolling tape rather than the traditional round dial. The tape scrolls downward during climbs and when altitude increases, and upward during descents or decreases in altitude.

Altitude is displayed in a large window in the center of the tape. The altimeter setting is controlled by a knob and displays at the bottom of the altimeter tape, similar to the Kollsman window found in analog altimeters.

The EFD altimeter receives its signal from the ADC, which processes air pressure from a standard static port.

Slide 17: The vertical speed indicator on an EFD is normally located to the right side of the altimeter tape. A flag moves up and down to indicate rates of climb or descent, and the markings are in 500-feet-per-minute increments for both climbs and descents. On some indicators, the display is the shape of an arc, similar to that seen on analog vertical speed indicators, but usually the VSI scale is vertical to conform to the shape of the altimeter.

The vertical speed indicator features a movable "bug" that enables the pilot to preset the autopilot to perform the desired climb and descent rate.

Similar to the EFD altimeter, the ADC processes static pressure coming from external ports into signals that get sent to the EFD for display.

Slide 18: Recall that the tachometer is the instrument that measures the speed of the engine in revolutions-per-minute, or RPM. The tachometer on an electronic flight display is normally found on the multi-function display (MFD) screen, but can be found on the primary flight display (PFD) in cases of MFD failure or malfunction.

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The exact location of the tachometer and the graphical representation used in the EFD depends on the manufacturer and preferences of the pilot or operator. Many such units are configurable by the pilot, and there is no industry-wide standard for such presentation. Pilots are cautioned to become very familiar with the display before flight so as to avoid confusion and possibly reading the wrong instrument or misreading its display.

Slide 19: In addition to the EFD's ability to display all the same information available with analog systems, the AHRS also enables the instruments to display trend information, that is, projections of the aircraft speed, attitude, and heading in 6 seconds based on current aircraft attitude and motion. The color symbols on the screen that display these projections are called trend vectors.

Trend vectors appear as moving magenta lines on the airspeed indicator, altimeter, and heading indicator. These lines grow and shrink continually in response to the ongoing projections by the AHRS of aircraft speed, heading and attitude in six seconds. Pilots use these trend vectors to more closely control the aircraft, enabling them to see six seconds into the future and plan their control inputs accordingly.

The ADC and other components of the AHRS make trend vectoring possible. Without fast processing speeds and highly sensitive sensors and accelerometers none of the capabilities of a modern EFD would be possible.

Slide 20: Complete the **Formative Assessment**.

Formative Assessment

Distribute a copy of **Electronic Flight Displays Student Activity 1** to each student. In this activity, students will watch two videos: one showing a primary flight display (PFD) in action during takeoff and one showing analog instruments during takeoff. Students should pause each video at the indicated times and answer each question. Depending on the number of devices available, students should watch the videos individually or together as a class. Finally, students will compare the appearance and functionality of analog and electronic flight instruments.

Correct answers to each question are provided in **Electronic Flight Displays Teacher Notes 1**.

[DOK-L2; *Interpret, Describe*]

EXTEND

Teacher Materials: Electronic Flight Displays Presentation, Electronic Flight Displays Teacher Notes 2
Student Material: Electronic Flight Displays Student Activity 2

Slide 21: If time allows, conduct the optional simulation activity. In this activity, students will fly the simulator using both analog gauges and an electronic flight display. At the end of the flights, students will answer questions related to which system was better/easier to use and why.

Teaching Tips

This exercise will only work with simulators that can present attitude and heading reference in both analog (round gauges) and digital ("glass") displays. In some cases, desktop simulators may require that students fly two different types of aircraft in order to experience both types of displays.

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EVALUATE

Teacher Materials: Electronic Flight Displays Presentation, Electronic Flight Displays Teacher Notes 3
Student Material: Electronic Flight Displays Student Activity 3

Slides 22-27: Quiz students on these questions from the Private Pilot Knowledge Test.

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

Summative Assessment

Distribute a copy of **Electronic Flight Displays Student Activity 3** to each student. In this activity, students will analyze electronic flight display readings to determine the attitude, airspeed, and heading of an aircraft in flight. Correct answers are provided in **Electronic Flight Displays Teacher Notes 3**.

[DOK-L3; *Analyze]*

Summative Assessment Scoring Rubric

- Responses show evidence of being able to analyze electronic flight display readings to determine:
  - attitude;
  - airspeed; and
  - heading.

Points **Performance Levels**

12 Responses show a thorough ability to correctly read electronic flight display readings. Each answer provided is accurate.
10-11 Responses show a sufficient ability to correctly read electronic flight display readings. Most answers are accurate, but 1-2 answers are inaccurate or incomplete.
6-9 Responses show a lack of an ability to correctly read electronic flight display readings. with several inaccurate answers.
0-5 Responses show little ability to correctly read electronic flight display readings with most answers being inaccurate or incomplete.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

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- **HS-PS4-2** - Evaluate questions about the advantages of using a digital transmission and storage of information.
    - Science and Engineering Practices
        - Asking Questions and Defining Problems
        - Engaging in Argument from Evidence
        - Obtaining, Evaluating, and Communicating Information
    - Disciplinary Core Ideas
        - PS4.C: Information Technologies and Instrumentation
    - Crosscutting Concepts
        - Systems and System Models
        - Interdependence of Science, Engineering, and Technology
- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
    - Science and Engineering Practices
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.B: Developing Possible Solutions
    - Crosscutting Concepts
        - None

COMMON CORE STATE STANDARDS

- **RST.9-10.4** - 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.
- **RST.9-10.8** - Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.
- **WHST.9-10.1** - Write arguments focused on discipline-specific content.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

REFERENCES

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