Aircraft Power Settings

Session Time: Four, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Comprehensive preflight planning is an integral (and regulatory) component of safety for all flights.
Safe and efficient aviation operations require that pilots use math, science, and technology.
Pilots rely upon a wide range of printed and electronic resources for flight planning.
A thorough understanding of how an aircraft operates enables a pilot to fly an aircraft safely within its design parameters.

ESSENTIAL QUESTIONS

How does a pilot use aircraft documentation to determine performance factors such as fuel consumption, range, endurance, and speed?

LEARNING GOALS

Students Will Know

- The factors that affect climb and cruise performance.
- How to determine fuel consumed, and distance in a climb.
- How to use performance charts and tables in a pilot's operating handbook (POH) or airplane flight manual (AFM) to determine percent power, cruise speed, and fuel consumption rate.
- How to determine range and endurance at given power settings.

Students Will Be Able To

- *Estimate* time, fuel, and distance required for a climb using industry standard tables and graphs. [DOK-L2]
- *Calculate* range, endurance, and required fuel using industry standard tables and graphs. [DOK-L1]
- *Explain* factors that affect fuel planning procedures. [DOK-L2]

ASSESSMENT EVIDENCE

Warm-up
In pairs, students will research fuel economy and capacity for their favorite vehicles to determine the vehicle's range and the changes to its fuel consumption as a result of how it is driven.

Formative Assessment
In pairs, students will use aircraft performance charts to determine fuel consumption in realistic flight planning scenarios.

Summative Assessment

Working individually, students will answer a variety of questions requiring them to use data from aircraft performance charts and demonstrate knowledge of factors that affect aircraft cruise performance.

LESSON PREPARATION

MATERIALS/RESOURCES

- Aircraft Power Settings Presentation
- Aircraft Power Settings Student Notes
- Aircraft Power Settings Student Activity 1
- Aircraft Power Settings Student Activity 2
- Aircraft Power Settings Student Activity 3
- Aircraft Power Settings Student Activity 4
- Aircraft Power Settings Teacher Notes 1
- Aircraft Power Settings Teacher Notes 2
- Aircraft Power Settings Teacher Notes 3
- Aircraft Power Settings Teacher Notes 4

LESSON SUMMARY

Lesson 1: Weight and Balance
Lesson 2: Density Altitude
Lesson 3: Takeoff and Landing Distances
Lesson 4: Aircraft Power Settings

The lesson begins with a warm-up in which students research their favorite vehicles to determine their fuel economy and fuel tank capacity, and compare that information to how aircraft fuel consumption calculations are derived.

A discussion about aircraft performance charts follows. Students are asked to examine sample performance charts to look for similarities, differences, patterns, and trends among the charts. Regulations related to reserve fuel requirements are discussed, and students are given the opportunity to offer opinions about why fuel reserves are important.

The next portion of the lesson walks the class through the use of the charts to determine the time, distance, and fuel in climb and cruise. Students complete an activity to practice using these charts.

During the final session, students continue to use performance charts and discuss the purpose of the range and endurance charts. The students will also use aircraft performance charts to answer sample FAA Private Pilot Knowledge Test questions. The lesson wraps-up with a summative assessment allowing students to demonstrate their knowledge about aircraft performance to answer questions related to aircraft flight planning scenarios.

BACKGROUND

In NTSB Safety Alert 67 (https://ntsb.gov/safety/safety-alerts/Documents/SA-067.pdf), pilots are reminded of the importance detailed fuel planning plays in the safe outcome of a flight. Knowing how much fuel is required for a particular flight, carrying a legal and comfortable amount of reserve fuel, monitoring fuel consumption in flight, being aware of factors that affect fuel consumption, and understanding the aircraft's fuel system are all key elements to the safe completion of a flight.

From Safety Alert 67: "Within fuel-related accidents, fuel exhaustion and fuel starvation continue to be leading causes. From 2011 to 2015, an average of more than 50 accidents per year occurred due to fuel management issues. Fuel exhaustion accounted for 56% of fuel-related accidents while fuel starvation was responsible for 35% of these accidents."

“Running out of fuel or starving an engine of fuel is highly preventable. An overwhelming majority of our investigations of fuel management accidents—95%— cited personnel issues (such as use of equipment, planning, or experience in the type of aircraft being flown) as causal or contributing to fuel exhaustion or starvation accidents. Prudent pilot action can eliminate these issues. Less than 5% of investigations cited a failure or malfunction of the fuel system.”

The current state of an aircraft’s fuel quantity is very important to a pilot. Monitoring fuel quantity and rate of consumption during a flight allows the pilot to be sure that enough fuel is on board to safely complete the flight. Actively monitoring fuel consumption enables the pilot to note any discrepancies between the estimated fuel consumption and the actual fuel consumption. Since aircraft refueling opportunities may be limited in comparison to finding a gas station when driving a car, pilots must be sure they are always in range of making a safe landing with adequate fuel aboard. Running out of fuel in a car may be a huge inconvenience, but running out of fuel in an aircraft can endanger lives both in the aircraft and on the ground.

Pilots are required by federal regulations (14 CFR 91.103) to conduct fuel planning as part of their preflight planning. While many drivers learn to anticipate when to refuel based on years of experience with their vehicle, a pilot should rely on data provided by the manufacturer to predict fuel use. Modern aircraft have a POH that has a portion entitled “Section 5: Performance” which contains tables, charts, and graphs that help pilots determine fuel consumption, power settings, range, and endurance. Regulations also stipulate how much additional, or reserve, fuel must be carried.

Unfortunately, some pilots have a cavalier attitude toward fuel, and fuel exhaustion has led to some flight mishaps. Sometimes, pilots will fly for years and not have any problems with fuel, which can make them complacent toward the seriousness of fuel planning and management.

A recognized hazardous attitude in which a pilot’s sense of urgency to complete a trip no matter what is known as “get-there-itis.” Pressure from any source–passengers, the weather, a schedule, or even pilots themselves–may blind pilots to factors that indicate fuel is a concern and the flight should end early.

MISCONCEPTIONS

Miles per gallon is a fuel consumption rating that students may be familiar with; however, aircraft use gallons per hour to measure fuel consumption. With cars, the terms “City MPG” and “Highway MPG” give an owner some indication of the amount of fuel likely to be used in certain conditions. With aircraft, pilots can tailor fuel consumption based upon a number of factors such as power setting, air/fuel mixture, weight, and configuration.

Car engines are governed by electronics that adjust the air/fuel mixture based on a number of variables. In most small aircraft, the pilot manually adjusts the air/fuel mixture to obtain the power and fuel consumption they want.

Aircraft operate using fuels that are specific to their engines-a jet and a piston aircraft do not use the same fuel, and it is the pilot’s responsibility to ensure the correct type of fuel is used when the aircraft is fueled.

Warnings about low fuel are not usually given to the pilot. Most aircraft do not have a light or sound that alerts the pilot to a low fuel condition. Pilots must be vigilant about the amount of fuel available during flight.

DIFFERENTIATION

To support student comprehension, provide simple, straightforward examples with brief instructional steps to support working memory. Encourage students to follow along on all example activities.

To reinforce learning, allow groups to perform a peer review of the work of another group prior to a large group discussion. This approach will reinforce the use of foundational skills with different match problems.

LEARNING PLAN

ENGAGE

Session 1

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

Slide 4: Conduct the **Warm-Up**. Display **Slide 4** to the class, and give them the opportunity to think about the **Warm-Up**. Students may talk amongst themselves before you call them together for a class discussion. The objective of this activity is to get the students thinking about the many variables that affect fuel consumption in aircraft. The variables you discuss with them will be reflected in the aircraft performance charts that are used in this lesson.

Warm-Up

Two pilots flying identical aircraft were talking about their most recent flights, and one had just flown 250 NM and used 25 gallons of fuel. The other pilot flew 200 NM but used 30 gallons of fuel.

- What factors could have contributed to this?
- How is it possible that the second pilot flew a shorter distance but used more fuel?

Student answers may include: *The pilots were flying at different altitudes. Flying at higher altitudes generally results in lower fuel consumption.*

- *The temperature was different for each of their flights. At higher temperatures, less fuel is consumed per hour of flight.*
- *The pilots used different power settings. Flying at a high power setting (usually indicated by high RPM settings on the tachometer) results in high fuel consumption.*
- *The air/fuel mixture was different. The pilot who used more fuel to fly a shorter distance may not have leaned the mixture as recommended by the manufacturer.*
- *One of the pilots may have been flying at a low weight. The lower weight would mean less fuel consumed during cruise flight.*
- *Perhaps the pilot who used more fuel had removed the aircraft's wheel pants or the aircraft was equipped with air conditioning (not exactly identical to the other aircraft in that case). It is possible the aircraft's flaps were extended.*
- *Weather could have been a factor. The pilot who used less fuel may have had a strong tailwind.*

EXPLORE

Teacher Material: Aircraft Power Settings Presentation
Student Material: Aircraft Power Settings Student Notes

Slide 5: Distribute **Aircraft Power Settings Student Notes**. This resource has three sections. The first section consists of four charts with data for a Cessna 172; the second section consists of four charts with data for a Cirrus SR22; the final section contains data from a fictional aircraft using charts from the Pilot's Handbook of Aeronautical Knowledge.

Have students review the charts and note similarities or differences.

Questions

Can you identify similarities and differences among the performance charts?

Student responses will vary but may include:

- *Aircraft climb charts are based on full throttle, standard temperature, and zero wind for the time, fuel, and distance charts*

- *They require an appropriate fuel mixture*
- *Some speeds are given in knots indicated airspeed (KIAS) and some are given in knots true airspeed (KTAS)*
- *Speed fairings are mentioned in the cruise performance charts*
- *Manifold pressure (MAP) is listed in the PHAK and Cirrus charts but not in the Cessna charts*

As with the charts students have seen previously, it is important to review the conditions for each table or graph. For example, students may note that both the Cessna and SR22 Time, Fuel and Distance to Climb charts are based on full throttle, standard temperature, and zero wind. The Cessna table and PHAK table specify “Flaps UP,” while the Cirrus table does not, so the implication is that flaps are expected to be up while climbing. The Cessna and Cirrus charts also require fuel mixture management or “leaning” in accordance with the POH.

Slide 6: In the Cessna and Cirrus Cruise Performance charts used in this example, both manufacturers help a pilot select a power setting by listing RPM and the resulting power the engine develops. The power is expressed as “% MCP” on the Cessna chart which means “percent of maximum continuous power.” The Cirrus chart uses “PWR” to represent power.

Note that the charts account for temperature variations by grouping performance data into temperature ranges below, at, and above standard temperature.

Slide 7: Note, too, that both the Cessna and Cirrus charts discuss the physical configuration of the aircraft. The Cessna calls for a change in performance calculations based on the presence of “speed fairings,” which the Cirrus calls “wheel pants and fairings.” Fairings or wheel pants are the covers that surround the wheels and are generally designed to reduce drag and increase aircraft performance. For various reasons, some pilots remove their fairings, and aircraft manufacturers account for this possibility with a change in the performance charts.

Similarly, note that in the Cirrus Cruise Performance charts there are notes about the air conditioner and synthetic vision. An aircraft air conditioner draws power from the engine and decreases performance, which the note accounts for in the chart with a percentage “penalty” in the final calculations. For Cirrus aircraft with synthetic vision installed, the opening for the synthetic vision on the outside of the airplane makes the aircraft slightly less aerodynamic, which reduces aircraft performance slightly.

Also, note that the units for fuel consumption are Gallons Per Hour (GPH).

Slide 8: Note that for both aircraft, the Time, Fuel and Distance to Climb charts use Knots Indicated Airspeed (KIAS) while the Cruise Performance charts use Knots True Airspeed (KTAS). Recalling earlier lessons on the different types of airspeed, true airspeed is the most accurate measure of the aircraft’s movement through the air mass. However, true airspeed varies with altitude, temperature, and density. For a climb, it is generally easier for pilots to fly a constant indicated airspeed rather than an airspeed that changes as altitude increases. In the climb charts, the best climb speed changes at certain altitudes even as the aircraft climbs. At low speeds and altitudes where most general aviation aircraft fly, the difference between true and indicated airspeed is small.

Slide 9: What do each of the columns mean? The slide contains an excerpt from a Cruise Performance table. The first column separates the rows by pressure altitude. The second column separates the rows by the RPM setting of the engine. There are then three overarching columns for three set temperatures: Standard Temperature in the middle, Standard - 20°C on the left, and Standard + 20°C on the right. In each of these major columns there are three sub-columns: Percent Maximum Continuous Power (%MCP), which is a measure of the power of the engine, KTAS, which indicates the resulting true airspeed at that power setting, and GPH, which indicates the fuel consumption at that power setting.

Slides 10-11: At this point in the curriculum, the effect on aircraft performance with changes in altitude and temperature are probably somewhat intuitive to most students. For example, the effect of density altitude and temperature on takeoff and landing has been previously discussed. Higher altitudes and temperatures result in decreased aircraft performance as well as longer ground rolls and higher required speeds. These trends are visible on the charts. For example, the rate of climb decreases as the aircraft's altitude increases, which makes sense because as density altitude increases, engine performance and lift decrease, which reduces the aircraft's ability to climb.

Questions

Have students reference the Cessna Cruise Performance charts in **Aircraft Power Settings Student Notes**. Find the Maximum Continuous Power (MCP) column for 2,000 feet and 2,300 RPM at standard temperature. Compare that value to the %MCP for the same altitude below and above standard temperature. What does this tell you about how temperature affects %MCP?

As temperature increases, the %MCP decreases. On a warmer day, the engine cannot produce as much power as it could on a colder day since the density altitude is higher at the warm temperature.

In cruise, if you set 2,300 RPM, how does the fuel usage (GPH) vary from 2,000 feet to 4,000 feet to 8,000 feet at 20°C below standard temperature?

The fuel flow rate decreases from 8.6 GPH to 8.2 and then 7.5 GPH at 8,000 feet. Fuel usage in GPH decreases with increasing altitudes at the same RPM setting. As the air density decreases, maintaining the correct air/fuel mixture means less fuel is used because fewer air molecules are available to mix with the fuel at higher altitudes.

Using the Cirrus Cruise Performance charts at 10,000 feet with 2,600 RPM, how does fuel usage (GPH) vary with temperature? Why?

Fuel flow decreases from 17.0 GPH at 30 degrees below standard temp to 16.1 and finally 15.3 at 30 degrees above standard temperature. This is because higher temperatures result in less dense air. As air density decreases, less fuel is required to maintain the same mixture. Thus, a properly-leaned engine will use less fuel.

Using the Cirrus Cruise Performance charts, if you set 2,600 RPM, what true airspeed will you be able to obtain at standard temperature at 2,000 feet? 6,000 feet? 10,000 feet? Why?

The values are 183 KTAS, 181 KTAS, 177 KTAS. At the same RPM setting, the power produced by the engine decreases with altitude, resulting in a lower airspeed.

EXPLAIN

Teacher Materials: Aircraft Power Settings Presentation, Aircraft Power Settings Teacher Notes 1, Aircraft Power Settings Teacher Notes 2
Student Materials: Aircraft Power Settings Student Activity 1, Aircraft Power Settings Student Activity 2, Aircraft Power Settings Student Notes

Slide 12: What weights are the Cessna and Cirrus charts based on? In both cases, these numbers are the maximum gross weights of the aircraft. This is important because, as discussed in other classes on performance, aircraft performance varies with weight. Just as with takeoffs and landings, increased weight tends to reduce the climb and cruise performance of aircraft and increase the amount of fuel used. In theory, maximum gross weight represents the "worst case" scenario for a pilot. A pilot flying an aircraft that is under max gross weight, for example, could expect to see higher climb rates and lower fuel usage in cruise. However, it is important to remember the parameters upon which these values are based. These charts represent the aircraft in a like-new condition being flown very precisely. Older aircraft may not always meet the expectations of "book numbers," and allowing for this variable is sometimes a good idea. When possible, pilots should attempt to compare the POH values with actual aircraft performance.

Slide 13: Recall that during previous lessons on cross-country planning, fuel was of primary concern to the pilot. Using these charts to accurately forecast fuel usage will allow the pilot to make wise decisions regarding leg distances and planning stops to refuel. Unlike a car, an aircraft cannot just pull over if it runs out of fuel. Pilots monitor their fuel levels frequently. Some pilots set timers that remind them to check the fuel and, in airplanes with switchable fuel tanks, switch from one tank to the other. Failure to properly manage and monitor fuel can result in fuel exhaustion, leading to the engine stopping and a forced landing.

Slide 14: Have students watch the following video for an explanation of some of the key factors in fuel planning.

- "Fuel Management Made Easy" (Length 2:58)
  https://video.link/w/rys1

For teachers unable to access Safe YouTube links, the video is also available here: https://youtu.be/cJrn3QO89Dc

Slide 15: As a reminder, Federal Aviation Regulations (FARs) require pilots to perform fuel planning.

FAR 91.103 Preflight action.

Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight. This information must include—

(a) For a flight under IFR or a flight not in the vicinity of an airport, weather reports and forecasts, **fuel requirements**, alternatives available if the planned flight cannot be completed, and any known traffic delays of which the pilot in command has been advised by ATC...

Slide 16: Also, remind students of the following FARs.

FAR 91.151 Fuel requirements for flight in VFR conditions.

(a) No person may begin a flight in an airplane under VFR conditions unless (considering wind and forecast weather conditions) there is enough fuel to fly to the first point of intended landing and, assuming normal cruising speed—

(1) During the **day**, to fly after that for **at least 30 minutes**; or

(2) At **night**, to fly after that for **at least 45 minutes**.

Teaching Tips

Helicopter pilots also need to follow FARs for fuel reserves; however, the reserve fuel requirement is different for rotorcraft:

FAR 91.151 Fuel requirements for flight in VFR conditions.
(a) No person may begin a flight in an airplane under VFR conditions unless (considering wind and forecast weather conditions) there is enough fuel to fly to the first point of intended landing and, assuming normal cruising speed—

(b) No person may begin a flight in a rotorcraft under VFR conditions unless (considering wind and forecast weather conditions) there is enough fuel to fly to the first point of intended landing and, assuming normal cruising speed, to fly after that for at least 20 minutes.

Slide 17: AOPA recommends increasing that reserve to 1 hour. Note that the requirement is for 30 minutes (or more) at "normal cruising speed," which will vary based on aircraft as well as the speed and altitude at which a pilot plans the flight.

Slide 18: Most of the discussion to this point has been on figuring out how much fuel will be needed. Regulations also require pilots to carry fuel reserves; if the flight is properly planned and flown, however, reserves should never actually be used. If this is so, why have them?

Questions

Beyond the fact that regulations require it, what are the practical reasons for carrying a fuel reserve? Have the class brainstorm reasons, and then discuss.

The purpose of a fuel reserve is to allow continued safe flight if unanticipated delays or circumstances are encountered. For example, if a pilot is preparing to land, and the runway is suddenly closed due to an incident, the pilot should have enough fuel on board to divert to another airport.

The purpose of the reserve is not to extend the range of the aircraft. Pilots should always plan to land with their full reserve. Hazardous attitudes like "get-there-itis" can tempt a pilot to fly into their fuel reserves if they've miscalculated, failed to account for winds, or simply experienced unexpected delays.

Slide 19: This graphic illustrates the phases of flight in which performance charts are used in fuel use calculations.

Slides 20-22: These three slides walk through a sample problem using the Cessna 172 performance charts available from the POH and included in the **Aircraft Power Settings Student Notes**.

Slide 20: The relevant fuel calculations are based on the following data:

- Total route distance: 360 nautical miles
- Takeoff weight 2,550 pounds
- Takeoff Pressure Altitude: 2,000 feet
- Takeoff Temperature: 28°C (16°C above Standard)

- Cruise Pressure Altitude: 8,000 feet
- Cruise Temperature: 16°C (16°C above Standard)
- Forecast enroute winds: 10-knot headwind

The pilot chooses an altitude for cruise at their discretion based on the trip length, winds aloft, and the aircraft's performance. The pilot chooses a cruise power setting at their discretion based on the aircraft's performance charts, which indicate speed, fuel, and time. In general, lower power settings use less fuel and provide longer range. In this example, the pilot has elected to use a power setting of approximately 65%, which is a common cross-country power setting.

TAKEOFF AND CLIMB.
The pilot needs to account for the climb and the cruise portions of the flight. For the climb portion, the ground speed is lower and the power setting is higher than for the cruise portion of the flight.

Referencing Figure 5-7 in **Aircraft Power Settings Student Notes**, the pilot will be climbing from approximately 2,000 feet MSL to 8,000 feet MSL. To calculate the values for the climb between those altitudes, simply find the difference between the values in the chart, as shown below.

- Time: 11 minutes
- Fuel: 2.2 gallons
- Distance: 15 nautical miles

Slide 21: This may be accurate enough for most flights, but pilots should see the note below the table that includes a correction for the nonstandard temperature. A change of 10% for every 10 degrees results in a change of 16% for 16°C above standard temperature. This would require an additional 0.4 gallons (for an adjusted fuel requirement of 2.6 gallons), an additional 3 NM in distance, and an additional 2 minutes.

Slide 22: CRUISE.

The Cruise Performance chart (Figure 5-8) is next. Enter the cruise chart at 8,000 feet PA and a temperature of 20°C above standard, which approximates the selected conditions of 8,000 ft/+16 C.

At 8,000 feet and +20°C, the selected power setting of approximately 65% occurs at 2,600 RPM. At 2,600 RPM, results for power, true airspeed, and cruise fuel are shown below.

- Power: 64%
- True airspeed: 117 knots
- Cruise fuel flow: 8.9 GPH

FUEL REQUIRED
The fuel required for the climb has already been calculated as 2.6 gallons.

With a total route distance of 360 NM and 18 NM covered in the climb, the cruise portion should be 342 NM.

With a forecast 10 knot head wind and a planned true airspeed of 117 knots, the ground speed for cruise should be 107 knots, resulting in a total cruise time of 3.2 hours. Thus, the fuel required for cruise is 3.2 hours at 8.9 GPH = 28.5 gallons.

In addition, the minimum required FAA 30-minute fuel reserve requires: 0.5 8.9 GPH = 4.5 gallons.

Slide 23: The total estimated fuel required is as follows.

- Engine start, taxi, and takeoff: 1.4 gallons (from the notes on the Time, Fuel, and Distance to Climb Chart)
- Climb: 2.6 gallons
- Cruise: 28.5 gallons
- Reserve: 4.5 gallons
- Total fuel required: 37.0 gallons
- Fuel onboard (C172S): 53 gallons useable

Note that there is no figure for descent and landing at the destination. The fuel consumption figures and the fuel reserve allow sufficient buffer for a descent to the traffic pattern and landing.

Slide 24: However, consider what would happen if the pilot were asked to make a last-minute change to their flight and carry a passenger weighing 118 lbs.

To keep the aircraft in weight and balance limits, 20 gallons of fuel is removed from the airplane. The aircraft now has 33 gallons on board, which is 4 gallons less than the total fuel required found above.

Questions

Can the trip still be made without stopping to refuel? What can the pilot do to reduce the fuel required for the trip?

Conceptually, reducing the throttle setting will result in a lower fuel use rate (GPH). However, a lower throttle setting will also result in a lower speed, meaning the trip will take longer. A longer flight will require more fuel. The precise savings from reducing the throttle setting would need to be determined from the charts.

The pilot could also fly higher, since increasing altitude generally results in a lower GPH. However, more fuel will be used in the climb. Again, any savings would need to be determined from the charts.

The important point is for students to realize that fuel use may be reduced through several methods, but that the fuel savings method must be re-calculated with the charts. The pilot may find that the amount saved is not as great as anticipated or needed.

Slide 25: Consider the same conditions but a power setting of 51%. The throttle setting is 2400 RPM, the fuel flow would be 7.4 GPH, which is a lower fuel consumption rate. A true airspeed of 104 KTAS would result in a 94-knot groundspeed, which would result in a cruise time of 3.6 hours, or about 0.4 hours longer than the original flight. At 7.4 GPH, the aircraft would burn 27 gallons of fuel in cruise during the longer trip, or 1.5 gallons less than the original setting. Because of the reduced cruise fuel flow, the reserve fuel would be 3.7 instead of 4.5 gallons. The total required fuel reduction is only 2.3 gallons, which is not enough to make up for the 4-gallon shortage.

What if the pilot climbed? By climbing to 10,000 feet instead of 8,000 feet, the new plan would use an additional 1.1 gallons and 9.6 miles (corrected for temperature) in the climb. This would be a total of 3.7 gallons in the climb and a distance of 27.6 NM, for a cruise distance of 332.4 NM. After leveling at 10,000 feet, setting 54% power (2500 RPM) would result in a fuel flow of 7.8 GPH at 109 KTAS, or 99 knots GS. This would result in a cruise time of 3.36 hours, burning 26.2 gallons of gas with a reserve of 3.9 gallons. The total fuel required for the flight would be 1.4 + 3.7 + 26.2 + 3.9 = 35.2 gallons. This is still more than the 33 gallons available.

Slide 26: Pilots should give themselves a safety margin that is comfortable when it comes to fuel consumption. It is good practice to carry a one-hour fuel reserve. Additionally, any changes, like a last-minute passenger, mean that the pilot should recalculate the fuel requirements for a trip.

Session 2

Slide 27: Begin this session by displaying the Fuel, time, and distance chart from the Pilot's Handbook of Aeronautical Knowledge. Give students an opportunity to look at the different areas of the chart.

Questions

How does this chart display the same information that was seen in the Cessna time, fuel, and distance to climb chart?

This chart is a graphical representation of how the temperature and pressure altitude affect time, fuel, and distance in a climb while similar information in the Cessna POH is displayed in a table.

The numbers on the side of the slide represent conditions at the departure airport and at the cruise altitude. Directions for finding the time, fuel, and distance for the climb follow. They are taken from the Pilot's Handbook of Aeronautical Knowledge.

1.

First, find the information for the departing airport.

2.
Find the OAT for the departing airport along the bottom, left side of the graph.

3.
Follow the line from 25°C straight up until it intersects the line corresponding to the pressure altitude of 6,000 feet.

4.
Continue this line straight across until it intersects all three lines for fuel, time, and distance.

5.
Draw a line straight down from the intersection of altitude and fuel, altitude and time, and a third line at altitude and distance. It should read three and one-half gallons of fuel, 6 minutes of time, and nine NM.

6.
Next, repeat the steps to find the information for the cruise altitude. It should read six gallons of fuel, 10.5 minutes of time, and 15 NM.

7.
Take each set of numbers for fuel, time, and distance and subtract them from one another (6.0 – 3.5 = 2.5 gallons of fuel).

8.
It takes two and one-half gallons of fuel and 4 minutes of time to climb to 10,000 feet. During that climb, the distance covered is six NM.

Remember, according to the notes at the top of the chart, these numbers do not take into account wind, and it is assumed maximum continuous power is being used.

Slide 28: Distribute **Aircraft Power Settings Student Activity 1** as an opportunity for students to practice using this type of performance chart. Students may work with a partner, and they will determine the fuel required for a cross-country flight. Review the solutions with the class to check for understanding.

Slide 29: Recall that to determine the time and fuel required for a cross-country flight, pilots need to use the performance charts in the POH for the airplane. Pilots need to make sure they read the notes for each chart to ensure they are using the correct chart for the configuration and conditions in which they're operating. They also need to account for any correction factors (wheel pants, fairings, accessories, etc.). Using the known airport conditions and desired cruise conditions, pilots can determine the time, fuel, and distance to climb to cruise, and then the time and fuel spent in cruise. Pilots then need to add the results from the climb with those from cruise, account for the fuel used during taxi and takeoff, and finally include a fuel reserve, and then they will know how much fuel is required for the flight and how long the flight will take.

Teaching Tips

Consider giving students a few minutes on the Internet to research the price of 100LL aviation fuel (colloquially known as "avgas") at a variety of airports from small to large. Inform them that jet fuel (Jet-A) is not the same thing as avgas, though it is often cheaper. You may wish to have the students calculate the fuel cost for the example flight used in slides 19-22.

Slide 30: Reference Figure 5-8 in the Cessna charts in the Aircraft Power Settings Student Notes. Consider a C-172 flying at 4,000 feet on a standard, no wind day at 2,500 RPM, which results in 115 KTAS on a planned flight of 250 NM.

The resulting flight would be 2.2 hours long. The charts indicate the fuel consumption during cruise would be approximately 21 gallons. At $5.00 per gallon, the cost of fuel for the cruise portion of the flight is $105.

Questions

Can the pilot save fuel (and money) by flying at a lower power setting like 2,200 RPM?

Students should be given the opportunity to look at the charts and discuss their findings. Ultimately, while a lower power setting should consume less fuel than a higher one, the lower power will also result in a slower speed, which will increase the time required to complete the flight. The longer the flight is, the more fuel the aircraft will use.

According to the charts, at 2,200 RPM the new airspeed would be 96 KTAS, resulting in a total time of 2.6 hours in cruise, using 18.2 gallons of fuel at a cost of $91. That's a savings of $14 on a flight that is almost 30 minutes longer.

Slide 31: Have students watch the following video, which highlights fuel monitoring techniques and notes a calculation of total time based on fuel onboard:

- "Fuel Management Made Easy" (Length 1:55)
  https://video.link/w/Ltg2

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/embed/cJrn3QO89Dc?start=414&end=589

Slide 32: The Range Profile Chart is a quick reference for how far an aircraft can travel at a given power setting and altitude. It is useful for helping a pilot balance decisions regarding airspeed, altitude, and fuel usage when choosing their planned cross-country flight conditions. However, it is important to remember the configuration data and notes for the chart. At the top of the Cessna Range Profile Chart, "Zero Wind" indicates that the numbers represent flight in a no-wind flight environment.

Example: How far can a C-172S travel at 6,000 feet PA at 70% power? The chart shows lines for 75% and 65% power. The 70% power curve would parallel those two lines, halfway between them. Starting at 6,000 feet on the left side of the chart and moving right to 70% power, and then down to the range scale reveals a range of 530 NM.

Remember to read the notes. The range chart notes indicate they are based on a C-172S with wheel fairings installed. If a pilot removes the fairings, the note says there is a 2-knot speed loss. For the Cirrus, removing the nose and main wheel pants and fairings results in a decrease of 15% in range.

Also, the header of the chart indicates it is calculated for "Standard Temperature, Zero Wind." If the winds are not calm, or the temperature is not standard, the pilot will have to use their own judgment to analyze the results from the chart, because the chart does not provide correction factors.

Slide 33: The Endurance Profile Chart enables a pilot to understand approximately how long they can stay airborne at a given power setting and altitude. For example, a C-172S at 65% power should have a maximum flight time of 4.9 hours, in addition to the 45-minute reserve indicated at the top of the chart. Note that wind is not mentioned, because wind does not play a role in how long the engine can operate with the specified fuel on board. If a pilot tops off the tanks with fuel, starts a timer, and takes off, the pilot should have a very good idea of how long the engine will continue to run. This would avoid situations like that seen in the video, where a Cessna with a calculated 3.1 hours of fuel onboard tried to stay airborne for 3.5 hours.

Slide 34: Complete the **Formative Assessment**.

Formative Assessment

Divide the class into pairs and distribute Aircraft Power Settings Student Activity 2. Students will work together using aircraft performance charts to determine fuel used in various flight scenarios.

[DOK-L2;*estimate*, DOK-L1;*calculate*]

EXTEND

Teacher Materials: Aircraft Power Settings Presentation, Aircraft Power Settings Teacher Notes 3
Student Materials: Aircraft Power Settings Student Activity 3, Aircraft Power Settings Student Notes

Session 3

Slide 35: In this session, students continue practicing the use of fuel consumption charts then answer FAA-style questions. Begin by distributing **Aircraft Power Settings Student Activity 3** and allowing students to work in pairs.

EVALUATE

Teacher Materials: Aircraft Power Settings Presentation, Aircraft Power Settings Teacher Notes 4
Student Materials: Aircraft Power Settings Student Activity 4, Aircraft Power Settings Student Notes

Slides 36-47: Review the Private Pilot Knowledge Test questions. This lesson works toward an understanding of material that will contribute to passing the FAA Private Pilot Knowledge Test. The questions on these slides mimic what is on that test.

Session 4

Slide 48: Conduct the **Summative Assessment**.

Summative Assessment

Distribute **Aircraft Power Settings Student Activity 4**. Students will work individually to evaluate aircraft performance in realistic scenarios using charts and pilot judgment. Potential responses are available in **Aircraft Power Settings Teacher Notes 4**.

[DOK-L2; *estimate*, DOK-L1; *calculate*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Postings show evidence of one or more of the following:
  - Correct recall of how to use performance charts, perform calculations, and determine the overall impact of performance data to aircraft operations.
  - Reasonable application of aircraft performance calculations to realistic 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 performance charts and calculations, and reasonably applies that understanding to realistic scenarios, with appropriate explanations.
7-8 Correctly understands most performance charts and calculations, with some errors, and generally reasonably applies that understanding to realistic scenarios, with some incomplete analysis or errors.
5-6 Understands some performance charts and calculations, or generally reasonably applies that understanding to realistic scenarios but lacks adequate explanation.
0-4 Provides few, if any, correct ideas about performance charts and calculations, and/or poorly applies them to scenarios with inadequate explanation.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-Dimensional Learning

- **HS-ETS1-2** - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
    - Science and Engineering Practices
        - Asking Questions and Defining Problems
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.A: Defining and Delimiting Engineering Problems
    - Crosscutting Concepts
        - None
- **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.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

REFERENCES

- PHAK Chapter 11: Aircraft Performance: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/13_phak_ch11.pdf
- FAA Airman Knowledge Testing Supplement (FAA-CT-8080-2H): https://www.faa.gov/training_testing/testing/supplements/media/sport_rec_private_akts.pdf
- AOPA Air Safety Institute's "Fuel Management Made Easy": https://www.youtube.com/watch?time_continue=589&v=cJrn3QO89Dc&feature=emb_log
- Average AVGAS/fuel price: https://www.airnav.com/fuel/report.html
- FAR 91