Thunderstorms

Session Time: Four, 50-minute session(s)

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Thunderstorms are formed and powered by warm, moist air that is rising in unstable air.

Thunderstorms are a great threat to all aircraft and must be avoided.

ESSENTIAL QUESTIONS

1. Is it ever safe to fly in a thunderstorm?

LEARNING GOALS

Students Will Know

- How thunderstorms form
- Where thunderstorms form
- Different types of thunderstorms
- The life cycle of a thunderstorm

Students Will Be Able To

- *Explain* the four types of lifting actions and their relationship to thunderstorm development. (DOK-L2)
- *Name* the conditions associated with each stage of thunderstorm development. (DOK-L1)
- *Assess* the risk associated with a thunderstorm forecast. (DOK-L3)

ASSESSMENT EVIDENCE

Warm-up
Students will begin by discussing the current weather conditions of the day. Students will fill in and assess their weather diary, first started in Unit 1, Section A, Lesson 1. Lead a class discussion regarding thunderstorms, to determine if it's a good day to fly. Were some days of the week better than others?

Formative Assessment
Students will individually demonstrate their knowledge of the four types of lifting actions and the stages of the thunderstorm life cycle.

Summative Assessment
In this activity, students will read parts of an actual NTSB accident report and explain the risks taken by the pilot that could have caused the accident.

LESSON PREPARATION

MATERIALS/RESOURCES

- Thunderstorms Presentation
- Thunderstorms Student Activity 1
- Thunderstorms Student Activity 2
- Thunderstorms Student Activity 3
- Thunderstorms Student Activity 4
- Thunderstorms Teacher Notes 1
- Thunderstorms Teacher Notes 2
- Thunderstorms Teacher Notes 3
- Thunderstorms Teacher Notes 4
- Student Daily Weather Diary

“Make Your Own Lightning” Activity (per group)

- Rubber gloves (one per student)
- Plastic fork
- Aluminum foil
- Wood or plastic cutting board
- Piece of Styrofoam, such as a plate or rubber balloon (inflated)
- Wool cloth (or hair on a student’s head)

LESSON SUMMARY

Lesson 1: Makeup of the Atmosphere
Lesson 2: Atmospheric Circulation and Winds
Lesson 3: Clouds and Precipitation
Lesson 4: Air Masses and Fronts
Lesson 5: Thunderstorms

This four-session lesson will begin with a warm-up in which students use their weather diaries to discuss the current local weather, focusing on the presence or absence of recent thunderstorms and students’ observations of weather phenomena in thunderstorms they’ve experienced. This will segue into a general review of thunderstorm information and a discussion of the power and prevalence of thunderstorms, reinforced by videos and a reading activity.

Next, students will study the conditions required for thunderstorms to form, followed by the four types of lifting action. Students will then learn about the different types of thunderstorms and the three stages of a thunderstorm’s life cycle. They will support their understanding of thunderstorms with an activity and a Formative Assessment. This will lead to a discussion of the threats associated with thunderstorms, including how they can damage an aircraft and how pilots can avoid them. Students will apply and visualize this information by completing an activity in which they produce static electricity.

Finally, students will review test questions from the Private Pilot’s Knowledge Test and complete a summative assessment in which they assess the risk associated with a thunderstorm forecast.

BACKGROUND

According to the National Oceanic and Atmospheric Administration (NOAA), there are approximately 2,000 thunderstorms in progress around the world at any given moment. In the United States alone, there are about 100,000 thunderstorms every year. This reveals the instability in the atmosphere.

Previous lessons have discussed many threats to aircraft operations, both while on the ground and in the air. Thunderstorms are unique because they have the potential to encompass the majority of the most perilous threats to aircraft, including hail, icing, extreme turbulence, tornadoes, microbursts, reduced visibility, and more. Because they can build so rapidly, they arguably present the greatest threat to all aircraft operations.

Three elements that are necessary for a thunderstorm to form are moisture in the atmosphere (i.e., water vapor), atmospheric instability, and a lifting action. These three elements cause clouds in the atmosphere to become increasingly vertical until they become cumulonimbus clouds, known as "thunderheads."

Pilots must have a deep understanding of the causes and life cycle of thunderstorms, as well as a good understanding of how to avoid them, in order to fly safely.

MISCONCEPTIONS

In most situations students have encountered, thunderstorms may not be much of a threat. Generally speaking, you have little to be concerned about if you are in your home or at school when a thunderstorm hits. But the situation is very different if you are in an airplane. Severe turbulence, lightning, icing and hail can make an aircraft uncontrollable, and even tear it apart. This lesson should reveal to students that flying through (or even near) a thunderstorm can be life threatening. While aircraft can penetrate clouds and other weather phenomena, thunderstorms should be avoided to the maximum extent possible.

DIFFERENTIATION

To promote student motivation and engagement during the **ENGAGE** section of the lesson, have students perform a Think-Pair-Share before conducting the class-wide discussion. This can ensure all students have an opportunity to participate in the discussion and have their ideas heard.

To assist struggling learners during the **EXPLORE** and **EXTEND** sections of the lesson plan, provide those students with graphic organizers or prompts to help them take notes while watching the videos. The graphic organizers or prompts should include keywords or headings that will help students focus on essential parts of the videos.

LEARNING PLAN

ENGAGE

Teacher Material: Thunderstorms Presentation
Student Material: Student Daily Weather Diary

Session 1

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

Slides 4-5: Conduct the **Warm-Up**.

Warm-Up

Ask: Is this a good day to fly?

Students will begin by discussing the current weather conditions of the day. Using their Daily Weather Diaries, have them compare the day's weather with the weather they've recorded for previous weeks. Then lead them into a discussion regarding thunderstorms:

- Have there been any thunderstorms recently? If so, have students share the conditions that they recorded before, during, and after the thunderstorm.

- Regardless of whether there have been thunderstorms recently, ask students use what they learned in previous lessons on Clouds and Precipitation and Air Masses and Fronts to deduce why there have or have not been thunderstorms recently.
- Ask whether students believe there will be a potential for thunderstorms in the coming days. What conditions could either produce or prevent them?

Once the discussion is wrapping up, go to the next slide and ask the students the following questions; if possible, use a whiteboard and marker to track how the students rank the threats:

- Think of a time when you have experienced a thunderstorm. What phenomena did you experience during the storm?
- Have you ever been on an airplane that flew through or close to a thunderstorm? Describe the situation.
- Assume you're a pilot flying an aircraft. How would you rank the possible threats accompanying a thunderstorm, from most to least hazardous? Why? What could each threat do to your aircraft?

EXPLORE

Teacher Materials: Thunderstorms Presentation, Thunderstorms Teacher Notes 1
Student Material: Thunderstorms Student Activity 1

Slide 6: According to the National Oceanic and Atmospheric Administration (NOAA), there are approximately 2,000 thunderstorms in progress around the world at any given moment. In the United States alone, there are about 100,000 every year. This reveals how unstable the atmosphere is by its nature.

Previous lessons have discussed many threats to aircraft operations, both while on the ground and in the air. Thunderstorms are unique because they have the potential to encompass the majority of the most perilous threats to aircraft. And because they can build so rapidly, they arguably present the greatest threat to all aircraft operations in general.

Teaching Tips

A live map of worldwide thunderstorms in real time can be seen at the following webpage: http://de.blitzortung.org/live_lightning_maps.php

Have students use this resource and then answer the following questions.

Questions

Where do the majority of thunderstorms appear to be occurring around the world right now? Why do you suppose there is such a dense concentration in those areas?

Answers will vary based on time of year and current conditions for those areas. Students should suppose that those areas had the most significant instability (warm air at the surface, moisture in the atmosphere, updrafts).

Slide 7: Show these videos and invite students to check out the amazing power and danger of thunderstorms, then to see how hail, one of the greatest threats to aircraft, caused serious damage to a Delta flight. Urge students to take notes, because they will use the information from the videos and the reading activity that follows to answer questions on **Thunderstorms Student Activity 1** worksheet.

- "The Amazing Power of Thunderstorms" (Length 4:32)
  https://video.link/w/zAQp

For teachers who are not able to access Safe YouTube links, this video can also be found here: https://www.youtube.com/watch?v=NOr7-hUbdvE

- "Plane emergency landing: Delta flight lands blind after hail storm damages windshield" (Length 1:00)
  https://video.link/w/gCQp

For teachers who are not able to access Safe YouTube links, this video can also be found here: https://www.youtube.com/watch?v=SLINrBScW8E

Slide 8: Provide students with **Thunderstorms Student Activity 1** worksheet, which contains the text of the following story, about a Marine fighter pilot who ejected at high altitude and fell through a raging thunderstorm with his parachute open:

- https://taskandpurpose.com/incredible-story-marine-rode-lightning

Students should read the story and then answer the questions based on the notes they took from the videos in the previous slide.

Slide 9: Three elements are necessary for a thunderstorm to form:

- There must be moisture in the atmosphere (i.e., water vapor).
- There must be atmospheric instability: for example, when warm air is below cooler air, the warm air "wants" to rise.
- There must be a lifting action, causing clouds in the atmosphere to become increasingly vertical until they become cumulonimbus clouds, sometimes known as "thunderheads."

Slide 10: The first of these three elements, moisture, is the fuel that drives the "engine" of a thunderstorm: moisture is necessary to create latent heat. Latent heat is the term used to describe the heat that must be absorbed from the atmosphere in order to transform a solid into a liquid or a liquid into a gas, or to the heat released into the atmosphere as a gas is transformed into a liquid and then a solid. The graph on this slide shows how water absorbs heat from the air as it changes phase from solid ice to liquid water, and then from liquid water to gas (water vapor). In contrast, as water changes phase in the opposite direction, it releases heat into the air.

Instruct students to imagine what happens as liquid water evaporates (latent heat of vaporization), rises, cools, and then condenses back into a liquid form (latent heat of condensation). (Students observed this process in Lesson 1.B.3—Clouds and Precipitation, during the "cloud in a bottle" experiment.) When the water vapor condenses into a visible liquid form, it gives off heat, which warms the surrounding air. That now-warmer air rises, forcing the thunderstorm higher into the atmosphere.

Questions

Have the students lick or moisten their wrist and then blow on it. Then ask: What happens? Why?

Students' skin should feel cool, proving that the air cools as liquid evaporates (transformation from liquid to gas). The opposite occurs when gas (water vapor) condenses into a liquid form (cloud), causing the heat from that moisture to be given off into the air around it.

Slide 11: Remind students that the second of the three elements, atmospheric instability, was thoroughly explained in Lesson 1.B.3—Clouds and Precipitation. A warm parcel of air will keep rising and expanding in an unstable atmosphere via the adiabatic process (recall the video from that lesson, "Adiabatic processes, lapse rates and rising air": https://video.link/w/Ycxp). However, a stable atmosphere will not cause sufficient rising for a thunderstorm to develop.

Questions

Recall the concept from Lesson 1.B.3—Clouds and Precipitation that measures atmospheric stability (environmental vs. adiabatic lapse rate). Give an example of a "layer" that occurs in a stable atmosphere? Why?

An inversion layer. This is caused because cooler air is trapped underneath a layer of warmer air, causing the air to "stay put" for the most part.

Slide 12: The third of the three elements, lifting action, can be described as the "engine" of a thunderstorm, fueled by the moisture in the atmosphere. Remind students of the four types of lifting action described in Lesson 1.B.3—Clouds and Precipitation: surface heating, wind convergence, mountains/geographic lifting (also known as orographic), and frontal uplifting. All four of these lifting actions can be referred to as convection. Significant updrafts and instability are necessary for thunderstorms to form; therefore, three of the four types of lifting are explored in greater depth in this lesson. Since adiabatic heating/cooling processes (surface heating) were thoroughly examined in Lesson 1.B.3—Clouds and Precipitation, this lesson starts with the second type, converging air.

EXPLAIN

Teacher Materials: Thunderstorms Presentation, Thunderstorms Teacher Notes 2
Student Material: Thunderstorms Student Activity 2

Session 2

Slide 13: Wind convergence, also known as lifting by convergence, occurs when air flows horizontally along the earth's surface and is then forced upward into the atmosphere when it collides with another air mass. This typically occurs when there is a low-pressure region (also known as a trough) into which air from various directions converges, collides, and moves skyward. Since this type of lifting is not as strong as the other types of convective air movements, it typically does not create enough instability or vertical development to create cumulonimbus clouds. Rather, it tends to create cirrostratus or similar types of clouds.

Slide 14: Orographic lifting typically occurs in mountainous regions that provide enough of a steep change in elevation for winds blowing along the earth's surface to force air skyward. Since the air is already rising in this direction due to the geography of the land, it does not require significant instability to continue rising. Neutral stability is sufficient for the air to continue on its path skyward.

Mountains with significant elevation may cause the ascending water vapor to reach its dew point and condense prior to reaching the mountain peak. This creates clouds along the slopes of the mountains. When air that is forced up the mountain due to orographic lifting is stable, then the stable air that crests over the mountaintop will fall along the backside of the mountain, causing downdrafts and a drying of the air. This helps to explain why many mountains have dry, desert climates, called "rain shadows," on the slope *opposite* the rising air.

Slide 15: The last and perhaps most powerful of the lifting types is the one most-often associated with convective activity: frontal lifting. As explained in Lesson 1.B.4—Air Masses and Fronts, this typically occurs along the leading edge of a cold front. The warm air ahead of the front is rapidly lifted into the atmosphere, causing it to cool and expand. If such air contains enough moisture, then the water vapor will condense, releasing its heat, and induce a further rise, increasing instability.

Although thunderstorms can form along any front, the most severe ones typically form along fast-moving cold fronts. Warm front thunderstorms are less severe, though they are more likely to be embedded (hidden) in stratus clouds, making them difficult for pilots to detect, especially if they lack weather radar in their aircraft. Additionally, frontal lines of thunderstorms can be hundreds of miles long, causing significant deviations which often require more fuel.

Slide 16: Long frontal lines of thunderstorms are known as squall lines. Pilots should always pay attention to fast-moving cold fronts, due to the possibility that bands of intense, fast-moving thunderstorms can form 10–180 miles ahead of the front. Due to intense instability and rapid lifting, these storms tend to contain some of the most severe weather, including large hail, destructive winds, and tornadoes.

Squall lines may also develop in especially unstable air far-removed from any front. The line may be too long to detour easily and too wide and severe to penetrate. It often contains steady-state thunderstorms (described in the next slide), and presents the single most intense weather hazard to aircraft. It usually forms rapidly, generally reaching maximum intensity during the late afternoon and the first few hours of darkness.

Show the animation video below to illustrate how squall lines form and are fed.

- "What is a squall?" (Length 1:51)
  https://video.link/w/a5Wp

For teachers who are unable to access SafeYouTube links, this video can also be found here: https://www.youtube.com/watch?v=JKR910Dyc2c

Slide 17: Regardless of the lifting action, for any thunderstorm to form, the air must have sufficient water vapor, an unstable lapse rate, and an initial lifting action to initiate the storm's creation. Some storms may occur randomly in unstable air, last for only an hour or two, and produce only moderate wind gusts and rainfall. These less-severe varieties of thunderstorms, known as air-mass thunderstorms, are typically formed by surface heating. Storms such as these are common in locations such as Florida, where lifting is not driven by fronts, yet conditions are unstable, warm, and humid enough to create such air-mass thunderstorms.

Conversely, steady-state thunderstorms are associated with weather systems. Fronts, converging winds, and troughs force air upward, spawning these storms that have the potential to form into squall lines. In steady-state storms, the mature-stage updrafts become stronger and last much longer than those in air-mass storms.

Slide 18: A thunderstorm makes its way through three distinct stages during the course of its life cycle. It begins with the cumulus stage, during which the initial lifting of the air begins. If sufficient moisture and instability are present, the cumulus clouds continue to increase in vertical height. Continuous, strong updrafts prevent moisture from falling. These updrafts carry water vapor further upward to the cooler upper regions of the cloud. The water vapor condenses into droplets, further releasing latent heat. The water molecules come together, growing ever larger and heavy enough to become rain; if not forced farther upward by updrafts, the rain falls to the earth. When rain begins falling, the mature stage begins.

Slide 19: Depending on atmospheric conditions, the mature stage may begin in as little as 15 minutes after the cumulus stage. The mature stage is the most violent portion of a thunderstorm's life cycle. At this point, drops of moisture, whether water or ice, are too heavy for the cloud to support and begin falling in the form of rain or hail. This falling creates a downdraft (downward motion of the air); downdrafts may also be caused by cold, dry air sucked into the cloud from high altitudes, which then descends. This combination of both updrafts (from the warm, rising air) and downdrafts (from the cool, falling air) causes violent, even extreme turbulence, which could cause massive structural damage to some aircraft. In fact, these updrafts and downdrafts can exceed 3,000 feet per minute. Due to this powerful kinetic activity, thunder and lightning begins to occur in this phase.

Turbulence exists not only within the cumulonimbus clouds, but also around the clouds for miles and underneath them as well. Underneath the cloud, as shown in the squall video, the down-rushing air increases surface winds dramatically and decreases the temperature. Once the vertical motion near the top of the cloud slows, the top spreads out and takes on an anvil shape, spread further by high-level winds that blow the cloud horizontally. At this point, the storm enters the dissipating stage.

Slide 20: In the dissipating stage, the downdrafts in the cloud spread out and counteract the updrafts, preventing the storm from growing further upward. When the warm air ceases to rise, precipitation ceases to form. As the remaining precipitation continues to fall to the earth, it bleeds the storm of its energy. The storm then begins to dissolve as the cloud fades and shrinks from both the top and the bottom. However, though the storm may be dying, it is still quite dangerous because powerful downdrafts and lightning are still common in the dissipating stage.

The timing of individual storms is subject to change; however, on average, the entire life cycle of a thunderstorm takes approximately one hour. Supercell thunderstorms are an exception; much larger and more powerful, they can last for several hours.

Slide 21: Conduct the **Formative Assessment**.

Formative Assessment

In this assessment, students will demonstrate their knowledge of the four types of lifting and the stages of the thunderstorm life cycle. Provide students with the **Thunderstorms Student Activity 2** worksheet. Have the students work individually to answer the questions. Sample responses can be found in **Thunderstorms Teacher Notes 2**.

[DOK-L2; *identify, explain*]

EXTEND

Teacher Materials: Thunderstorms Presentation, Thunderstorms Teacher Notes 3, Thunderstorms Teacher Notes 4
Student Materials: Thunderstorms Student Activity 3, Thunderstorms Student Activity 4

Session 3

Slide 22: Once students have learned how and why thunderstorms grow and fade, they can explore the hazards and threats associated with thunderstorms and the effects they have on pilots and aircraft. All of the hazards discussed in the following slides can occur in various combinations; while every thunderstorm will not contain every hazard, it is not possible to determine visually which hazards a particular thunderstorm contains.

Slide 23: The most-violent thunderstorms suck air into their cloud bases rapidly and aggressively. If the incoming air has rotating motion, it can form a concentrated vortex that extends from the earth's surface up into the cloud. Wind vortices can exceed 200 knots, with extremely low pressures inside them. The combination of strong winds gathering dust and debris and low pressures generates a funnel-shaped cloud that extends from the cumulonimbus base to the earth. If the cloud does not reach the ground, it is known as a funnel cloud; if it does contact the ground, it is a tornado; if it contacts water on the ground (whether a lake, a river, or an ocean), it is known as a waterspout.

Tornadoes can occur in both isolated and squall line thunderstorms. If tornadoes are forecast, then atmospheric conditions will likely contain violent turbulence. Any aircraft that enters a tornado will almost certainly suffer loss of control and critical structural damage. Since these vortices can extend high up into the cloud, any aircraft that penetrates a severe thunderstorm could encounter a hidden vortex. Families of tornadoes have been observed as appendages of the main cloud extending several miles away from the area of lightning and precipitation. Therefore, any cloud connected to a severe thunderstorm has potential for violent and damaging winds.

Slide 24: All thunderstorms contain turbulence, some of which can be extreme and have the potential to cause structural damage or even destroy an aircraft. The severe and extreme varieties of turbulence occur within the mature storm clouds when updrafts and downdrafts significantly shear against one another. Even outside the clouds, this shearing turbulence has been encountered several-thousand feet above and twenty miles laterally from severe storms. The roll clouds on the storm's leading edge portray the top of the eddies in the most significant shearing air, which has the potential for extreme turbulence.

The following video provides an excellent explanation of turbulence.

- "The Ups and Downs of Air Turbulence" (Length 3:25)
  https://video.link/w/jBXp

For teachers who are unable to access Safe YouTube links, the video can also be found here: https://www.youtube.com/watch?v=S5tN9nVLgcM

Slide 25: Areas of low-level turbulence near the ground are known as shear zones and are caused by the storm's gust front. Gust fronts may move up to 15 miles ahead of the precipitation that follows. They cause rapid and significant changes in surface winds, known more commonly as wind shear. Wind shear can create another potentially deadly threat for aircraft taking off and landing: the microburst.

Slide 26: Pilots use standardized terms to report turbulence. These are: light, moderate, severe, and extreme. Refer to the table on this slide to see how turbulence of varying intensities affects aircraft and passengers.

Slide 27: A microburst is a focused column of sinking air (a downdraft) within a thunderstorm that is typically less than 2.5 miles across. Microbursts can cause extensive damage at the earth's surface and can be life-threatening for pilots. The two types of microbursts are wet and dry, meaning they may or may not be accompanied by heavy precipitation.

A microburst begins to form inside a thunderstorm when large quantities of water or hail are suspended by an updraft far up into the atmosphere. The air around the water or hail may rapidly cool, sink, and counteract the updraft. This causes the precipitation core to plummet until it hits the ground and spreads out in every direction. Wherever the microburst first impacts the ground experiences the highest winds and greatest damage. Microburst wind speeds have been known to reach more than 100 mph, equal to an EF-1 tornado. Winds this strong can significantly damage homes and level trees, and can force an aircraft downward into the ground.

This video discusses the true story of a Delta flight that experienced a microburst:

- "This Is Why You Don't Want to Fly into a Microburst" (Length 3:44)
  https://video.link/w/XNXp

For teachers who are unable to access Safe YouTube links, the video can also be found here: https://www.youtube.com/watch?v=HDfodeURad0&t=1s

Slide 28: The video on the previous slide makes it clear that microbursts are one of aviation's most serious weather hazards, which can overcome even the most powerful airplanes. Invite students to dig deeper into the variables that can cause a microburst, the warning signs of a microburst, and best practices for responding to a microburst.

Show the following video; instruct students to take notes and be prepared to answer the questions that follow.

- "Microbursts and Wind Shear – Sporty's Private Pilot Flight Training Weather Tips" (Length 4:40)
  https://video.link/w/fQXp

Questions

An individual microburst rarely lasts longer than how many minutes after it hits the surface?
Answer: 15 minutes

Once microburst activity starts, formation of multiple microbursts is _____. (Common or uncommon?)
Answer: Common

As an airplane starts entering a microburst, performance ______. (Increases or decreases?)
Answer: Increases

Microbursts are probable under what conditions?
Answer: convective weather with localized strong winds, heavy precipitation, virga, moderate or greater turbulence, high dew point spread, pilot report of indicated airspeed change of 15 knots or more

What is the best strategy for dealing with low-level wind shear?
Answer: Avoidance

Slide 29: Icing is an additional serious threat associated with thunderstorms. Since students learned about icing causes and countermeasures in Grade 10, Lesson 8.B.2—Anti-Icing Systems, this lesson will only touch briefly on the threat of icing from a thunderstorm.

Because of the powerful updrafts within thunderstorms, thunderstorms support copious amounts of large droplets of liquid water. This water becomes supercooled when above the freezing level (0 °C). However, when temperatures decrease to below –15 °C, most of the water vapor sublimates as ice crystals. The amount of supercooled water decreases as altitude increases and temperatures further decrease. However, pilots must still be extremely cautious because hail may exist in these low-temperature altitudes.

Supercooled water freezes as it meets an aircraft. Clear icing can occur at any altitude above the freezing level, and at high altitudes smaller droplets may form as rime or mixed ice. Clear ice formation can occur rapidly and frequently between 0°C and –15 °C, making thunderstorm icing extremely hazardous. However, even outside of thunderstorms, pilots must always be alert for the icing threat whenever temperatures are below (or even slightly above) 0 °C and there is visible moisture.

Slide 30: Again, since students already learned how hail forms in Lesson 1B3—Clouds and Precipitation, this part of this lesson will only briefly cover the hail threat.

Hail forms when supercooled drops above the freezing level begin to freeze. Once frozen, other drops latch on and freeze, making the hailstones grow larger and larger until the updraft wind speeds can no longer support them. However, the updrafts and horizontal winds still have the potential to throw hailstones several miles horizontally from the storm clouds. This is yet another reason why thunderstorm clouds should be given a wide berth, especially at high altitudes.

As a precaution, the possibility of hail should be assumed with any thunderstorm, especially beneath large anvil tops. Due to an aircraft's significant true airspeeds and the opposing winds pushing hailstones horizontally, hailstones only one-half-inch wide can significantly damage an aircraft.

Slide 31: Ceilings and visibility are also significant considerations when thunderstorms are nearby. Within a thunderstorm itself, visibility is almost zero. But between the cloud base and the ground, and even for miles surrounding the cloud, ceiling and visibility may be restricted by precipitation or blowing dust. As always, pilots must be prepared and properly trained to conduct instrument approaches and departures in these low ceiling/visibility environments.

Slide 32: Altimeters can also be affected when thunderstorms are nearby. Pressure tends to fall rapidly as a thunderstorm approaches, then rise sharply with the onset of the first gust and arrival of the cold downdraft and heavy rain, and finally fall back to normal as the storm departs. This pressure change cycle may occur in as little as 15 minutes. A pilot could easily receive an altimeter reading within radio reception of an airport (perhaps 100 miles away) and fly into a significantly lower pressure trough while on approach and landing. Under these circumstances, the wrong altimeter setting could be off by more than 100 feet, which could be deadly if there are low ceilings on the approach. Remember the phrase, “high to low, look out below!”

Slide 33: Lightning that strikes an aircraft typically travels through the airframe and exits through the bottom, leaving the occupants unharmed. However, a lightning strike can puncture the aircraft’s skin and damage communications and electronic navigation equipment. Although lightning has been suspected of igniting fuel vapors and causing explosions, significant incidents caused by lightning strikes are rare.

Lightning poses other hazards, however. Nearby lightning can blind pilots, visually incapacitating them for a brief time. Nearby lightning can also induce magnetic compass errors. And even distant lightning has the ability to disrupt radio communications on low and medium frequencies. Severe storms tend to have a high incidence of lightning.

Show this video and instruct students to watch carefully as lightning strikes the top of the aircraft and continues out the bottom:

- Airplane Struck By Lightning” (Length 0:45)
  https://video.link/w/alYp

For teachers who are unable to access Safe YouTube links, the video can also be found here: https://www.youtube.com/watch?v=sY56uIuCu-8

Slide 34: Complete **Thunderstorms Student Activity 3**. In this activity, students will work in pairs or small groups to make their own “lightning” by producing static electricity. Additional Teacher Tips and sample answers to the analysis questions are in **Thunderstorms Teacher Notes 3**.

Session 4

Slide 35: Another significant threat, and a reason why aircraft operating guidelines have pilots avoid heavy precipitation, is the potential for engine water ingestion. Turbine engines have mechanical and operational limits on the amount of water that they can ingest. The velocity of updrafts carrying water upward within thunderstorms may match or exceed the falling raindrops’ velocity, creating significantly high concentrations of water. These concentrations can exceed the turbine engine’s water ingestion limits, resulting in flameout or even structural failure. In other words, even if the body of an aircraft penetrates a thunderstorm without damage, its engines might not.

Slide 36: Given all these threats, it is vitally important for pilots to fully understand thunderstorms and how to avoid their hazards. It is impossible for light aircraft to fly over developed thunderstorms. Even airliners and higher-performance aircraft would not be able to climb over severe thunderstorms, which can punch through the tropopause and reach staggering heights of 50,000–60,000 feet, depending on latitude. Flying under thunderstorms is also highly inadvisable, since this can subject aircraft to rain, hail, lightning, microbursts, and violent turbulence.

So, if a pilot can’t go over or under thunderstorms, the only remaining option is to go around them, giving them a wide berth while remaining aware of the direction in which they are moving. Severe thunderstorms (those giving an extreme radar echo) should be circumnavigated by at least 20 nautical miles (nm), since hail may be projected miles away from the clouds. This means that pilots should not attempt to fly *between* severe cells that are not separated by at least 40 nm; otherwise, the aircraft will be closer than 20 NM as it passes at least one of the cells. Pilots should also ensure that nearby cells are not converging, which they can do rapidly, before attempting to pass between them. If flying around a thunderstorm is not an option, it is best to divert your course of flight or to stay on the ground until the storms pass.

Show students the following video, which offers a sped-up view of an air traffic control screen as aircraft try to make their way around thunderstorms and into the world's busiest airport, Atlanta-Hartsfield. As the video shows, even airliners avoid penetrating severe storms. Point out to students the tracks of aircraft flying racetrack-shaped holding patterns as they wait for the storm to clear.

- "Airplanes around thunderstorms" (Length 1:10)
  https://video.link/w/43Yp

For teachers who are unable to access Safe YouTube links, this video is also available here: https://www.youtube.com/watch?v=eWv4wyy_Jqg&t=2s

Slide 37: Students will work as a class and individually to:

- Instruct students to go to AOPA's "Thunderstorm Avoidance" webpage. If they haven't already done so, students will need to create a free account.
  https://www.aopa.org/training-and-safety/air-safety-institute/safety-spotlights/thunderstorm-avoidance.

Once logged in, students should select the "Thunderstorms" Safety Quiz. Ask questions on the quiz to students selected at random, and then ask the rest of the class if they agree.

- Next, return to AOPA's "Thunderstorm Avoidance" webpage and select the "T-Storm Toolbox" video. A "safe" version of the YouTube video is also available here: https://video.link/w/venq (Length 4:39)
- Have students take notes as they watch the video. Then have students use their notes to create 4 quiz questions. Students will then have another student take their quiz and then give them feedback and discuss the answers.

EVALUATE

Teacher Materials: Thunderstorms Presentation, Thunderstorms Teacher Notes 4
Student Material: Thunderstorms Student Activity 4

Slides 38-43: Quiz students on the Private Pilot Knowledge Test questions.

Slide 44: Conduct the **Summative Assessment**.

Summative Assessment

In this activity, students use an NTSB accident report to identify the risks that were taken that likely caused the accident. Have the students complete the **Thunderstorms Student Activity 4** worksheet. Answers are provided in the **Thunderstorms Teacher Notes 4** document.

[DOK-L3; *assess*, DOK-L2; *interpret*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Postings show evidence of one or more of the following:
  - Knowledge of thunderstorm threats and avoidance measures
  - Provides details about the thunderstorm threats and avoidance measures
- Contributions show understanding of course 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 correctly identifies that developing and unexpected rain conditions leading to the storm cause the airplane to descend and crash. The student correctly identifies at least two hazards associated with flying close to thunderstorms. The student correctly assesses that the pilot should have diverted the storm area entirely, or waited out the storm before takeoff.

7-8 The student identifies that storm conditions caused the crash. The student gives only one possible hazard associated with thunderstorms and only one action the pilot could have taken to avoid the crash.

5-6 The student relates the storm with the crash. The student gives an incorrect or unsafe measure the pilot could have taken to avoid the crash. There are many gaps in understanding of the lesson objective.

0-4 The student gives an inadequate reason for the crash and is unable to explain how the crash could have been avoided. The student does not understand the lesson objectives.

GOING FURTHER

Slide 45: If time allows, students should complete the "Weather or Not: Thunderstorm Challenge," located at AOPA's "Thunderstorm Avoidance" webpage:

https://www.aopa.org/training-and-safety/air-safety-institute/safety-spotlights/thunderstorm-avoidance

This activity steps students through a scenario in which they must decide which actions to take to avoid thunderstorms and other potential hazards during a simulated flight. To begin, students will need to select the online course "Weather or Not: Thunderstorm Challenge," then the "Take the Course" box; if they haven't already done so, students will need to create a free account.

Once students are logged in, they should select "Begin Course" followed by "Start Scenario." Students may complete the activity individually or in small groups, or you may talk through each decision as a class.

Teaching Tips
Once logged into the course, the "Weather Strategy" option links to some excellent, detailed strategies and videos regarding thunderstorms and flight safety.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-Dimensional Learning

- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
    - Science and Engineering Practices
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.B: Developing Possible Solutions

- Crosscutting Concepts
    - Influence of Science, Engineering, and Technology on Society and the Natural World

COMMON CORE STATE STANDARDS

- **RST.9-10.2** - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.4** - Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.
- **WHST.9-10.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- **WHST.9-10.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

FAA AIRMAN CERTIFICATION STANDARDS

The applicant demonstrates understanding of:

- **PA.I.C.K2** Weather products and resources required for preflight planning, current and forecast weather for departure, en route, and arrival phases of flight.
- **PA.I.C.K3** Meteorology applicable to the departure, en route, alternate, and destination under VFR in Visual Meteorological Conditions (VMC) to include expected climate and hazardous conditions such as:
    - **PA.I.C.K3a** a. Atmospheric composition and stability
    - **PA.I.C.K3b** b. Wind (e.g., crosswind, tailwind, wind shear, mountain wave, etc.)
    - **PA.I.C.K3c** c. Temperature
    - **PA.I.C.K3d** d. Moisture/precipitation
    - **PA.I.C.K3e** e. Weather system formation, including air masses and fronts
    - **PA.I.C.K3f** f. Clouds
    - **PA.I.C.K3g** g. Turbulence
    - **PA.I.C.K3h** h. Thunderstorms and microbursts

REFERENCES

FAA PHAK Chapter 12–Weather Theory: https://www.faa.gov/regulations_policies/handbooks.../phak/.../14_phak_ch12.pdf

NWS—What is a Microburst: https://www.weather.gov/bmx/outreach_microbursts

Volatile Virga: https://www.aopa.org/news-and-media/all-news/2014/june/03/training-tip-volatile-virga

Weather Video Tip: Microbursts and wind shear: https://studentpilotnews.com/2017/09/06/weather-video-tip-microbursts-wind-shear/

Make Your Own Lightning: https://www.education.com/science-fair/article/make-your-lightning/