Aerodynamic Stalls

Session Time: Three, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The intended purpose and use of an aircraft drives aircraft design considerations and construction techniques, materials, and components. (EU1)

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 enables a pilot to fly the aircraft to its maximum capabilities in both normal and abnormal situations. (EU5)

ESSENTIAL QUESTIONS

1. What will make an airplane stop flying?
2. How does understanding stalls make a pilot safer?
3. What are the limits for an airfoil producing lift?

LEARNING GOALS

Students Will Know

- The definition of an aerodynamic stall
- The causes and effects of an aerodynamic stall on an aircraft
- The recovery process for an aerodynamic stall in an aircraft
- How an aircraft that is uncoordinated during a stall can enter a spin

Students Will Be Able To

- Analyze the causes and effects of aerodynamic stalls on an aircraft in flight. (DOK-L2)
- Describe how pilots recover from aerodynamic stalls. (DOK-L2)
- Analyze an airplane's design to determine if it has safe and predictable stall characteristics. (DOK-L2)
- Explain the causes and hazards of entering a spin in a fixed wing aircraft. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students watch a video of a model airplane flying a series of stalls and recoveries. Students will predict why the airplane behaved a certain way.

Formative Assessment
Students complete research and report on the stall characteristics of an assigned planform wing shape.

Summative Assessment
Through the creation of mini comic books, students will analyze what is happening to an airplane leading up to a stall, during the stall, and as the airplane recovers. Simultaneously, students will describe how pilots recognize a stall and then successfully correct the situation.

LESSON PREPARATION

MATERIALS/RESOURCES

- Aerodynamic Stalls Presentation
- Aerodynamic Stalls Student Activity 1
- Aerodynamic Stalls Student Activity 2
- Aerodynamic Stalls Student Activity 3
- Aerodynamic Stalls Teacher Notes 1
- Aerodynamic Stalls Teacher Notes 2

Adventures in Stalls Activity

- Markers and/or colored pencils
- Rolled paper or poster board (optional)

Flight Simulation Activity

- Flight simulation equipment

Recommended Student Reading

- **Pilot's Handbook of Aeronautical Knowledge**
  Chapter Five, Section on Stalls
  https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/07_phak_ch5.pdf

LESSON SUMMARY

Lesson 1: Theories of Lift
Lesson 2: Airfoils and Lift Production
Lesson 3: Calculating Lift
Lesson 4: Aerodynamic Stalls

In this lesson, students will learn what aerodynamic stalls are, the conditions that induce a stall, the impact of a stall on an aircraft in flight, and how a pilot in flight recovers a stalled airplane to normal conditions. To begin, students watch a video of a model airplane flying a series of stalls and recoveries. Students will predict why the airplane behaved a certain way.

During the next part of the lesson, students will learn about the critical angle of attack, what a stall is and different types of stalls. The teacher will show videos of aircraft experiencing a stall and the airflow disruption on an airfoil.

To conclude the first session, students will cover some of the tools and techniques designers use to build favorable stall characteristics into airplanes, and they will complete research and report on the stall characteristics of an assigned planform wing shape.

In the second session, students will be taught the various ways to recognize a stall in an airplane and the recovery procedure from an aerodynamic stall. The definition of a spin and how this can result from an uncoordinated stall will also be discussed. A simulator activity will reinforce students' knowledge of stalls, define 'accelerated stalls,' and let them experience ways to enter and recover from accelerated stalls.

To conclude the lesson, students will create mini comic books as a way to analyze what is happening to an airplane leading up to a stall, during the stall, and as the airplane recovers. Simultaneously, students will describe how pilots can recognize a stall and then successfully correct the situation.

BACKGROUND

Students have learned the theories associated with lift production and the relationship between angle of attack and the amount of lift produced by an airfoil. An aerodynamic stall results from a "rapid decrease in lift caused by the separation of airflow from the wing's surface, brought on by exceeding the critical angle of attack. A stall can occur at any pitch attitude or airspeed."

Airflow over an airfoil must be smooth in order to generate lift. When the airflow first strikes the wing, it is smooth and layered. This portion of the airflow is known as laminar. As the laminar flow is disrupted, it becomes turbulent. After the turbulent layer, the airflow separates from the surface over which it is flowing, called the separation point.This airflow separation produces high drag and ultimately destroys lift. Therefore, it is ideal to have as much laminar flow as possible over a greater surface of the wing, while the turbulent flow and separation points are pushed as far behind the leading edge as possible.

Students learned in the lesson on airfoils and lift production that five different factors affect the lift generated by an airfoil. These factors are airspeed, angle of attack, camber, air density, and wing area. However, the point at which the airfoil stalls is always when the critical angle of attack has been exceeded, irrespective of these factors. The critical angle of attack typically varies from 16° to 20°, depending on the design of the airfoil. Each airfoil has a unique critical angle of attack.

As an airplane stalls, the ailerons become less effective and the pilot may lose control of the roll axis. To regain control, the aircraft must be recovered from the stalled condition. Although it is not possible to prevent an airplane from experiencing an aerodynamic stall once the critical angle of attack is exceeded, the loss of control effectiveness and stalling characteristics can be mitigated. Manufacturers mitigate the onset or effects of aerodynamic stalls in a number of ways including wing washout, wing planform, wing camber and vortex generators.

A pilot must know how to recover an airplane from a stalled condition. An airplane stalls because its critical angle of attack has been exceeded, leading to airflow separation from the surface of the wing. Consequently, to recover from a stall, the angle of attack should be reduced in an effort to reattach the flow of air over the wing. If necessary, power should be increased to restore airspeed and controllability of the airplane.

This lesson also describes a stalled condition called a spin. A spin is a stall in which a side-to-side motion has been introduced resulting in an airplane descending in a helical, or corkscrew path. For a spin to occur, an airplane first has to be stalled and uncoordinated. This means that there is a yawing (side to side) movement at the time the airplane is stalled, resulting in one wing having a higher angle of attack than the other, which causes the downward corkscrew path. Typically, the wing on the outside of the turn is less stalled than the wing on the inside of the turn.

MISCONCEPTIONS

When discussing aerodynamic stalls, a common misconception is to assume an airplane's pitch attitude and its angle of attack are the same. The pitch attitude of an airplane is the angle between the airplane's longitudinal axis (imaginary line from the nose to the tail of the airplane) and the natural horizon (the line that separates the earth from the sky). The angle of attack is the angle between the chord line of the airfoil (wing) and the relative airflow.

It is also common to assume that when an airplane exceeds its critical angle of attack and stalls, it stops producing lift entirely. In fact, when an airplane exceeds its critical angle of attack, it still produces lift, but the amount of lift it generates rapidly deteriorates and is insufficient to support level flight.

Among new flight students and the non-flying public, stalls are often assumed to be related to an engine failure and not an aerodynamic phenomenon.

DIFFERENTIATION

For learners with low working memory, ask students to record and review their notes for the **EXPLORE** and **EXPLAIN** sections using a graphic organizer (e.g., table) to be able to recall this information more easily.

LEARNING PLAN

ENGAGE

Teacher Material: Aerodynamic Stalls Presentation

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

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

Warm-Up

Show students the video of a model airplane flying. Note the moment when the airplane's nose points up, pauses, then drops. While watching the video, prompt students to think about what they've previously learned about the lift equation and angle of attack.

- "What's Happening Here" (Length - 00:33) http://video.link/w/lmke

Ask students what they think happened to cause this behavior. Have them discuss the questions below with a partner and then have them share their answers with the class.

- Why did the nose drop?
- What made the airplane return to level flight?
- Do you know what this is called?
- Based on your observations can you keep increasing lift by increasing the angle of attack indefinitely?

Questions

The model stalled. The nose up attitude exceeded the wing's critical angle of attack, which caused the wing to produce less lift. Without enough lift to support the weight, the nose dropped. Once the nose dropped, the airplane accelerated, angle of attack was reduced, and the airplane resumed flying.

As students will learn in this lesson, a stall is a loss of lift caused by an aircraft exceeding its critical angle of attack. Stated more plainly, a stall happens when the wing gets pointed too high relative to the oncoming wind.

Although stalls are a predictable occurrence, pilots have stall-related accidents, some of them deadly, every year. . That's why students in this lesson will learn to recognize the conditions leading to a stall and the warning signs that a stall is imminent and where they are likely to encounter them.

Students will also learn the recovery steps to use should a stall occur.Students will learn that, with proper pilot training, stalls are a normal and predictable part of an aircraft's flight regime that can easily be avoided or handled.

EXPLORE

Teacher Material: [Aerodynamic Stalls Presentation]()

Slide 5: As students learned in the lesson on airfoils and lift production, there are two factors related to lift production that a pilot controls in every airplane, airspeed and angle of attack. At small angles, increasing the angle of attack results in more lift. At some point, that relationship breaks down and lift drops off sharply, even if the angle of attack continues to increase. The point where lift drops off is always at the same angle of attack for a particular aircraft because that angle is a fixed design feature of the airfoil.

The point at which the direct relationship between angle of attack and lift breaks down is called the critical angle of attack. When the wing exceeds the critical angle of attack, the aircraft is said to be stalled.

A stalled aircraft wing is still producing lift, just not as much as before the stall was reached and not enough to sustain level flight.

Slide 6: A stall is caused by the separation of the airflow from the wing's surface. As students will recall from Unit 3, the Coanda Effect describes the tendency for air to stick to the convex surface of a wing as it flows past. As the angle of attack increases, the flow separates from the surface of the wing, starting at the trailing edge. The separation progresses forward as angle of attack increases.

When the airflow first comes into contact with the leading edge of the airfoil, the flow is called laminar, and is smooth and layered. As it travels toward the trailing edge, the laminar flow is disrupted and becomes turbulent. Even farther toward the trailing edge, the turbulent flow detaches from the wing at the separation point. As the angle of attack increases, this separation point moves forward until lift eventually starts to decline, which is the beginning of the stall.

Use this video to demonstrate airfoils in a stall.

- "Airflow During a Stall" (Length 2:28)
  http://video.link/w/bSce

In the video(s), show students that when the strips of yarn are in the laminar flow, they look straight and hardly disturbed. The areas of the strips toward the trailing edges in both videos can be seen to move erratically. This is indicative of the turbulent flow prevalent toward the trailing edge of the wings. When the strips begin to move violently along the whole length of the wing (more pronounced near the wing root), it can be inferred that an increase in angle of attack has forced the turbulent layer to move further forward. As the angle of attack continues to increase and the turbulent air continues to move forward, the wing eventually stalls. This is immediately followed by a downward pitch as the pilot begins the recovery process. A reattachment of the laminar flow over the wing, shown when the strips stop moving erratically, indicates recovery from the stall.

Teaching Tips

Air next to the surface of a wing is called a boundary layer. The boundary layer is a result of the viscosity of the airflow over the wing.

EXPLAIN

Teacher Materials: Aerodynamic Stalls Presentation, Aerodynamic Stalls Teacher Notes 1
Student Material: Aerodynamic Stalls Student Activity 1

Slide 7: Stalls can be divided into two categories, normal and accelerated. As related to stalls, accelerated means experiencing a load in addition to the force of gravity. This occurs any time an aircraft is in a steep turn, or during a quick pull on the elevator as when recovering from a dive. This is important because additional load is experienced by the aircraft as more weight. As students will recall from the lesson on forces, there must be enough lift to offset the additional weight. That excess lift requires additional speed. If the speed is not available, the wing will reach the critical angle of attack and stall.

To avoid unintentional stalls, pilots need to be aware of the higher airspeeds required while experiencing a G load.

Watch this AOPA Air Safety Institute video showing the difference between a normal and accelerated stall. Ask students to closely watch the airspeed indicator on the top left side of the avionics panel. In a normal stall, the stall occurs at 70 knots and 1G. In the accelerated stall, the airplane stalls at 100 knots and 3.5Gs.

- "Normal Versus Accelerated Stall" (Length 00:50)
  http://video.link/w/epke

Slide 8: Everybody experiences load factor in everyday life. That little feeling of heaviness or lightness when an elevator starts and stops is load factor. So is that motion (pull and push) upward and downward when riding a roller coaster. When someone feels as if they are getting lifted out of their seat, that's called 'negative' load factor, because they are experiencing less than one gravity (G load). When they get to the bottom of the roller coaster and start upward again, they feel as if they are getting pushed down into their seat; that's positive load factor, because they feel as though they weigh more than normal. In other words, they are experiencing more than one "G."

Aircraft stall speed increases in proportion to the square root of the load factor. That means that a load factor of 4Gs will increase an unaccelerated stall speed of 50 mph to 100 mph (Accelerated Stall Speed = Unaccelerated Stall Speed X Square Root of Load Factor.)

Load factor increases quickly with increasing angle of bank. At 45 degrees, the load factor is 1.4Gs, 60 degrees 2Gs, 72 degrees 3Gs.

To look at it another way, the load factor is squared as the stall speed doubles, meaning that it is possible to put heavy loads on an aircraft by stalling it at a relatively high speed.

Watch this video showing the effect of load on stall speed. The explanation ties to the accelerated stall demonstrated in the video on the previous slide.

- "Load Factor and Accelerated Stalls" (Length 1:22)
  https://youtu.be/8SK7JqLRcAE

Slide 9: In order the keep airplanes safe and flyable, designers seek to make their stall characteristics safe and predictable. Among the desired characteristics that designers seek is the ability to maintain control, especially of the roll axis controlled by the ailerons, as far into the stall as possible. It's also an advantage to delay the stall as much as possible (meaning that the stall occurs at a slower airspeed) though this desire often comes into conflict with other goals, such as the aircraft being able to cruise at a certain airspeed.

The following slides will cover some of the tools and techniques designers use to build these characteristics into airplanes, which include wing washout, camber, vortex generators and planform.

Slide 10: As angle of attack increases, separation of the airflow from the wing begins at the trailing edge of the wing. When the ailerons, located on the trailing edges at or near the wing tips, encounter this separation, they lose effectiveness. The result is that the pilot can lose control over the roll of the aircraft as the aircraft stalls, causing a wing to drop, which in extreme cases could lead to entering a spin.

To avoid this situation, designers build a twist into the wing, known as washout. The forward tips of the wings are twisted down, so that they have a lower angle of attack than the wing root, near the fuselage. Because of this lower angle of attack, the tips of the wings will still have attached airflow, even when the wing root is stalled. This smooth airflow will help the ailerons maintain effectiveness on stall entry and allow the pilot to maintain control longer.

Show students the following video again. Ask students where the wing stalls first and explain why.

- "Airflow During a Stall" (Length 2:28)
  http://video.link/w/bSce

Slide 11: Camber, or curve of the wing, affects stall characteristics. Generally, a wing with more camber will have improved airflow about the wing, allowing it to maintain lift at higher angles of attack. The stall will also be more gradual, giving the pilot warning of the onset. The drawback of this design is that the extra camber produces more drag than a wing with less camber. The extra drag is not that much of a problem for slow aircraft, such as trainers, but for airplanes intended for high speed transportation, designers prefer wings with less camber, even though the stall characteristics of such wings tend to be more abrupt.

Just as washout can be used to delay a stall at the wing tip, camber can be increased along the span of the wing from root to tip to help keep the ailerons in smooth air and effective.

Slide 12: Vortex generators are small vanes attached to the leading edge of an airfoil. They are installed at an angle to the airflow so as to produce vortices that bring in fast moving air from the airstream to mix with the slow moving boundary layer air next to the wing. The purpose of the vortices is to delay separation of the air from the wing. Since a laminar flow is more likely to separate from the wing than turbulent flow, making the flow turbulent helps the airflow to stick to the wing, thus delaying the stall to a higher angle of attack and slower airspeed. Simply stated, vortex generators help airplanes fly at a slower speed.

Use this video further explain how vortex generators delay the onset of a stall.

- "How Do Vortex Generators Work?" (Length 4:51)
  http://video.link/w/2lde

Slide 13: Complete the **Formative Assessment.** Start the formative assessment during the end of session 1. Students will likely complete their work at the beginning of session 2.

Formative Assessment

Divide students into five groups and direct them to **Aerodynamic Stalls Student Activity 1.** Assign each group one of the five wing planforms in the activity. Each group will use the Internet to research its planform. Each group member should complete the table on the activity sheet for the assigned planform by filling in the columns for design characteristics of the wing shape, stall characteristics of the wing shape, and aircraft types that employ that particular wing planform.

Once the groups have completed their research, have each group present information about the planform it was assigned, giving the rest of the class the opportunity to complete the table for the other planforms on the activity
sheet.

[DOK L3; *formulate*, DOK L2; *explain*, DOK L1; *list*]

Slide 14: Except for training scenarios, where pilots practice stalls and are taught to recognize and respond to them, stalls are not considered a desirable occurrence. A stall is, after all, the aerodynamic point at which an airplane stops flying. Pilots are most likely to encounter stalls when they are flying slowly or when putting Gs on the aircraft in steep turns or dive recoveries. Since aircraft must slow down to land, landing patterns are high risk locations for inadvertent stalls.

Intentional stalls are a part of the standard training for all pilots and are easily handled. More problematic are stalls that catch pilots unaware. To help ensure that pilots aren't surprised by stalls, pilots are taught the naturally occurring warning signs, which are supplemented with devices manufacturers install to aide with stall awareness. These indicators can be used singly or in combination.

- Visual Cues
  - High pitch attitude - Most small airplanes do not have enough power to maintain a high pitch attitude for very long. A high pitch attitude is usually, though not always, indicative of a high angle of attack. PIlots should recognize that a high pitch attitude is likely to lead to a stall.
  - Angle of attack indicator - An instrument that measures angle of attack.
  - Low airspeed indicator - An airplane stalls due to reaching the critical angle of attack, which can occur at any airspeed. On the other hand, low airspeed indicates the likelihood of a stall.
- Aural Cues
  - Stall warning horn - Many airplanes have an audible horn that alerts the pilot when the airplane is approaching the critical angle of attack. This sound gives the pilot sufficient time to reduce the airplane's angle of attack before reaching the full stall.
  - Quieter air flow in low airspeed stalls - An airplane can stall at any airspeed as long as the critical angle of attack is exceeded. However, stalls most often occur at low airspeeds, and pilots are alerted to the approaching critical angle of attack by an obvious quietness in the airflow around the airplane.
- Kinesthetic Cues
  - Buffett - As an airplane approaches the critical angle of attack, airflow over the wings becomes turbulent. When this turbulent flow hits the horizontal stabilizer, the pilot feels the result as a buffet or shaking.
  - Stick shaker - Some manufacturers install a shaker that transmits a vibration to the stick or yoke at the approach of a stall.
  - Sticker pusher - a hydraulic or electro-mechanical device that pushes forward on the elevator control system whenever the aircraft's angle of attack reaches a pre-determined value.

Slide 15: The best way to deal with unintentional stalls is to ensure that they don't happen in the first place. That's why recognition is the first step. Pilots must be able to recognize that the aircraft is in a situation, such as takeoff and departure, that can lead to a stall, and then recognize specific cues should a stall develop.

An aircraft in a stalled condition isn't producing enough lift to stay airborne. It is not a hazardous condition as long as there is enough altitude to allow for the resulting descent and coordination is maintained with the rudder so that no yawing, or side-to-side motion is allowed to develop. Recognizing a stall early minimizes the chances of a spin and reduces altitude loss.

Stall recovery requires reducing the angle of attack. Following are the typical steps a pilot will take to recover from a stall. Individual aircraft and situations may have additional steps. Left alone, most aircraft will recover from a stall without pilot input, though perhaps with more altitude loss than is desirable.

- Reduce the angle of attack by lowering the pitch attitude.
- Add power to increase airspeed.
- Use the rudder to maintain coordination
- Reduce drag as necessary by raising flaps and landing gear

Show students the video of a recovery from a power off stall.

- "Power Off Stall" (Length 2:48)
  http://video.link/w/I6ke

Slide 16: Define the term *spin*: A spin is a stall resulting from a combination of a stall and a yawing (side to side) movement. This is sometimes referred to as an uncoordinated stall. In a spin, one wing is producing more lift than the other. The wing producing less lift drops and the other rises, causing the aircraft to rotate. This rotation results in a corkscrew-like motion as the aircraft descends on a nearly vertical flightpath. Emphasize to students that most general aviation aircraft will not enter a spin unless actively forced into one by aggressive pilot control inputs.

Identify the four stages of a spin and the characteristics of each stage.

- Entry phase: Pilot, intentionally or unintentionally, provides the necessary elements for the spin, including the stall as well as yaw.
- Incipient phase: This is the phase between the moment the airplane starts rotating to the when the spin fully develops. It takes about 2 to 4 turns of the airplane in this phase. The aerodynamic forces acting on the airplane in this stage are not yet stabilized. Airspeed is generally stabilized at a low and constant level.
- Developed phase: Airplane's angular rate of rotation, airspeed, and vertical speed have achieved balance and the flight path of the airplane is nearly vertical. In small airplanes, for each 3-second turn, the airplane loses approximately 500 ft in altitude. It is expected that the airplane will continue in this state unless corrective action by the pilot is taken.
- Recovery phase: Corrective action by the pilot in this phase results in stopping the rotation and decreasing the angle of attack. Depending on the airplane, this phase could last from one-quarter of a turn to several turns.
- The most common actions for a pilot to recover from a spin are reducing the engine power to idle, neutralizing the ailerons, applying full opposite rudder against the rotation, and moving the controls forward to reduce the angle of attack. Once the rotation stops, the rudder is neutralized, the pitch is smoothly returned to a normal flight attitude, and power is added to maintain or regain altitude.

Slide 17: Use these videos to demonstrate spins and spin recovery.

- "Condor Simulations of a Glider in a Spin - External View" (Length 0:30)
  http://video.link/w/QRce

- Video 2 = pilot view (Length 1:16)
  http://video.link/w/VRce

- Cessna 152 Multiple Spins Recovery (Length 1:30)
  http://video.link/w/WRce

EXTEND

Teacher Materials: Aerodynamic Stalls Presentation, Aerodynamic Stalls Teacher Notes 2
Student Material: 10_IntroductionToFlight_4_B_4_AerodynamicStalls_StudentActivity2

Slide 18: Students will complete Aerodynamic Stalls Student Activity 2 by first answering comprehension questions related to accelerated stalls, their cause, and how to recover from them. Teachers should lead a class discussion to ensure students understand all questions prior to beginning the simulation activity. Answers to the questions can be found on **Aerodynamic Stalls Teacher Notes 2.**

Simulator Extension Powered by Redbird

Once the comprehension check is complete, pair the students in crews of two and move to the simulators. Instructions are provided in the student activity and teacher notes documents for how to configure the simulator and complete the demonstration. Each crewmember should work through the demonstration and then compare their observations. Finally, students will work individually to write a response to the thought questions at the end of the activity.

This will complete the second session.

EVALUATE

Teacher Material: Aerodynamic Stalls Presentation
Student Material: Aerodynamic Stalls Student Activity 3

Slides 19-22: Review private pilot practice test questions with the students.

Slide 23: Conduct the **Summative Assessment.**

Summative Assessment

In small groups, students will create mini comic books to illustrate the causes and effects of an aerodynamic stall on
an airplane and the recovery procedure. By completing this assessment, students will analyze what is happening to
an airplane leading up to a stall, during the stall, and as the airplane recovers. Simultaneously, students will
describe how pilots recognize a stall and then successfully correct the situation. Students will choose a

character(s), an airplane, a background, and compose illustrations and related dialogue in order to communicate
the following:

- A scenario that could lead to a stall (e.g. pilot is in the traffic pattern and increases the angle of attack
while trying to maintain pattern altitude, and the airspeed slows)
- What is happening to the airflow over the wings as the airplane nears the stall (e.g. airflow becomes
turbulent as the airplane nears the critical angle of attack)
- When and how a stall occurs (e.g. reaches the critical angle of attack, wings stop flying)
- What the pilot hears, feels and sees to identify the stall
- The recovery procedure and why recognizing a stall early is important
- What happens to the airflow as the wings start to fly again

In addition to dialogue, students should use illustration to depict important concepts like angle of attack, pitch
attitude, laminar and turbulent airflow, airspeed and pilot recovery techniques.

Provide students Aerodynamic Stalls Student Activity 3. Students can use the comic strip planning tool included in the activity to draft and revise their story. Students can draw their books using the comic book panels
provided in the activity, or they can use rolled paper or poster board. Teachers may want to offer students the
opportunity to use a free online comic book creator, such as ToonDoo, to create their comics.

If time allows, hang the student's comics around the room and allow each group to present its creation to the class.

Summative Assessment Scoring Rubric

- Student follows instructions
- Creates a mini comic book that displays their understanding of stalls and stall recovery
    - Accurately describes the role of airspeed and angle of attack as they relate to aerodynamic stalls
    - Describes how airflow transitions from laminar to turbulent leading up to a stall
    - Accurately describes the critical angle of attack
    - Thoroughly describes how a pilot can recognize a stall
    - Provides practical instructions and explanation for a stall recovery
- Answers show understanding of the concepts covered in the lesson
- Answers show in-depth thinking, including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 Provides accurate and complete explanations and illustrations of all required information. I nformation is very organized with well-constructed captions and dialogue. Illustrations add to the reader's understanding of the topic.

7-8 Provides nearly all of the required information. Dialogue and illustrations are mostly accurate and information is presented in a logical manner. Most illustrations add to the reader's understanding of the topic.

5-6 Provides most of the required information. Information is organized, but captions and dialogue are not well constructed. Some of the illustrations clearly add to the reader's understanding of the topic.

0-4 Large amounts of information are missing. The information is disorganized and images are not helpful to the reader's understanding of the topic.

[DOK L4; *Create*, *Connect,* DOK L3; *Explain,* DOK L2; *Summarize*]

STANDARDS ALIGNMENT

NGSS STANDARDS

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS2-3** - Apply scientific and engineering ideas to design, evaluate and refine a device that minimizes the force on a macroscopic object during a collision.
    - Science and Engineering Practices
        - Constructing explanations and Designing Solutions
    - Disciplinary Core Ideas
        - PS2.A Forces and Motion
    - Crosscutting Concepts
        - Cause and Effect
- **HS-ETS1-2** - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering
    - Science and Engineering Practices
        - Asking Questions and Defining Problems
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.A: Defining and Delimiting Engineering Problems
    - Crosscutting Concepts
        - None

- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
    - Science and Engineering Practices
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.B: Developing Possible Solutions
    - Crosscutting Concepts
        - None

COMMON CORE STATE STANDARDS

- **RST.9-10.1 -** Cite specific textual evidence to support analysis of science and technical texts attending to the precise details of explanations and descriptions.
- **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.
- **SL.9-10.2 -** Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source.
- **SL.9-10.4 -** Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task.
- **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.

REFERENCES

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