Density Altitude

Session Time: Two, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Pilots must understand how external factors can affect aircraft performance.
Flight planning must take into account a wide range of factors to ensure safety.

ESSENTIAL QUESTIONS

1. How does aircraft performance affect the safety of a flight?
2. What factors can affect aircraft performance?

LEARNING GOALS

Students Will Know

- The definition of density altitude.
- How density altitude affects aircraft performance.
- How to use airplane flying manual charts to determine the effect of density altitude on performance.
- Why aircraft performance calculations are an important element of flight planning.

Students Will Be Able To

- *Recall* important information relevant to density altitude. [DOK-L1]
- *Calculate* density altitude using a variety of tools, including charts and the E6B. [DOK-L1]
- *Predict* how different density altitude conditions will affect aircraft performance. [DOK-L2]
- *Assess* the safety of a proposed flight based on performance calculations for varying density altitude conditions. [DOK-L3]

ASSESSMENT EVIDENCE

Warm-up
Students will be asked a series of questions about density altitude, reviewing knowledge they should have gained in previous lessons. A question concerning the formula for density altitude will also be included.

Formative Assessment
Students will work in groups of three or four. Teacher will present three scenarios and ask the groups to use their E6B computers to calculate density altitude. Teacher will lead a class discussion on how density altitude might affect aircraft performance.

Summative Assessment
Teacher will provide three realistic scenarios and ask students to provide information on density altitude and takeoff distance, with an emphasis on making a sound go/no-go decision in each scenario.

LESSON PREPARATION

MATERIALS/RESOURCES

- Density Altitude Presentation
- Density Altitude Student Activity 1
- Density Altitude Student Activity 2
- Density Altitude Student Activity 3
- Density Altitude Teacher Notes 1
- Density Altitude Teacher Notes 2
- Density Altitude Teacher Notes 3
- E6B Flight Computers (one per group)

LESSON SUMMARY

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

The lesson will begin with a warm-up exercise asking students a series of questions about density altitude (DA); this material has been covered in a previous lesson from Grade 10, Unit 3. A discussion of the various factors that influence density altitude will also include a review of the formula for density altitude.

Next, students will review two slides from Grade 10, Unit 3, Section B, Lesson 1 to assist them in recalling how to use a density altitude chart. An activity will have students answer three more questions using the DA chart as a reference.

Students will then be reminded that DA can have a significant effect on aircraft, and that a high DA can dramatically reduce aircraft performance. Students will be reminded of the factors that affect DA, and will be introduced to the concept of "high, hot, and humid" as flight conditions that can significantly degrade performance. Students will be reminded that high DA affects both engine performance and airfoil performance. Slides and a video will explain the use of the E6B flight computer to calculate density altitude and true airspeed.

A formative assessment will ask students to use their E6B computers in groups to calculate DA and the effects of DA on flight parameters such as true airspeed. This activity will also measure student retention of the material presented to date.

The next session of the lesson will highlight the safety importance of including DA calculations in flight planning. DA affects true airspeed, the amount of fuel the aircraft can carry, aircraft range, and endurance. Tools to help pilots plan and adjust for DA and its effects will be presented, with emphasis on the integrated approach within aircraft performance charts found in the pilot's operating handbook (POH) for a particular aircraft.

Finally, students will demonstrate their knowledge by answering seven questions relating to DA taken from the FAA Private Pilot Knowledge Test and by completing a summative assessment that will test them on all the material in this lesson.

BACKGROUND

In previous lessons, students learned that aircraft depend on air in two important ways: 1) air feeds the engine, where it mixes with fuel and burns to produce power, and 2) air flowing over the wings and other aircraft structures creates forces such as lift and drag.

As the thickness of the air (air density) changes, so does the performance of the aircraft. High air densities improve aircraft performance, while lower air densities degrade performance. The term density altitude (DA) refers to the conditions for flight compared to standard conditions (15°C, 29.92” Hg). Low air density creates higher density altitude; fewer molecules of atmosphere per unit of volume (low air density) make the aircraft perform as if it is at a higher altitude than it really is. The term “high density altitude” can be thought of as “high altitude.”

High air density creates lower density altitude; more molecules of atmosphere per unit of volume (high air density) make the aircraft perform as if it is at a lower altitude than it really is. The term “low density altitude” can be thought of as “low altitude.”

Higher density altitudes degrade aircraft performance, while lower DAs enable the aircraft to perform better. Performance factors affected by DA include takeoff weight, takeoff and landing distances, rate of climb, true airspeed, engine output. Factors that influence DA are temperature, altitude, and humidity. Changing one or more of these values changes DA and affects aircraft performance.

To make good decisions, pilots must be able to predict aircraft performance based on density altitude, then apply those predictions to the all-important go/no-go decision. Fortunately, pilots have several tools available that enable them to determine density altitude based on temperature and elevation. Using these tools and applying the data they provide are basic to good flight planning and risk management.

MISCONCEPTIONS

Because density altitude is often discussed as part of determining takeoff distances or climb rates, students may assume that it is only a factor when the aircraft is on the ground or close to the ground. In fact, density altitude can be a factor regardless of where the aircraft is operating. Since DA affects true airspeed (TAS), its effects can often be felt even while cruising at high altitudes.

Another misconception may be that density altitude is always the same at a given location. While it’s true that DA is usually much higher at high-elevation airports, the actual DA at that airport can change dramatically based on the outside air temperature (OAT) at that field. For example, the DA on a standard day at Truckee Tahoe Airport in California (KTRK) is 5,904 feet MSL. During the winter months, the DA can drop to below 4,000 feet, but during the summer, the DA at that same airport can reach 9,000 feet or higher. As a result, aircraft performance can vary widely, from outstanding to poor.

DIFFERENTIATION

To promote student comprehension during the EXPLAIN and EVALUATE sections of the lesson plan, have a volunteer or volunteers write down answers to the discussion questions on the board that occur at the end of the formative and summative assessments. Likewise, you might want to encourage students to take notes individually to help them retain what they’ve learned and synthesize the concepts presented in the lesson.

LEARNING PLAN

ENGAGE

Teacher Material: [Density Altitude Presentation]

Session 1

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

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

Warm-Up

Ask students the following questions to see what they remember from previous lessons (particular Grade 10, lessons 3.A.2 and 3.B.1).

What factors affect the density of the air?

Responses may include altitude, temperature, pressure, and humidity.

What impact does the density of the air have on aircraft performance?

Responses may include that dense air improves engine performance and lift. Less dense air can result in reduced lift and less efficient engine performance. As a result, air density can affect critical factors such as the length of the takeoff roll, the rate of climb, and the speed of the aircraft.

Can you recall the formula for calculating density altitude?

The formula is DA = PA + [120 x (OAT - ISA)], where:

DA = Density altitude
PA = Pressure altitude
OAT = Outside air temperature in degrees Celsius
ISA = Standard temperature in degrees Celsius

It is not essential that students recall this equation for the purposes of this lesson because the calculations they will be making focus on using performance charts. The goal is simply to remind students of the factors that go into calculating density altitude. It may be worth asking students what factor affecting the density of the air is not accounted for in this equation. The answer is moisture or water vapor. While the presence of moisture (humidity) does affect air density, it is less important than temperature in determining aircraft performance and it is not part of the density altitude calculation.

[DOK-L1; *recall*]

EXPLORE

Teacher Materials: Density Altitude Presentation, Density Altitude Teacher Notes 1
Student Material: Density Altitude Student Activity 1

Slides 5-7: It is not necessary to use the formula found in the Warm-Up to determine density altitude. Instead, a convenient chart has been developed. Work through the sample problems on Slides 6 and 7, which explain to students how to read the chart.

Here are the steps for reading the density altitude chart, given airport elevation, altimeter setting, and outside air temperature (OAT). Slide 6 illustrates the first three steps; slide 7 illustrates the last three steps.

1. Locate the altimeter setting in the chart column labeled “Altimeter.”
2. Read the corresponding number to the right, in the chart column labeled “Pressure Altitude Conversion Factor.” Note that factor.
3. Subtract (or add if the number is positive) that conversion factor from the airport altitude. The result will be pressure altitude.
4. Use the scale at the bottom of the graph to locate the outside air temperature (OAT).
5. Draw a vertical line up from the OAT to the band for the pressure altitude identified in Step 3.
6. Draw a horizontal line to the left from the pressure altitude identified in Step 3, and note where that line intersects with the left axis of the chart. This will be the density altitude for the given set of conditions.

Slide 8: Distribute **Density Altitude Student Activity 1**. Working individually, students will use the provided density altitude chart to determine density altitude for three different airports. Students will then answer two additional questions related to density altitude. Answers and explanations are available in **Density Altitude Teacher Notes 1**.

EXPLAIN

Teacher Materials: Density Altitude Presentation, Density Altitude Teacher Notes 2
Student Materials: Density Altitude Student Activity 2, **E6B Computer**

Slide 9: The basic definition of density altitude is "pressure altitude corrected for non-standard temperature." When outside air temperature (OAT) is standard, density altitude will equal pressure altitude. When OAT is warmer than standard, density altitude will be higher than pressure altitude, and when the temperature is cooler than standard, density altitude will be lower than pressure altitude.

Several factors go into determining density altitude. The most influential factors are OAT and airport elevation (or altitude if flying). Other less-important factors are atmospheric pressure and humidity. Determining density altitude before taking off is an important part of a pilot's preflight planning. Pilots are taught early in their training that the expression "high, hot, and humid" can serve as a reminder that extra caution should be exercised when operating from airports under those conditions, especially airports located at high altitudes.

Slide 10: Operations from high density altitude airports require planning for decreased aircraft performance. Since the air is thinner (less dense) during high density altitude conditions, the engine will produce less power. This reduction in power results in less thrust to propel the aircraft forward. With less thrust comes less lift, and aircraft performance can be dramatically reduced.

High density altitude can affect most parameters of flight, including:

- takeoff and landing distances
- load-carrying ability
- rate of climb
- true airspeed
- aircraft range
- maneuverability
- fuel burn/economy of flight

The graphic on this slide illustrates that an airplane requires more room to take off, and climbs less rapidly, when density altitude is greater. This is because the air in high density altitude conditions is thinner, with fewer molecules flowing over the wings and control surfaces, thereby creating less lift. Since the engine is also producing less power due to the thinner air, the acceleration during takeoff will be slower at high density altitudes, therefore requiring more runway to reach takeoff speed.

Slide 11: In addition to using the mathematical formula or chart to determine density altitude, pilots can also use the E6B computer to find density altitude and true airspeed quickly and efficiently. You may hand out E6Bs to the students and allow them time to refamiliarize themselves with them.

Instruct students to watch the following video on how to find density altitude using the E6B. Encourage students to follow along by operating their E6Bs as the narrator demonstrates the steps.

- "Calculating Density Altitude with E6B" (Length 2:01)
  https://video.link/w/7RA1

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/embed/2wpT1sQTHrI?start=323&end=444

Slide 12: Finding density altitude on the E6B is done using two small windows on the flight computer side. Have students find the windows marked "Pressure Altitude" and "Air Temperature." The Pressure Altitude window is located directly beneath the Air Temperature window.

Remind students that density altitude is pressure altitude corrected for nonstandard temperature, so they must first calculate pressure altitude. Have them use the density altitude chart (as seen on Slide 8) to determine pressure altitude for the relevant airport elevation. Once the pressure altitude has been determined, they should follow the steps below.

1. Turn the wheel on the E6B to position pressure altitude beneath outside air temperature on the designated scales.
2. Read density altitude on the density altitude scale.

Teaching Tips

The scales on the E6B are very small, making it difficult to differentiate values. Students may find it hard to see the fine lines and arrange those lines properly to arrive at a satisfactory answer. Teachers should expect to walk around the room with their E6B, demonstrating proper setup as needed.

The E6B is also the least accurate of the three methods of determining density altitude, due to the narrow scaling of the values in the windows. Teachers should expect a variety of answers, depending on student ability to discern differences in the fine lines. An error tolerance of +/- 500 feet is acceptable.

Remind students that the temperature scale has a positive and negative side. A common error is to align the altitude with a temperature that has the opposite sign.

Slide 13: While students have their E6Bs set to calculate density altitude, show them that they can easily find true airspeed without doing any additional set-up. They can simply read Indicated Airspeed on the lower of the two numerical scales (rotating wheel). True airspeed will be read directly above the Indicated airspeed value on the upper ring scale.

Slide 14: Complete the **Formative Assessment**.

Formative Assessment

Divide students into groups of three or four and provide students in each group with **Density Altitude Student Activity 2**. Using their E6B computers and the provided density altitude chart, each group will calculate density altitude for three scenarios involving field elevation, temperature, and altimeter setting. They will then answer questions and participate in a class discussion. This activity will assess students' ability to use the E6B. Answers and explanations are available in **Density Altitude Teacher Notes 2**.

[DOK-L2; *calculate*]

EXTEND

Teacher Material: Density Altitude Presentation

Session 2

Slide 15: Recall that density altitude is defined as "pressure altitude corrected for nonstandard temperature."
High density altitude means lower air density: the number of air molecules per unit of volume is low. Low density altitude means higher air density: the number of air molecules of air per unit of volume is high.
The most significant factor in density altitude is temperature; higher temperature means higher density altitude.

Factors in calculating density altitude are field elevation, temperature, altimeter setting and (to a lesser degree) humidity.
High density altitude conditions reduce aircraft performance, require longer takeoff distances, and result in slower climb rates. High density altitude = "high, hot, and humid."

Density altitude can be determined in three ways:

1. applying a formula
2. using a density altitude chart
3. using an E6B computer

Slide 16: Density altitude is an important consideration in flight planning. Failure to adequately plan for the effects of density altitude can create hazards to flight, such as failure to take off or climb fast enough to avoid obstacles or terrain. Instruct students to watch the video for a look at what can happen if a pilot fails to take density altitude into consideration before taking off.

- Video: "Airplane Crash In-Cockpit Footage" (Length 3:50)
  https://video.link/w/7W80

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/watch?v=OVM3RRd1vf0

To plan a flight effectively, it's important to take into account as many factors as possible to ensure that there is always an adequate margin of safety.

Density altitude affects many characteristics of aircraft performance. Pilots are trained from their very first days of instruction to include density altitude in their flight planning to ensure that their aircraft is capable of performing safely.

On high-density altitude days, pilots may have to choose airports with longer runways to accommodate the added takeoff distance required. It may be necessary to carry less fuel or baggage, or even leave a passenger behind to be picked up later. Since climb rates will be reduced, it may take longer to reach the desired altitude, adding to fuel burn and total time for the trip; and because airspeed and fuel consumption are also affected, you may need to plan for an additional fuel stop along the way.

Slides 17-20: For takeoff and landing distances, most performance charts found in the POH will not require students to calculate density altitude. Instead, the charts automatically adjust for density altitude by showing pressure altitude and temperature. The same is true for rate of climb charts; time, fuel, and distance to climb charts; and cruise performance charts. Students should understand that, even if they are not directly calculating density altitude, the charts in the POH are taking density altitude into account "behind the scenes" when they adjust pressure altitude for temperature.

- **Slide 18** shows an example of a takeoff distance chart that does not mention density altitude. Instead, pilots are asked to find pressure altitude and temperature in the left side of the chart, then apply those values to other important considerations for takeoff such as aircraft weight, wind, and obstacles. Total takeoff distance is provided at the right margin of the chart. Density altitude is derived within the chart, not by the pilot applying a formula or referring to a specific density altitude chart. This integrated approach to determining takeoff distance greatly streamlines flight planning, providing pilots with everything they need to know about takeoff in one chart, simplifying the go/no-go decision.

- **Slide 19** shows another way of determining takeoff distance: through a table, also found in the POH. Again, density altitude is not a specific calculation but is integrated into the table through reference to pressure altitude along the left side and temperature along the top of the chart. In essence, the chart does the calculation for the pilot.

- As shown on **Slide 20**, takeoff distance charts aren't the only tables in the POH that integrate density altitude into their displays. Tables that show time, fuel, and distance to climb also show pressure altitude and temperature as a means of calculating their data. Knowing the pressure altitude and outside air temperature, pilots can quickly determine the efficiency of their climb to altitude, and apply that in their flight planning.

Inform students that factors affecting takeoff, landing, and cruise performance—and their relationship to density altitude—are coming in subsequent lessons.

EVALUATE

Teacher Materials: Density Altitude Presentation, Density Altitude Teacher Notes 3
Student Materials: Density Altitude Student Activity 3, E6B Computer

Slides 21-34: Sample FAA Test Questions and Answers

Slide 35: Conduct the **Summative Assessment**.

Summative Assessment

Provide students with **Density Altitude Student Activity 3**, which contains three scenarios. Instruct students to calculate density altitude and takeoff distance for each scenario, using a density altitude chart, a takeoff distance table, and an E6B computer. Students will then answer questions about each scenario and state whether the flight in each scenario can be conducted safely and why/why not. If time allows, include a classroom discussion of the provided **Going Further** questions.

[DOK-L2; *predict, calculate*; DOK-L3; *assess*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Postings show evidence of one or more of the following:
  - Understands the basic concept of density altitude
  - Can use tools available to calculate density altitude given a realistic scenario of flight conditions
  - Is able to apply density altitude solutions to go/no-go decision making
- Contributions show understanding of the concepts covered in the lesson and ability to complete required calculations
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 Demonstrates a thorough understanding of how to calculate and evaluate density altitude and use it to assess safety conditions
7-8 Demonstrates a sufficient understanding of how to calculate and evaluate density altitude and use it to assess safety conditions

5-6 Demonstrates an insufficient understanding of how to calculate and evaluate density altitude and use it to assess safety condition; gaps in content knowledge is evident
0-4 Demonstrates little or no understanding of how to calculate and evaluate density altitude and use it to assess safety condition; student work is missing or incomplete

GOING FURTHER

Slide 36: Select from the questions below for classroom discussion, as time permits.

Questions

1) Do you think airline pilots use density altitude charts or an E6B to calculate density altitude before each flight?

No, pilots of larger aircraft have onboard computers, called flight management systems, that calculate critical flight performance numbers (like takeoff distance) based on temperature, humidity, aircraft weight, runway condition, and other factors.

2) What other technology do you think pilots could use to get density altitude and aircraft performance information?

There are numerous apps available to pilots containing critical performance data specific to aircraft type, which enable pilots to perform calculations based on a few inputs.

3) What additional equipment is available on aircraft that enables better performance in high density altitude conditions?

Many aircraft that operate in high density altitude conditions have engines equipped with devices called turbochargers. These devices are essentially air compressors that push air into the engine under higher pressure than is available through ambient atmospheric pressure. Turbochargers (and sister devices called superchargers) increase the effective density altitude for an engine enabling the aircraft to perform from high altitude airports as though they were at or near sea level. These devices also enable them to maintain high climb rates and climb to higher altitudes than is possible with non-turbocharged aircraft.

4) What effect do you think density altitude has on aircraft powered by electric motors?

Electric motors will eliminate the power discrepancies between low-altitude and high-altitude operations, since electric motors do not use air (oxygen) in a combustion process. Electric motors will be able to generate the same power at 20,000 feet (or even higher) as at sea level. This does not mean that density altitude will have no impact on aircraft performance. The air is still less dense at higher altitude, so there will be less air flowing over the propeller, wings and stabilizers. Less lift is generated at any given airspeed. Performance will still be affected, just not as dramatically as with an air-breathing engine.

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

REFERENCES

FAA Pilot's Handbook of Aeronautical Knowledge
FAA Airplane Flying Handbook
https://www.faasafety.gov/files/gslac/library/documents/2011/Aug/56396/FAA%20P-8740-02%20DensityAltitude%5Bhi-res%5D%20branded.pdf
Cessna 172N Takeoff Distance Chart