Density Altitude

Session Time: Three, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The principles of aerodynamics allow an aircraft to fly, yet those same principles limit its ultimate performance and capabilities. (EU2)

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

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

ESSENTIAL QUESTIONS

1. How is density altitude related to aircraft performance?
2. Why would a pilot want to calculate density altitude?
3. Does a pilot need to understand density altitude?

LEARNING GOALS

Students Will Know

- How to determine density altitude
- Why aircraft performance decreases with an increase in density altitude
- How density altitude can affect the safety of flight
- Under what conditions density altitude is most relevant

Students Will Be Able To

- *Calculate* density altitude using multiple methods. (DOK-L2)
- *Explain* the effect density altitude has on aircraft performance and safe operations. (DOK-L2)
- *Explain* the conditions that most affect density altitude. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Use a 3-2-1 teaching strategy to help students review what they already know about air density and begin thinking about how changes in air density may affect aircraft performance.

Formative Assessment
Students will practice calculating density altitude for three different scenarios, based on data provided for elevation, temperature, and pressure.

Summative Assessment
Students will analyze how variations in elevation and temperature affect the performance of a Cessna 172. Students will then write a short paragraph explaining how pilots must consider performance calculations to fly safely.

LESSON PREPARATION

MATERIALS/RESOURCES

- Density Altitude Presentation
- Density Altitude Student Activity 1
- Density Altitude Student Activity 2
- Density Altitude Student Activity 3
- Density Altitude Student Activity 4
- Density Altitude Student Notes
- Density Altitude Teacher Notes 1
- Density Altitude Teacher Notes 2
- Density Altitude Teacher Notes 3

Flight Simulation Activity

- Flight simulation equipment

Recommended Student Reading

Pilot's Handbook of Aeronautical Knowledge
Chapter Eleven, Section on Pressure and Density Altitude
https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/13_phak_ch11.pdf

LESSON SUMMARY

Lesson 1: Density Altitude

In this three-session lesson, students will be introduced to the concept of density altitude, which can be described as pressure altitude corrected for non-standard temperature. When the density altitude is high, the air is less dense than it would be at standard pressure altitude, so the aircraft behaves as if it is flying at a higher altitude than it actually is. This is important because high density altitudes negatively impact aircraft performance, reducing the wing's ability to produce lift and the engine's ability to produce thrust.

The lesson will begin with a review of what the students learned about air density in the previous lesson and begin thinking about how changes in air density may affect aircraft performance.

Students will then be introduced to the conditions that affect density altitude. They will use simple equations to calculate standard air temperature, pressure altitude, and density altitude. Density altitude charts will be discussed as a method to determine density altitude. Following the equations, students will apply these concepts to data describing aircraft takeoff and landing performance.

A flight simulation activity will give students first-hand experience of high density altitude on aircraft performance. Finally, they will analyze how variations in elevation and temperature affect the performance of a Cessna 172. Students will then write a short paragraph explaining how pilots must consider performance calculations to fly safely.

BACKGROUND

Students should recall from the previous lesson that air density directly affects aircraft performance. The density of the air is determined primarily by pressure and temperature. Air density decreases as altitude increases, so it's not surprising that the air is less dense at airports situated at higher elevations. However, other factors—such as temperature and air pressure—can also affect air density, causing it to increase or decrease even as altitude remains constant. Airports in areas with higher temperatures and at higher elevations have higher density altitudes. Weather conditions, such as low pressure systems, can also contribute to higher density altitudes. This means the air is less dense, and so there is less air for the engine to use to create power, to lift the wings, and to push through the propellers to generate thrust. This leads to longer takeoff and landing distances and a general decrease in aircraft performance.

MISCONCEPTIONS

Some students may believe that humidity is a factor included in the density altitude calculation. While humidity does affect density altitude somewhat, the effect of humidity is not part of the calculation for determining density altitude.

Another common misconception is that only the wing or the powerplant of an aircraft is affected by density altitude. In fact, density altitude affects the efficiency of both.

DIFFERENTIATION

To support student organization of background knowledge and desired learnings in the **ENGAGE** section, provide a graphic organizer such as a Know/Want-to-Know/Learned (KWL) for students to complete. You can adapt this graphic organizer to better fit the 3-2-1 activity in the Warm-Up; students should list the three things they know in the "K" column of the graphic organizer, and the two things they don't understand plus the one thing they want to learn in the "W" column.

To support a deep understanding of the density altitude calculations presented in the **EXPLORE** section, provide students with additional scenarios for which to calculate density altitude. Specifically, adapt slide 15 by providing students with data for elevation, pressure, and temperature at several additional airports. Then, have students form small groups and participate in reciprocal teaching by using the process they have learned for calculating density altitude. For a greater challenge, have students make up their own problems to solve.

LEARNING PLAN

ENGAGE

Teacher Material: Density Altitude Presentation

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

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

Warm-Up

Use a 3-2-1 teaching strategy to help students review what they already know about air density and begin thinking about how changes in air density may affect aircraft performance. In this strategy, students first list three things that they already know about air density. This will be a review of previous lessons. Then, they should list two things they don't understand about the topic. This will provide an opportunity to revisit previous content to make sure that students are prepared for the content of this lesson. Finally, students should identify one thing they want to learn about air density impacts aircraft performance.

[DOK-L2; *summarize, predict*]

EXPLORE

Teacher Material: [Density Altitude Presentation]

Slide 5: The formal definition of density altitude is “the altitude relative to standard atmospheric conditions at which air density would be equal to the indicated air density at the place of observation.” It may also be defined as the pressure altitude adjusted for a non-standard temperature. In practical terms, density altitude is a way of describing the density of the air as a height above mean sea level. When the density altitude is higher than standard for a given location, the density of the air itself is lower than standard for that location. A complete understanding of density altitude is necessary for a pilot to fly an aircraft safely.

Slide 6: Ask students what factors can affect air density. Answers should include pressure and temperature. Then ask, “Why does the density of the air matter to pilots?” Explain that as the density of the air decreases, aircraft performance also decreases. In this lesson, students will learn the reasons why.

Slide 7: Air density decreases as altitude increases, so it’s not surprising that the air is less dense at airports situated at higher elevations. However, other factors—such as temperature and air pressure—can also affect air density, causing it to increase or decrease even as altitude remains constant. Airports in areas with higher temperatures and at higher elevations have higher density altitudes. Weather conditions, such as low pressure systems, can also contribute to higher density altitudes. This means the air is less dense, and so there is less air for the engine to use to create power, to lift the wings, and to push through the propellers to generate thrust. This leads to longer takeoff and landing distances and a general decrease in aircraft performance. Keep in mind that the same airport will experience different density altitudes on different days, as air temperature and pressure change.

Slide 8: Show students the videos “Density Altitude - Flight Training” and “How Can It Be Too Hot to Fly?” for a more in-depth look at the concept of density altitude and its effects on flight.

- “Density Altitude - Flight Training” (Length 2:46)
  http://video.link/w/azUd
- “How Can It Be Too Hot to Fly?” (Length 3:02)
  http://video.link/w/LzUd

Questions

After students have watched the videos, ask them to describe scenarios when conditions at the airport would create the greatest risks to aircraft performance.

What conditions make for poor aircraft performance and potentially unsafe situations for pilots?

Possible Answers include:

A hot day, especially at a high elevation airport, increases density altitude which reduces airplane performance and creates potentially unsafe flight conditions.

Slide 9: Have students imagine a hot day at a high-altitude airport, and then predict how these conditions would likely impact an aircraft’s performance as it takes off. (The airplane would likely have a slower acceleration down the runway, a longer takeoff roll, and a slower climb.) Then, instruct students to predict what would likely happen if an airplane tried to take off with a density altitude that was too high for the aircraft's performance. After students have made their predictions, watch the video showing this very situation: the airplane attempts to take off at an airport at a high elevation on a warm day, is unable to climb, and subsequently crashes.

- "Airplane Crash In-Cockpit Footage: Stinson 108-3" (Length 3:50)
  http://video.link/w/B0Xd

EXPLAIN

Teacher Materials: Density Altitude Presentation, Density Altitude Teacher Notes 1, Density Altitude Teacher Notes 2
Student Materials: Density Altitude Student Activity 1, Density Altitude Student Activity 2

Slide 10: In the next part of the lesson, students will learn how to calculate density altitude. First, briefly review the key points about air density:

- Air density and density altitude are inversely related.
- At higher air density, there are more air molecules per cubic unit to pass over the aircraft's wings, increasing the amount of lift.
- High air density also provides more air molecules to push through the engines, increasing thrust.
- Both of these factors serve to increase aircraft performance in regions of higher air density.

Slide 11: A "standard day" serves as a baseline for measuring atmospheric pressure. On a standard day, air pressure is 29.92 inches of mercury at sea level and a temperature of 15 degrees C (59 degrees F). These conditions define the International Standard Atmosphere (ISA). Deviations from these standard conditions affect the density of air, impacting aircraft performance.

Slide 12: The standard lapse rate is the rate at which temperature and pressure change as altitude increases under "standard" conditions. The standard lapse rate is necessary for density and pressure altitude calculations. The lapse rate for temperature is a decrease of 2 degrees Celsius (2 °C) for every 1,000-foot increase in altitude. The lapse rate for pressure is a decrease of 1 inch of mercury (1 "Hg) for every 1,000-foot increase in altitude. Students should keep in mind that the lapse rate does not account for other factors, like weather systems, that can affect temperature and pressure at a given altitude.

Slide 13: Pressure altitude corrects for the difference between barometric pressure (the actual pressure exerted by the air above as read from a barometer at that location) and standard pressure (29.92 "Hg). (Note that for our purposes the terms barometric pressure and atmospheric pressure are interchangeable.) Pressure altitude tells you whether pressure is higher or lower than the standard—and therefore whether you can expect your aircraft to perform better or worse than it would perform under standard conditions. When barometric pressure is affected by factors such as storm fronts and other weather phenomena, the pressure altitude can vary from the standard. Keep in mind, however, that pressure altitude doesn't tell the whole story. It corrects only for differences in pressure. It does not account for variations in temperature, which can also impact aircraft performance.

Slide 14: At the beginning of the second session, students will learn how to calculate for density altitude. The calculations for determining density altitude require only simple math, but involve several steps. The equation for density altitude is: **DA = PA + [120 (OAT ISA)]**

DA - Density Altitude

PA - Pressure Altitude
OAT - Outside Air Temperature

ISA - ISA at Measured Pressure Altitude

This equation will be broken down with examples in the next few slides.

Slide 15: The first step is to find the pressure altitude. The equation for pressure altitude is:

PA = (29.92 – Barometric Pressure)1,000 + Elevation

In this case, we'll say you're at an airport where the barometric pressure reading is 30.13 "Hg and the elevation is 1,800 feet above sea level. Plug these values into the equation to determine the current pressure altitude at this location. In this example, the current pressure altitude at the airport is 1,590 feet.

Slide 16: The second step is to find the ISA for this pressure altitude. Use the standard lapse rate of 2 degrees C per 1,000 feet of altitude. In this example, the calculated pressure altitude is 1,590 feet. You can calculate the temperature difference at the standard lapse rate as follows: 2 / 1,000 x 1,590 = 3.18°C. For our purposes, you can simplify the calculation by rounding this to 3°C. Since standard temperature at sea level is 15°C, you can find the standard temperature at the calculated pressure altitude as follows: 15 - 3 = 12°C. In other words:

ISA = 15 - (2 / 1,000 x PA)

You can now plug these values into the density altitude calculation:

DA = PA + [120 (OAT ISA)]

DA = 1,590 + [120 (OAT - 12)]

Slide 17: The third step is to plug in the outside air temperature and complete the density altitude calculation. In this example, we'll say the OAT is 18°C.

DA = 1,590 + [120 (18 - 12)] = 2,310 feet

Even though the elevation of this airport is 1,800 feet above sea level, the aircraft will perform as if it is at an elevation of 2,310 feet above sea level.

Slides 18-21: Provide students with **Density Altitude Student Activity 1** and instruct them to fill in the provided example. Then walk through the steps with them using the slides and the answers provided in **Density Altitude Teacher Notes 1** includes the correct answers.

Slides 22-23: Explain to students that another way to determine density altitude is by using a chart similar to the one shown on the slide. Charts like this may be found in an aircraft's *Pilot's Operating Handbook* (POH). (This particular chart is from the FAA's *Pilot's Handbook of Aeronautical Knowledge*.)

Provide students with **Density Altitude Student Activity 2** and have them use the chart on the last page of the activity sheet to follow along with the sample below. This particular sample is drawn for them on the provided chart.

Airport elevation - 5,883 ft

OAT - 21 °C

Altimeter reading - 30.10 "Hg (the altimeter reading equates to the barometric pressure.)

1. To determine the density altitude for this airport, first locate 30.10 "Hg in the column of the chart labeled "altimeter." Read across to the corresponding number in the column to the right, labeled "Pressure altitude conversion factor." In this example, that number is –165.

2. Then, subtract 165 (because the conversion factor is negative) from the airport's altitude, resulting in a pressure altitude of 5,718 feet.

3. Next, use the scale at the bottom of the graph to locate the OAT: in this case, 21°C. Draw a vertical line up from the OAT (along the bottom axis), stopping about two-thirds of the way into the pressure altitude band of 5,000–6,000 (because the airport's pressure altitude in this example is 5,718).

4.
Then, draw a horizontal line left from the pressure altitude and note where the line intersects with the left axis of the chart. This is the approximate density altitude (in thousands of feet). In this example, the density altitude is approximately 7,700 ft.

Slide 24: Conduct the **Formative Assessment.**

Formative Assessment

Provide students with **Density Altitude Student Activity 2.** In this activity, students are provided with data on elevation, outside air temperature, and outside atmospheric pressure for three different scenarios. Students will use these values to calculate density altitude for each scenario. They will also explain why density altitude may vary depending on whether it is calculated using equations or using a chart.

You may find answers to these questions in **Density Altitude Teacher Notes 2.**

[DOK-L1; *calculate*, DOK-L2; *interpret, explain*]

EXTEND

Teacher Material: Density Altitude Presentation
Student Materials: Density Altitude Student Activity 4, Density Altitude Student Notes

Slide 25: Conduct the flight simulation activity. This will conclude the second session.

Simulator Extension Powered by Redbird

Provide students with **Density Altitude Student Activity 4**. For this activity, students will work in pairs on the simulator to experience firsthand the effects of density altitude on aircraft takeoff and climb performance in different scenarios. Before they begin, ensure students understand what instruments they should monitor; point out the airspeed indicator and vertical speed indicator (VSI).

Slide 26: Students will begin the third session by using aircraft performance charts to determine aircraft performance. As students have learned, density altitude affects aircraft performance. Understanding and accounting for density altitude is important for flight safety. Charts contained in the *Pilot's Operating Handbook* for an aircraft show how temperature and elevation affect its performance.

From a practical standpoint, pilots should be aware that the values in the charts are obtained by a test pilot in a new aircraft, so it's a good idea to use them conservatively to ensure an adequate safety margin.

Questions

Ask students: Where does density altitude appear on this chart?

Possible Answer:

It's built into the chart. The temperature and pressure columns combine to account for density altitude.

Slide 27: Students will now see an example of how density altitude affects takeoff performance to understand how to calculate takeoff and landing performance figures for a Cessna 172 (a four-seat, single-engine, high wing airplane). Provide students **Density Altitude Student Notes** which contains a chart with takeoff and landing conditions.

Point out that the intersection of pressure altitude and temperature in the ground roll column shows them the distance needed for the aircraft to lift off.

Questions

Help students answer the following questions by referencing the chart provided in **Density Altitude Student Notes:**

How long is the ground roll for the aircraft if the pressure altitude is 3,000 ft and the temperature is 10°C?
Starting in the left column, find 3,000. Using your finger, trace a line to the intersection with the 30° C column. Be sure to look at the number under ground roll rather than total to clear a 50 ft obstacle. The answer is 1,215 ft.

What about if the pressure altitude is 3,000 ft and the temperature is 30°C?
Use the same procedure, looking at the 30°C ground roll column. The answer is 1,410 ft.

What does this tell you about the impact of temperature on aircraft performance?
Performance declines as temperature goes up. In this case it takes an additional 195 feet of runway for the aircraft to lift off. That's a 16% increase.

Slide 28: Use the same chart and procedure to see what happens if temperature is constant but change the pressure altitude.

Questions

How long is the ground roll for the aircraft if the pressure altitude is 2,000 ft and the temperature is 10°C?
The answer is 1,110 ft.

What about if the pressure altitude is 7,000 ft and the temperature is 10°C?
The answer is 1,785 ft.

What does this tell you about the impact of altitude/elevation on aircraft performance?
Performance declines as altitude increases. In this case, the aircraft needs an additional 675 ft of runway to lift off. That's a 60% increase.

Slide 29: Ask students what happens when the value they need isn't on the chart. The answer is that pilots use interpolation to find the answer. Interpolation is process of calculating or estimating an intermediate value from a set of known data points.

Slide 30: Use the chart provided in **Density Altitude Student Notes** to lead students through an example of interpolation using the following conditions:

Pressure altitude - 3,500 ft
Temperature - 15°C.

There are several ways to interpolate the data. The simplest is to bracket the information you're seeking and divide. In this case we're looking for an altitude that's halfway between 3,000 ft and 4,000 ft and a temperature that's halfway between 10°C and 20°C. Therefore, answer will be a number that is halfway between the available values for altitude and temperature.

3,000 ft and 10°C = 1,215
3,000 ft and 20°C = 1,310

Now find the difference between these numbers, divide by two, and add to the smaller number:

(1,310 - 1,215) / 2 + 1,215 = 1,262.5

Repeat for the next set of values:

4,000 ft and 10°C = 1,335

4,000 ft and 20°C = 1,440

(1,440 - 1,335) / 2 + 1,335 = 1387. 5

The takeoff roll will be halfway between 1,262.5 ft. and 1387.5 ft.

Answer: 1,325 ft.

Advise students that this is only an introduction to interpolation and they do not have to master it at this time. They will learn about interpolation in greater detail in preparation for the FAA Knowledge Exam during the 11th grade course.

Teaching Tips

For more of a challenge ask students how this calculation would be different if you were trying to find the takeoff roll for an altitude of 3,700 ft. and a temperature of 20°C?

You'd be looking for a value that is approximately two-thirds of the way between 3,000 ft and 20° C and 4,000 ft and 20°C. In this case:

3,000 ft. and 20°C = 1,310 ft

4,000 ft and 20°C = 1,440 ft

(1,440 - 1,310) / 3 x 2 +1,310 = 1,397.6 ft

EVALUATE

Teacher Materials: Density Altitude Presentation, Density Altitude Teacher Notes 3
Student Material: Density Altitude Student Activity 3

Slide 31: Conduct the **Summative Assessment.**

Summative Assessment

Provide students with **Density Altitude Student Activity 3**. In this activity, students will be given different elevations and temperatures; they will analyze how these differences affect the performance of a Cessna 172, using the performance charts from the Pilot's Operating Handbook (POH). Students will then write a short paragraph explaining why pilots must consider performance calculations to fly safely.

Answers are provided in **Density Altitude Teacher Notes 3.**

[DOK-L3; *analyze*, DOK-L2; *explain*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Student work shows evidence of:
  - How atmospheric pressure changes as altitude changes
  - The effects of pressure and temperature on air density
  - Knowledge of how to use charts to determine the takeoff and landing ground rolls and associated distances over a 50-ft obstacle for a Cessna 172
- 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 The student accurately calculates takeoff and landing ground rolls and distances using the Pilot's Operating Handbook (POH). The student's paragraph makes a clear connection between aircraft performance and changes in temperature and altitude.

7-8 The student calculates takeoff and landing ground rolls and distances using the Pilot's Operating Handbook (POH) with minor errors. The student's paragraph makes a fair connection between aircraft performance and changes in temperature and altitude.

5-6 The student calculates takeoff and landing ground rolls and distances using the Pilot's Operating Handbook (POH) with many errors. The student's paragraph does not make an adequate connection between aircraft performance and changes in temperature and altitude.

0-4 The student is unable to calculate takeoff and landing ground rolls and distances using the Pilot's Operating Handbook (POH). The student's paragraph makes little or no connection between aircraft performance and changes in temperature and altitude.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS2-2** - Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
    - Science and Engineering Practices
        - Using Mathematics and Computational Thinking
    - Disciplinary Core Ideas
        - PS2.A: Forces and Motion
    - Crosscutting Concepts
        - Systems and System Models
- **HS-PS3-1**- Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
    - Science and Engineering Practices
        - Using Mathematics and Computational Thinking
    - Disciplinary Core Ideas
        - PS3.A Definitions of Energy
        - PS3.B Conservation of Energy and Energy Transfer
    - Crosscutting Concepts
        - Systems and System Models

COMMON CORE STATE STANDARDS

- **RST.11-12.7** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
- **WHST.11-12.2** Write informative/explanatory texts, including the narration of historical events, scientific procedures /experiments, or technical processes
- **WHST.9-12.9** Draw evidence from informational texts to support analysis, reflection, and research.
- **HSN.Q.A.1** Use units as a way to understand problems and to guide the solution of multi=step problems, choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and displays.
- **HSN.Q.A.2** Define appropriate quantities for the purpose of descriptive modeling
- **HSN.Q.A.3** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities
- **HSA.SSE.A.1** Interpret expressions that represent a quantity in terms of its context
- **MP.2** Reason abstractly and quantitatively
- **MP.4** Model with mathematics

REFERENCES

https://www.faasafety.gov/files/gslac/library/documents/2011/Aug/56396/FAA%20P-8740-02%20DensityAltitude%5Bhi-res%5D%20branded.pdf
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