# Takeoff and Landing Distances

**Session Time:** Two, 50-minute session(s)

## 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 the distance needed for takeoff and landing?

### LEARNING GOALS

**Students Will Know**

- What factors affect takeoff and landing distances.
- How to use performance charts and tables in a pilot's operating handbook (POH) or airplane flight manual (AFM) to estimate the takeoff and landing distance required under specific conditions.

**Students Will Be Able To**

- *Estimate* takeoff and landing distances using industry standard tables and graphs. [DOK-L2]
- *Explain* factors that affect required takeoff and landing distances for aircraft. [DOK-L2]

## ASSESSMENT EVIDENCE

**Warm-up**
As a class, students brainstorm as many factors as possible that could affect takeoff and landing distances.

**Formative Assessment**
Students calculate takeoff and landing distances using performance charts and tables. They also identify factors that affect takeoff and landing distance. If time permits, the class will also discuss questions about safety margins and the effects of different runway surfaces.

**Summative Assessment**
Students demonstrate what they have learned by solving problems regarding takeoff and landing distance calculations and safety considerations at specific airports.

## LESSON PREPARATION

## MATERIALS/RESOURCES

- Takeoff and Landing Distances Presentation
- Takeoff and Landing Distances Student Activity 1
- Takeoff and Landing Distances Student Activity 2
- Takeoff and Landing Distances Student Activity 3
- Takeoff and Landing Distances Teacher Notes 1
- Takeoff and Landing Distances Teacher Notes 2
- Takeoff and Landing Distances Teacher Notes 3
- Takeoff and Landing Distances Student Notes

## LESSON SUMMARY

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

Session 1 begins with a warm-up in which students brainstorm factors that might affect takeoff and landing distance. They also consider certain unusual factors, such as tire pressure, illusions, runway conditions, and mixture setting. Students then focus on how wind affects takeoff and landing distances, learning how to use a crosswind component chart to determine headwind, crosswind, and tailwind components of the wind relative to a given runway.

Students study performance charts in greater detail, considering how pressure altitude and temperature play a role in determining takeoff and landing distances. They learn that data on these charts is derived by professional pilots flying brand new airplanes. Students then solve a series of practice problems that require them to apply what they have learned to calculate wind components and takeoff distances. The session ends with a formative assessment, in which students apply their knowledge by solving additional problems and answering questions about safety margins and the effects of different runway surfaces.

In Session 2, students continue to solve problems in which they calculate takeoff and landing distances under a variety of conditions. They then answer a series of FAA Private Pilot Knowledge Test questions and complete the summative assessment, which requires them to apply what they have learned to determine whether takeoffs and landings can be conducted safely at particular airports under specific conditions.

If time permits, the Going Further section presents photographs of airports with particularly tricky runways. Students discuss what makes these runways challenging for takeoff and landing.

## BACKGROUND

During the early days of aviation, pilots noticed that their aircraft performance varied depending on a number of factors including temperature, elevation, weight, and runway surface. For example, on hot days or at high-elevation airports (such as those located in mountains), airplanes were slow to gain speed and required considerably longer runways during takeoff. Pilots also noticed that greater distances were necessary when taking off from wet or grassy airfields than from dry or paved surfaces. To quantify the performance changes, early engineers and aviators created tables and charts that would assist pilots in predicting aircraft performance. These charts incorporated factors such as aircraft weight, wind velocity, temperature, and pressure altitude. For takeoff and landing distance charts, factors such as flap position, obstacles, and runway surface were also taken into account.

Government regulation requires that aircraft manufacturers provide owners with an airplane flying manual (AFM) with standard sections, and the AFM comprises the bulk of the pilot's operating handbook (POH). This was the topic of Grade 10 Unit 10, Section A, Lesson 1: Airplane Flying Manual and Pilots Operating Handbook. This lesson focuses on what is commonly Section 5: Performance. Takeoff and landing distance charts and the wind component chart used in this lesson are typically found in Section 5.

Originally, an AFM could follow any format and contain any content the manufacturer thought was appropriate, but that is no longer true. Today, there is a standardized format for all general aviation flight manuals.

A Pilot's Operating Handbook (POH) typically includes FAA-approved AFM information. For most small aircraft built after 1975, the POH is also designated as the FAA-approved AFM. POHs contain the standardized information used in AFMs but may add additional sections as the manufacturer deems appropriate.

The performance figures in these charts are developed by the manufacturer using new aircraft in ideal weather conditions with highly proficient test pilots at the controls. Pilots should therefore approach aircraft performance with this in mind and allow for a margin of safety when planning a flight.

Since it is impossible to present data for every possible scenario, pilots use the chart data to interpolate appropriate figures for the flight at hand. Knowing that the performance figures represent ideal conditions, pilots typically increase the values in the tables by as much as 50%.

## MISCONCEPTIONS

Students may assume that wind is always a problem and makes controlling an aircraft more difficult during takeoffs and landings. While crosswinds and tailwinds can present challenges, a steady headwind is often welcomed by pilots—it can significantly shorten the distance required and make taking off and landing easier.

Another misconception is that aircraft must take off and land on runways. In reality, aircraft can safely take off and land from virtually any semi-smooth surface that is sufficiently long. In many parts of the world, including backcountry parts of Alaska and some other Western states, aircraft routinely take off from and land on roads, fields, dry lake beds, sand bars, and any other surface long enough and firm enough to enable a safe operation.

Conversely, some students may believe that any aircraft can take off or land from any runway. In fact, a runway's condition and length, as well as the materials from which it is constructed, must always be taken into consideration. An aircraft must be able to perform in such a manner as to accommodate a runway's particular conditions. If the runway is too short or rough, or surrounded by terrain or other obstacles too high for a given aircraft to climb above, that runway is not suitable for that aircraft. An aircraft also may not be able to depart from a given runway if the outside air temperature is too high. In such cases, the pilot may have to wait for cooler conditions to depart.

Many people believe that a large aircraft, such as an airliner, can take off or land regardless of the weight of its passengers and cargo. Again, this is not true. Airliners are subject to the same limitations as small aircraft. While their load-carrying capacity can be quite large, any aircraft can be loaded beyond its limits, rendering it incapable of taking off or maintaining safe flight.

### Teaching Tips

The following resources may be useful when reviewing information or presenting new content:

- This Air Safety Institute "Reality Check" video (Length 4:14) investigates the accuracy of takeoff and landing distance calculations: https://www.aopa.org/news-and-media/all-news/2019/august/pilot/performance-reality-check
- This article from *Flight Training* discusses the steps required to calculate takeoff and landing distances: https://www.aopa.org/news-and-media/all-news/2018/may/flight-training-magazine/technique-takeoff-calculation
- This article from *Flight Training* discusses factors that affect takeoff and landing distances for all types of aircraft, from training aircraft to multiengine aircraft to passenger jets: https://www.aopa.org/news-and-media/all-news/2003/march/flight-training-magazine/a-new-look-at-takeoff-performance

## DIFFERENTIATION

To aid student comprehension, perform demonstrations of several simple, straightforward examples and calculations in preparation of the formative and summative assessments. Circulate around the room to assist students as they work on practice activities. Examples should be given prior to introducing challenging topics, such as interpolation, runway slope, and headwind or tailwind components.

To help students recall the topic of Density Altitude, prepare a brief review of the Grade 10, Unit 3, Section B, Lesson 1 lesson: Density Altitude: https://drive.google.com/drive/folders/1w4iED_ERkMJBS_FA7g5OArLlOgE3tu0C.

Provide access to course materials for students who do not recall the subject matter or were not participants in the course.

## LEARNING PLAN

### ENGAGE

**Session 1**

**Teacher Material:** Takeoff and Landing Distances Presentation

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

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

**Warm-Up**

Ask students to brainstorm factors that might affect the takeoff and landing performance for an aircraft. List students' ideas on the board, and leave the list up to reference and develop throughout the lesson.

- *Students' ideas will vary but should include some of the following:*
- *Density altitude (higher density altitudes degrade aircraft performance, requiring greater distance for takeoff and landing)*
- *Aircraft weight (heavier aircraft require greater distance for takeoff and landing)*
- *Runway surface and condition (rough or wet surfaces can increase the distances required for takeoff and landing; grassy surfaces require greater distances than paved surfaces; icy or snow-covered surfaces can result in the aircraft sliding on or off the runway)*
- *Aircraft age (older engines may require greater distances for takeoff and landing)*
- *Tire pressure (low tire pressure means more rolling resistance, increasing the distance required for takeoff)*
- *Flap position (flaps down may decrease the distance required for takeoff and landing; landing with flaps up may increase landing distance)*
- *Type of propeller (constant speed props may shorten the distances required for takeoff and landing)*
- *Terrain and obstructions (elevated terrain and other obstructions may require a longer takeoff or landing distance)*
- *Wind direction and strength (headwinds can shorten the distances needed for takeoff and landing, while tailwinds can increase the distances needed)*
- *Fuel mixture (an improperly set mixture makes the engine run less efficiently, increasing the distances required for takeoff and landing)*
- *Turbulence (turbulent conditions can make it more difficult to land on a desired point, increasing the distance required)*
- *Pilot skill level (good piloting skill can significantly decrease the distances required for takeoff and landing)*

- *Illusions (a pilot may misjudge distance and height, affecting the actual distances required for safely taking off and landing)*
- *Aircraft speed (approaching a runway too quickly will increase landing distance; improper speed control on takeoff can affect takeoff distance)*
- *Slope of runway (upslopes increase required takeoff distance and decrease required landing distance; downslopes decrease required takeoff distance and increase required landing distance)*
- *Displaced threshold (pilots may ignore, misjudge, or be unaware of the available landing distance when a displaced threshold is in place)*

[DOK-L2; *explain*]

## EXPLORE

**Teacher Material:** Takeoff and Landing Distances Presentation

**Slides 5-6:** Some factors that affect takeoff and landing distances are less obvious than others. Density altitude is a known factor, so temperature and altimeter setting are factors that immediately come to mind. Wind strength and direction are easily related to takeoff and landing distances as well; a strong headwind generates more lift, causing an airplane to takeoff more quickly and require less runway. On landing, a strong headwind allows for a slower groundspeed and a shorter landing distance. Tailwinds are notoriously bad for takeoff and landing. Even a small tailwind can dramatically increase takeoff and landing distances.

Below are several less-obvious factors.

- Tire pressure can be an important influence on both takeoff and landing distance. An under-inflated tire, or tires, can create significant rolling resistance resulting in increased takeoff distance.
- Another reason is that tire pressure is related to hydroplaning. Hydroplaning happens when a thin layer of water develops between an aircraft's tires and the runway. Because this layer of water reduces friction between tire and runway, hydroplaning can dramatically reduce braking action, resulting in significantly greater landing distances. Furthermore, during takeoff hydroplaning can increase drag, lengthening the distance required for takeoff. The speed at which hydroplaning occurs for an aircraft equals 9 multiplied by the square root of the aircraft's tire pressure.
- Illusions can be caused by runway width. Pilots approaching a runway that is wider than normal can sometimes feel that they are closer to the ground than they actually are. This can result in the pilot flaring too high, extending the distance used for landing. Conversely, runways that are narrower than normal can produce the illusion of being farther above the runway than they are, causing the pilot to flare too late; in some cases, the pilot may even impact the runway before flaring.
- Runway slope can significantly affect takeoff and landing distances. Upslope runways tend to increase takeoff distance, since more time is necessary to accelerate to takeoff speed. On the other hand, upslopes tend to decrease landing distances; the upslope tends to slow the airplane after touchdown, thereby decreasing the total distance required to stop after landing.
- Another factor in determining takeoff and landing distance is runway condition. Runways that are wet or contaminated with oil or other fluids can produce a slippery surface and result in poor braking action. These conditions can dramatically increase landing distances, and should be taken into consideration when planning a flight in rain or snow or on a runway that may have been otherwise contaminated. The graphic on Slide 6 shows how the materials that make up a runway affect the friction between wheels and runway, thereby affecting takeoff performance.

**Slide 7:** Takeoff and landing distance charts often contain valuable information about factors that are likely to affect an aircraft's performance. This information is often found in the notes sections of the charts, rather than the data tables, which are based on runway surfaces that are dry, level, paved, and smooth. This slide shows a takeoff distance chart and a landing distance chart for a Cirrus SR22. Instruct students to study the charts and identify factors relevant to takeoff and landing distance.

**Questions**

How many factors can you find in these performance charts that might affect takeoff and landing distances for a Cirrus SR22?

*Some of the factors detailed in the notes at the top of these takeoff and landing distance tables are aircraft weight, flap setting, power setting, runway condition, wind, runway slope, and type of runway surface. For this particular aircraft, there is a note about how air conditioning affects performance. It is uncommon for small general aviation aircraft to have air conditioners because of the weight penalty.*

*In the tables themselves, pressure altitude and temperature are clearly factors. Of the two, temperature has the greatest effect on landing distance, though pressure altitude is also a very important factor in aircraft performance.*

Point out that takeoff and landing distance charts, such as the two examples on the slide, are divided into bands by pressure altitude, and that each pressure altitude band actually consists of two distinct rows:

- In the takeoff distance chart, each pressure altitude band contains data for ground roll ("Grnd Roll") and data for "50 ft" Ground roll refers to how much runway the aircraft needs to cover before it can lift off the ground; "50 ft" refers to how much runway the aircraft needs to cover before it can lift off *and* clear a 50-foot obstacle at the end of the runway. Note that airplanes require considerably more runway to clear a 50-foot obstacle than simply to take off.
- In the landing distance chart, each pressure altitude band contains data for ground roll ("Grnd Roll") and data for "Total." In the context of landing, ground roll refers to how much runway an airplane needs to cover between the time its wheels first touch the ground and the time it stops—think of it as stopping distance. "Total" refers to how much runway is needed after clearing a 50-foot obstacle near the runway threshold, touching down, and then stopping. Again, this distance is considerably longer.

**Slide 8:** Performance charts aren't the only source of information regarding factors that may affect takeoff and landing distances. Sometimes chart supplements can provide additional data. This slide shows an excerpt from a chart supplement for

Coeur d'Alene Airport (KCOE), in Idaho. As in the previous slide, instruct students to

identify factors relevant to takeoff and landing distances.

**Questions**

How many factors can you find in this chart supplement excerpt that might affect takeoff and landing distances at this airport?

*Students' responses may vary, but they may notice the abbreviation GRVD. This indicates that the runway has a grooved surface. The grooves in a runway provide channels to divert water from the surface of the runway. This reduces the chance that hydroplaning will occur.*

*Also, RW 06-24 has a 0.6% upslope to the northeast (RW 06), which could lengthen takeoff and shorten landing distances on RW 06; the opposite is true for RW 24 (shorter takeoff distance and greater landing distance).*

*There is a barbed line near the beginning of runway 01. This indicates that the terrain before the threshold rises rapidly. Providing an adequate amount of clearance above this terrain may cause a pilot to land further down the runway resulting in less runway available for stopping.*

Discuss students' ideas and findings as a class before proceeding to **EXPLAIN.**

## EXPLAIN

**Teacher Materials:** Takeoff and Landing Distances Presentation, Takeoff and Landing Distances Teacher Notes 1
**Student Materials:** Takeoff and Landing Distances Student Activity 1, Takeoffs and Landing Distances Student Notes

**Slide 9:** Having a thorough knowledge of the takeoff and landing distance required at a particular airport is a major component in every pilot's flight planning.

Every aircraft has a different takeoff speed, and a number of factors affect the aircraft's ability to reach that speed. Both the weight of the aircraft and its acceleration affect takeoff distance. Runway surfaces and slope also play a role, with dry, paved runways requiring less distance for takeoff than wet or grassy surfaces. Wet and grassy surfaces create more drag; this slows an aircraft's acceleration when taking off but aids its deceleration when landing.

**Slide 10:** Sometimes, multiple factors that affect takeoff and landing distances can be present at the same time. Students should watch this video, then answer the following questions:

- "Cessna 185: Taking Off and Landing on a Muddy Jungle Airstrip" (Length 1:04)
  https://video.link/w/WvJ1

For teachers unable to access Safe YouTube links, the video is also available here: https://www.youtube.com/embed/pSUbcFGzc4s?start=60&end=124

**Questions**

How many factors that affect takeoff and landing distances did you see in this video?

*Students' responses may include a single-engine airplane; a wet, grassy, muddy surface; a sloping runway; a rising terrain; and an experienced pilot.*

Would you consider this a safe airport for takeoffs and landing? Why or why not?

*Students' responses may vary.*

*Remind students that many pilots would deem this airport unsafe due to the factors listed above, while others would find it sufficiently safe for normal operations. Takeoffs and landings in challenging environments are part of daily life for pilots in remote areas, and these actions become easier and less stressful with practice and experience.*

**Slides 11-12:** The type of runway surface can have a dramatic effect on takeoff and landing distances. For instance, wet, grassy, or muddy surfaces can create friction between an aircraft's tires and the runway surface, increasing the takeoff distance. This friction, however, can also reduce the landing distance, since deceleration increases after touchdown and the airplane stops in a shorter distance. On the other hand, if hydroplaning occurs during landing, friction between the tires and runway decreases; the tires may lose contact with the runway, reducing directional control and brake effectiveness. Recall that the speed at which hydroplaning occurs can be predicted by applying the following formula: hydroplaning speed = (9)  (square root of tire pressure)

In addition to its effect on hydroplaning, tire pressure itself can impact takeoff and landing distance. Lower tire pressure exposes more tire surface to the runway, increasing friction and increasing takeoff distance. Conversely, the increased friction from low-pressure tires can help the airplane stop more quickly and shorten overall landing distances. Encourage students to think about riding a bicycle with underinflated tires compared to properly inflated tires. Pedaling is more difficult with underinflated tires compared to pedaling with properly inflated tires. The same principle applies to airplane tires during takeoff and landing.

Grooved runways can reduce the impact of water on the runway surface by keeping the airplane tires in closer contact with the surface. Grooves improve traction allowing more effective braking and directional control.

Other contaminants can also affect takeoff and landing distances. Ice produces slick surfaces that can significantly increase landing distance, and even cause a pilot to lose directional control of the aircraft. Takeoff distances may be increased due to the reduced friction between tires and runway. If the aircraft swerves on the takeoff roll, the takeoff distance can be dramatically increased. If the pilot needs to abort the takeoff, stopping safely may not be possible.

The diagram on Slide 12 is an excerpt from the chart supplement for Rocky Mountain Metropolitan Airport, in Colorado. Note that each runway's surface (asphalt and grooved asphalt) and slope (1.0% down; 1.1% up; 1.1% up NW; 0.5% up) are featured in the supplements.

**Slide 13:** Excess power decreases the distance required for takeoff. Excess weight increases the distance required for takeoff.

Student pilots on their first solo flight often report their surprise at how quickly the airplane accelerated and took off; the loss of the weight of the instructor is enough to significantly increase acceleration and shorten takeoff distance.

Rules of thumb exist regarding the relationship between weight and takeoff distance:

- A 10 percent increase in weight results in:
    - a 5 percent increase in liftoff speed
    - a 9 percent or greater decrease in acceleration
    - a 21 percent increase in takeoff distance

**Questions**

If a 3,000-pound aircraft takes on 50 gallons of fuel and has a takeoff speed of 80 knots, what liftoff speed should the pilot expect based on the rule of thumb above?

*The 50 gallons of fuel equate to 300 pounds (50 gallons x 6 pounds/gallon = 300 pounds) which is a 10% increase in weight. The resulting increase in liftoff speed is 5% of 80 knots (4 knots), so the liftoff speed is 84 knots.*

Older engines may not be able to produce the same power as when they were new; consequently, they may not be able to accelerate an airplane as quickly as the performance tables indicate. Airplanes with older engines often require greater takeoff distances than their associated takeoff charts and tables specify, and pilots must take this into consideration during preflight planning.

Setting the fuel mixture properly is also a factor in takeoff distance. Pilots should adjust the mixture for the local density altitude before takeoff to ensure maximum available thrust is attained. Attempting to take off with the mixture set too rich (or too lean) will reduce the efficiency of the engine and increase the necessary takeoff distance.

**Slide 14:** Wind is another factor that can have a major impact on takeoff and landing distances. Headwinds have the effect of shortening takeoff and landing distances. During takeoff, a headwind provides additional lift by effectively increasing the velocity of air across the wing. This allows the airplane to reach takeoff airspeed more quickly and decreases the required takeoff distance. The same principle applies to landing with a headwind; the airplane lands at a slower groundspeed (airspeed minus headwind equals groundspeed), thus requiring less distance to stop.

As an aircraft accelerates on takeoff with a tailwind, the wind is causing the aircraft to move down the runway faster than in no-wind or headwind conditions. This push extends the takeoff distance both along the ground and on climbout.

On landing, the higher groundspeed that results from the tailwind pushing the airplane forward necessitates a greater distance to clear obstacles and come to a stop.

In short, headwinds are usually good for takeoffs and landing, whereas tailwinds are bad.

The performance charts in the POH take wind into account when determining takeoff and landing distances—as illustrated at the top of the example chart on this slide. First, however, the pilot must calculate the headwind or tailwind component of the wind on the surface at the airport. This is done by referencing a crosswind component chart, as explained on the next slide.

**Slides 15-17:** A crosswind component chart (such as the example on Slide 16) enables a pilot to calculate the amount of headwind, tailwind, or crosswind, given the wind velocity and the runway being used for takeoff or landing. Follow these steps to use this chart:

1. Determine the angle between the wind and the runway.

1. Remember, runway numbers correspond to the magnetic direction *toward which* the runway is pointing; simply add a zero to the end of the runway number to obtain the magnetic direction. Wind direction (received through an ATIS or AWOS broadcast) is given in the magnetic direction *from which* the wind is blowing.

2. Suppose that a pilot wants to take off from a runway numbered 34 (a magnetic heading of 340°), and the wind is blowing at 40 knots from the direction 010°. Since the wind is blowing from 010°, the angle between the runway direction and the wind is 30°.

1. 340° + 20° clockwise takes us to 360°, then another 10° takes us to 010°.

2. 20° + 10° = 30°, the angle between the runway and the wind

3. Look for the diagonal line on the crosswind component chart that corresponds to 30°: see the red line AB in the chart on Slide 16.

3. Wind speeds are represented by the round arcs on the chart. Find where the arc for 40 knots intersects with the 30° diagonal. Make a pencil mark on this point (labeled B in the chart on Slide 16).

4. Draw a straight line horizontally to the vertical axis on the left. This intersection on the chart is Point C. This scale is the headwind component. In this example, the value is 35 knots. This is the headwind value that you will apply when using the takeoff or landing charts and tables in the POH.

5. Returning to the point in Step 2 (Point B), draw a vertical line down from this point to the horizontal axis of the chart. This scale is the crosswind component. In this case, the wind strength is 20 knots (Point D).

Note that the crosswind component tells the pilot the wind strength blowing directly across the runway. Airplanes undergo crosswind testing during the certification process. Manufacturers publish the maximum demonstrated crosswind component in airplane flight manuals (see the excerpt from the POH for a Cirrus SR22, on Slide 17). This wind value does not mean the aircraft cannot operate in stronger crosswinds. The value of the crosswind stated in the manual is the greatest in which the test pilots flew during certification.

**Questions**

What are the headwind and crosswind components in the following scenarios?

1. An airplane is taking off from Runway 25; the wind is from 300° at 20 knots.
   *Applying the steps above:*
   *The angle between the wind (300°) and the runway (250°) is 50°.*
   *On the crosswind components chart, place a pencil mark where the 50° diagonal intersects the 20-knot arc.*
   *Draw a straight line from this intersection to the left. The headwind component is about 14 knots.*
   *Draw another straight line from the intersection down to the horizontal axis. The crosswind component is about 16 knots.*
   *Allow answers +/- 2 knots.*

1. An airplane is taking off from Runway 09; the wind is from 180° at 30 knots.
   *The angle between the wind (180°) and the runway (090°) is 90°*
   *On the crosswind components chart, place a pencil mark where the 90° diagonal intersects the 30-knot arc.*
   *Draw a straight line from this intersection to the left. The headwind component is zero.*
   *Draw another straight line from the intersection down to the horizontal axis. The crosswind component is 30 knots.*

**Slide 18:** Once the pilot has determined the headwind or tailwind component for their takeoff or landing, they are ready to consult the relevant performance chart for details about the distances required. Takeoff and landing charts predict the amount of runway needed based on several factors, including aircraft weight, flap setting, runway surface, headwind or tailwind, runway slope, wet or dry conditions, pressure altitude, and temperature.

The distances presented on the performance charts are derived by experienced test pilots flying new airplanes on days with good weather. Since takeoff and landing distance is also affected by pilot skill, pilots often build a safety factor into these distances. For example, they may increase the distances required based on their personal experience. A conservative rule of thumb would be to add 50 percent to the distances provided on the charts.

**Slides 19-20:** Provide two practice problems for students to work out in class, in preparation for the sample FAA Knowledge Exam questions to be presented after the Formative Assessment. Students should use the takeoff distance chart on Slide 20 and the crosswind component chart on Slide 16.

**Teaching Tips**

You may wish to print and distribute the **Takeoff and Landing Distances Student Notes**, which contains copies of the crosswind components chart, the azimuth chart, and the takeoff distance chart necessary to solve the following practice problems.

**Questions**

**Scenario 1:** An airplane that weighs 2,200 lbs is taking off from Runway 21, which has a surface of dry pavement. The wind is from 240° at 10 knots, the temperature is 30°C, and the pressure altitude is 6,000 feet. Calculate the headwind and crosswind components and the total ground roll distance.

- Headwind = 9 knots
- Crosswind = 5 knots
- Total ground roll distance = 1,300.5 feet

Use these steps to calculate the answers:

1. Determine the angle between the runway direction and the wind direction:
   Runway direction is 210° (add zero to the end of Runway 21).
   Wind direction is 240° (given).
   Angle between wind and runway directions = 240° – 210° = 30°.
2. Use the crosswind component chart to determine the headwind and crosswind components:
   Find the 30° diagonal on the chart.
   Draw a point on the chart where the 30° diagonal intersects with the 10-knot arc (10 knots is the given wind speed).
   Draw a straight line to the left margin of the chart to identify the headwind component: 9 knots.
   Draw a straight line down to the bottom margin of the chart to identify the crosswind component: 5 knots.
3. Use the takeoff chart to determine the ground roll distance:
   Find the 30°C column on the chart. Focus on the smaller sub-column for "Grnd roll (ft)."
   Follow this sub-column down to the row for 6,000 feet pressure altitude on the 2,200-lb weight scale. The base ground roll distance is 1,445 feet.
   At the top of the takeoff distance chart, Note 2 states to deduct 10 percent from the base ground roll distance for each 9 knots of headwind.
   Calculate 10 percent of 1445 feet = 144.5 feet.
   Deduct this amount from the base ground roll distance = 1,445 feet – 144.5 feet = 1,300.5 feet.

**Scenario 2:** An airplane that weighs 2,000 lbs is taking off from Runway 14, which has a surface of dry grass. The wind is 160° at 20 knots, the temperature is 20°C, and the pressure altitude is 4,500 feet. Calculate the headwind and crosswind components and the takeoff distance necessary to clear a 50-foot obstacle.

- Headwind = 19 knots

- Crosswind = 7 knots
- Takeoff distance to clear a 50-foot obstacle = 1,501 feet

To find the headwind and crosswind components, apply Steps 1 and 2 from the explanation for Scenario 1 above. To find the takeoff distance necessary to clear a 50-foot obstacle, follow these steps:

1. On the takeoff distance chart, find the 20° C column. Follow the larger sub-column ("Total feet to clear 50 ft OBS") down to the 2,000-lb weight scale.
2. Within this weight scale, interpolate between 4,000 feet and 5,000 feet pressure altitudes to find the distance to clear a 50-foot obstacle with no extra conditions. Because 4,500 feet is midway between the two altitudes, simply average the distances: the distance to clear a 50-foot obstacle at 4,000 feet pressure altitude is 1,615 feet; the distance at 5,000 feet pressure altitude is 1,790 feet. Averaging the two gives us 1,703 feet.
3. Now, apply the necessary corrections for conditions:
   A 19-knot headwind reduces the total distance by 20 percent, or 341 feet. (There is a 10 percent reduction for each 9 knots of headwind.) Therefore, 1,703 –341 = 1,362 feet. This is the distance to clear a 50-foot obstacle factoring in the headwind of 19 knots.
   A dry grass runway increases the total distance by 15 percent of the ground roll distance. Students should interpolate the ground roll distance for a 2,000-lb airplane at 4,500 feet PA and 20°C:
   Ground roll distance for 4,000 feet PA is 880 feet
   Ground roll distance for 5,000 feet PA is 970 feet
   Averaging the two gives us 925 feet of ground roll.
   15 percent of 925 feet is (0.15 x 925) 139 feet.
   139 feet is the additional runway length required because of the grass surface.
4. Calculate the sum of all the numbers: 1,703 feet (distance to clear 50-foot obstacle given pressure altitude and temperature) – 341 feet for headwind correction + 139 feet for dry grass runway = 1,501 feet total distance to clear 50-foot obstacle given the specified conditions.

Note that these values are for full throttle at brake release. These numbers are the lowest possible at the given weights and conditions. Most pilots apply a personal safety factor to increase the distances in keeping with their personal minimums and experience level.

**Formative Assessment**

Students will complete **Takeoff and Landing Distances Student Activity 1** by listing as many factors as possible that affect takeoff and landing distance. Students will then calculate takeoff and landing distance given two scenarios involving dry grass runways, with one solution factoring in a 50% safety factor above chart values. Correct answers and sample responses are provided in **Takeoff and Landing Distances Teacher Notes 1**.

[DOK-L2; *estimate,* DOK-L2; *explain*]

## EXTEND

**Teacher Materials:** Takeoff and Landing Distances Presentation, Takeoff and Landing Distances Teacher Notes 2
**Student Material:** Takeoff and Landing Distances Student Activity 2

Session 2

**Slide 22:** Students will complete **Takeoff and Landing Distances Student Activity 2** and participate in a class discussion, as time allows. Correct answers and explanations are provided in **Takeoff and Landing Distances Teacher Notes 2**.

## EVALUATE

**Teacher Materials:** Takeoff and Landing Distances Presentation, Takeoff and Landing Distances Teacher Notes 3
**Student Material:** Takeoff and Landing Distances Student Activity 3

**Slides 23-38:** Sample FAA Knowledge Exam Questions

**Slide 39:** Conduct the **Summative Assessment**.

**Summative Assessment**

Students will complete **Takeoff and Landing Distances Student Activity 3**, a worksheet containing two airport scenarios, and will determine whether the given aircraft can safely perform a takeoff or **landing. Correct answers and sample responses are provided in Takeoff and Landing Distances Teacher Notes 3**.

[DOK-L2; *estimate, explain*]

**Summative Assessment Scoring Rubric**

- Follows assignment instructions
- Postings show evidence of one or more of the following:
  - Knowledge of the factors that affect takeoff and landing distance
  - Ability to read charts and graphs that predict takeoff and landing performance
  - Knowledge of the relative effects of the various factors affecting takeoff and landing distance
  - Ability to use available data to make a good go/no-go decision
- 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 Accurately completes calculations for Scenario 1 and Scenario 2; correctly incorporates density altitude, weight and balance, and takeoff and landing issues using the graphs and tables; Demonstrates a thorough understanding of the lesson objectives
7-8 Completes calculations for Scenario 1 and Scenario 2 with some errors; Incorporates density altitude, weight and balance, and takeoff and landing issues using the graphs and tables with some gaps in understanding; Demonstrates a sufficient understanding of the lesson objectives
5-6 Performs calculations for Scenario 1 and Scenario 2 with many errors; Incorrectly incorporates density altitude, weight and balance, and takeoff and landing issues using the graphs and tables with many gaps in understanding; Demonstrates a partial understanding of the lesson objectives
0-4 Calculations for Scenario 1 and Scenario 2 are mostly incorrect; Shows little or no understanding of density altitude, weight and balance, and takeoff and landing issues; Demonstrates a poor understanding of the lesson objectives

## GOING FURTHER

**Slides 40-41:** Show students the photos in these slides. Students should be able to identify factors from the photographs that make takeoff and landing especially challenging at these airports.

- Juancho E. Yrausquin Airport (Slide 40), on the Caribbean island of Saba, contains these challenges
- Very short runway
- Cliff at both ends

- Ocean winds create headwinds/tailwinds

- Tenzing-Hillary Airport (Slide 41), in Nepal, contains these challenges:
- Very short, sloping runway
- Mountains at far end

Additional photos can be found here:

- https://www.travelandleisure.com/slideshows/the-worlds-scariest-runways?slide=311009#311009
- https://www.placesyoullsee.com/15-of-the-weirdest-airport-runways-in-the-world/

## 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

## FAA AIRMAN CERTIFICATION STANDARDS

**PRIVATE PILOT**
**I. Preflight Preparation**
**Task F. Performance and Limitations**

- **Knowledge** The applicant demonstrates understanding of:
    - **PA.I.F.K1** Elements related to performance and limitations by explaining the use of charts, tables, and data to determine performance.
    - **PA.I.F.K2** Factors affecting performance, to include:
        - **PA.I.F.K2a** Atmospheric conditions
        - **PA.I.F.K2b** Pilot technique

        - **PA.I.F.K2c** Airplane configuration
        - **PA.I.F.K2d** Airport environment
        - **PA.I.F.K2e** Loading (e.g., center of gravity)
        - **PA.I.F.K2f** Weight and balance
    - **PA.I.F.K3** Aerodynamics.
- Risk Management The applicant demonstrates the ability to identify, assess and mitigate risks, encompassing:
    - **PA.I.F.R1** Inaccurate use of manufacturer's performance charts, tables, and data.
    - **PA.I.F.R2** Exceeding airplane limitations.
    - **PA.I.F.R3** Possible differences between calculated performance and actual performance.
- **Skills** The applicant demonstrates the ability to:
    - **PA.I.F.S2** Utilize the appropriate airplane manufacturer's approved performance charts, tables, and data.

## REFERENCES

- FAA Airplane Flying Handbook
- FAA Pilots Handbook of Aeronautical Knowledge
    - https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/13_phak_ch11.pdf
- Airman Knowledge Testing Supplement
    - https://www.faa.gov/training_testing/testing/supplements/media/sport_rec_private_akts.pdf
- https://www.aopa.org/news-and-media/all-news/2018/may/flight-training-magazine/technique-takeoff-calculation
- https://www.aopa.org/news-and-media/all-news/2003/march/flight-training-magazine/a-new-look-at-takeoff-performance
- https://www.youtube.com/watch?v=pSUbcFGzc4s