Stability in Aircraft Design

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. How does the stability or instability of an aircraft affect the way it flies?
2. How does aircraft design impact stability in flight?
3. What are the tradeoffs between stability and maneuverability?

LEARNING GOALS

Students Will Know

- Different types of aircraft stability
- Design features that contribute to aircraft stability
- How the weight and balance of an aircraft affect stability

Students Will Be Able To

- *Distinguish* between positive, neutral, and negative static and dynamic stability characteristics. (DOK-L2)
- *Describe* design factors that can be altered to affect stability. (DOK-L2)
- *Explain* the effects of aft versus forward center of gravity on aircraft stability and control. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Use “popcorn” or another teaching method to have students call out various types of vehicles or objects that have different levels of stability and discuss what the characteristics are that lead to stability versus instability.

Formative Assessment

Students apply their knowledge of aircraft stability and design features to identify the type of stability issues that are encountered with two different aircraft designs. Students must choose the design features best suited to the given mission and explain their reasoning for each choice.

Summative Assessment
Students will first identify and explain various terminology and other features relevant to aircraft stability. Then students will read about a new aircraft design and identify the type of stability it exhibits and propose design alterations to improve stability.

LESSON PREPARATION

MATERIALS/RESOURCES

- Stability in Aircraft Design Presentation
- Stability in Aircraft Design Student Activity 1
- Stability in Aircraft Design Student Activity 2
- Stability in Aircraft Design Student Activity 3
- Stability in Aircraft Design Student Activity 4
- Stability in Aircraft Design Teacher Notes 1
- Stability in Aircraft Design Teacher Notes 2
- Stability in Aircraft Design Teacher Notes 3
- Stability in Aircraft Design Teacher Notes 4

Stability In Action Activity (Per Pair)

- Marble
- Bowl with a rounded bottom and curved sides (the bowl should not have a lip on bottom of the outside surface)
- A key with a hole in the top
- A 10-inch length of string

Recommended Student Reading

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

LESSON SUMMARY

Lesson 1 - Stability in Aircraft Design
Lesson 2 - Rotorcraft Lift and Stability

This three-session lesson will begin by asking students to brainstorm types of vehicles and answer questions about their stability and instability. This warm-up will lead to a definition of aerodynamic stability.

During the next part of the lesson, students will be introduced to the various types of stability, including positive, neutral, and negative as well as static and dynamic. Students will also complete several activities in which they use everyday objects such as a marble and a pendulum to model aircraft stability.

In the second session, students will consider how stability affects aircraft movement around the three axes of flight. They will distinguish between stability and maneuverability and consider how these two goals are often opposed. S tudents will also learn how different aircraft design features can affect aircraft stability. They will then apply that knowledge to identify the type of stability issues encountered with two different aircraft designs. Students must choose the design features best suited to the given mission and explain their reasoning for each choice. This formative assessment will likely continue into the third session.

During the third session, students will work with a partner and apply what they have learned about stability to work through several scenarios in a flight simulator. Finally, they will complete a summative assessment in which they identify and explain various terminology and other features relevant to aircraft stability. Then students will read about a new aircraft design and identify the type of stability it exhibits and propose design alterations to improve stability.

BACKGROUND

Students have already learned principles of basic aerodynamics relevant to flight, and they should understand how the various control surfaces of a fixed-wing aircraft control the three axes of flight (lateral, longitudinal, vertical). In this lesson, students will learn how engineers and aircraft designers apply basic aerodynamic principles when designing for stability and maneuverability, two important factors in flight utility and safety.

Aerodynamic stability is defined as the tendency of an aircraft to return to its original flight path when disrupted or upset by pilot inputs or by outside forces, such as turbulence or wind. Stability is a factor around all three axes that an airplane can move: roll, pitch and yaw. Roll stability refers to the aircraft's stability around the longitudinal axis, which is controlled by the ailerons. Pitch stability refers to stability around the lateral axis, which is controlled by the elevator. Yaw stability refers to stability around the vertical axis, which is controlled by the rudder.

There are two main kinds of stability: static stability refers to the initial reaction of an aircraft when displaced from its normal flight path; dynamic stability refers to the ongoing behavior of the displaced aircraft over time. Both static and dynamic stability may be described as positive, neutral, or negative, depending on the direction of movement relative to the aircraft's original attitude. Stability can be displayed around all three axes of flight: roll, pitch, and yaw. Aircraft are designed to provide the desired amount of stability around each of these axes. Because there is a tradeoff between stability and maneuverability, which is the speed at which an airplane can change the rates of its roll, pitch, and yaw, the desired amount of stability for a given aircraft depends on its mission. Highly maneuverable aircraft, such as fighter jets, tend to be less stable because their priority is to maneuver quickly. On the other hand, airliners and most civil airplanes are designed to be more stable to add to flight safety, ease of control, and passenger comfort.

Both static and dynamic stability are affected by the location of an aircraft's center of gravity (CG). During flight testing for initial certification of an aircraft design, much time and effort is spent establishing that design's fore and aft CG limits; these limits are based largely on the stability of the aircraft when it is loaded with various CG locations. For most certified civil airplanes, it is critical for the airplane to remain both statically and dynamically stable throughout the allowable CG range. Problems often occur when airplanes are loaded outside those limits (often due to fuel or cargo imbalance), a practice that should be avoided by all pilots and operators everywhere. Pilots' and passengers' lives literally depend on the accurate and precise calculating of weight and balance each time an aircraft is flown.

MISCONCEPTIONS

A common misperception is that pilots have to constantly manipulate the controls to fly an airplane. If that were true, pilots would quickly become exhausted. Good piloting technique actually takes advantage of the natural stability of the aircraft to make flying easier and smoother. With proper use of trim, much flying can be done with minimal control inputs using only fingertip pressure, even in aircraft without an autopilot. Stability is what makes that possible.

DIFFERENTIATION

To promote reflective thinking and guided inquiry in the **ENGAGE** section of the lesson plan, ask students if they think it's a good idea to design airplanes that can return to normal flight on their own, without pilot interference, when disturbed from their flight path by turbulence or abrupt movement of the controls. Are there types of airplanes where this would be a bad idea?

To support student comprehension in the **EXPLORE** section, allow students to manipulate model airplanes and demonstrate what happens physically during recovery oscillations in aircraft with positive stability. This strategy provides students with support in any sensory integration needs they may have, but also allows them to focus on the acquisition of new information.

LEARNING PLAN

ENGAGE

Teacher Material: Stability in Aircraft Design Presentation
Slides 1-3: Introduce the topic and learning objectives of the lesson.
Slide 4: Conduct the **Warm-Up.**

Warm-Up

Using a "popcorn" strategy, invite students to call out various types of vehicles or other objects that have different levels of stability (e.g., unicycle, bicycle, motor vehicle, upside-down pyramids, people). Use students' ideas and guiding questions to conduct a class discussion of the characteristics that promote stability or instability.

- Thinking back to previous lessons, what is center of gravity (CG)?
  The center of gravity is the point at which an object (the aircraft) would balance on a fulcrum.
- Do all objects have a center of gravity (CG)?
  Yes, all objects with mass have a center of mass, also called CG.
- How does one change an object's CG?
  CG can be changed in either of two ways:
  - *Add or subtract weight from a part of the object. For example, adding a rider to a bicycle will change the bike's CG, as would removing the seat or handlebars.*
  - *Move weight from one part of the object to another part. For example, the CG would move forward if a bike rider leaned forward over the handlebars while riding.*
- What characteristics make objects more or less stable than others?
  The position of the center of gravity of an object affects its stability. The lower the center of gravity, the more stable the object (a racecar). The higher the CG, the more likely the object is to topple over if it is pushed (a semi truck). Increasing the area of the base will also increase the stability of an object. Rugby players will stand with their feet well apart if they expect to be tackled.

EXPLORE

Teacher Materials: Stability in Aircraft Design Presentation, Stability in Aircraft Design Teacher Notes 1
Student Material: Stability in Aircraft Design Student Activity 1

Slide 5: Aerodynamic stability is the tendency of an aircraft to return to a condition of equilibrium (or steady flight) after being displaced by an outside force (e.g. wind, turbulence) or by pilot control input. An aircraft that is more stable has a greater tendency to return to its original attitude following a disturbance.

Stability contributes to aircraft safety. A stable aircraft is easier to fly and reduces pilot fatigue during climbs, descents, in turns, and at both high and low airspeeds. An aircraft's stability also affects its ability to recover from conditions that could lead to stalls and spins. An aircraft that is considered stable will require less effort to control.

Most aircraft, such as training aircraft, are designed with a high degree of stability as a goal, but that's not always the case. Some aircraft, such as certain military aircraft have been intentionally designed to be unstable, because instability makes them more maneuverable; for these aircraft, maximizing maneuverability is more important than maximizing safety. Fighter jets tend to be very unstable, and can even be unflyable without the help of computer-controlled fly-by-wire systems.

Slide 6: There are several different kinds of stability relevant to aircraft. The kind of stability that a particular aircraft has is determined by the motion of the aircraft after it is displaced.

- Stability can be static or dynamic
- Within each of those categories, stability can be positive, neutral, or negative.

Describing an aircraft as positively, neutrally, or negatively stable, or its stability as static or dynamic, conveys more specific information than simply saying that the aircraft is stable or unstable.

Slide 7: Positive stability is the tendency of an object to return to its original attitude when displaced.

For example, imagine an airplane in straight and level flight; the pilot pulls back sharply on the controls, causing the airplane to pitch upward, then releases the controls. A positively stable airplane will return to straight and level flight without any pilot input. In other words, the aerodynamic forces on the airplane will correct the airplane's attitude without the pilot's intervention.

Imagine a ball at the bottom of a slope; if you move the ball up the slope and then release it, the ball will roll back to its original position at the bottom.

Slide 8: Negative stability is the tendency of an object to move farther away from its original attitude when displaced.

For example, imagine an airplane in straight and level flight; the pilot pulls back sharply on the controls, causing the airplane to pitch upward, then releases the controls. A negatively stable airplane will continue to pitch up at ever increasing angles, never making any motion back toward its original orientation. In practice, negatively stable airplanes are uncontrollable by pilot input alone.

Imagine a ball at the top of a slope; if you push the ball even a bit down the slope, the ball will continue rolling—and picking up speed—in that direction.

Slide 9: Neutral stability happens when there is no movement either toward or away from the direction of displacement.

For example, imagine an airplane in straight and level flight; the pilot pulls back sharply on the controls, causing the airplane to pitch upward, then releases the controls. A neutrally stable airplane will remain at this attitude in the absence of additional pilot input (or some other disturbance).

Slide 10: Static stability refers to the *initial* tendency of an aircraft to return to its original position when it's disturbed. Static stability can be positive, neutral, or negative. For each of the following descriptions, imagine an airplane that has been disturbed in an upward direction—i.e., its attitude has changed from straight and level to nose-up.

If the airplane exhibits positive static stability, the first motion of the airplane will be to pitch down, back toward its original attitude. All positively stable aircraft exhibit positive static stability.

If the airplane exhibits neutral static stability, the aircraft will have a tendency to remain in the newly commanded attitude. For example, an airplane is put into a turn and the pilot lets go of the controls and the aircraft remains in that turn. The bank angle of the turn neither increases nor decreases.

If the airplane exhibits negative static stability, the first motion of the airplane will be to continue pitching upward, away from its original attitude. For example, if an aircraft is rolled to a high bank angle, letting go of the controls results in the aircraft continuing to roll further.

Slide 11: Dynamic stability refers to the tendency of the aircraft's ongoing (continuing) motion *over time*. As with static stability, dynamic stability can be positive, neutral, or negative.

It is important to underscore to students that an aircraft must have positive static stability before it can have any type of dynamic stability. In other words, an airplane that is statically stable, will have some form of oscillatory behavior (dynamic stability). The amplitude of the oscillations determine if it has positive, negative or neutral dynamic stability.

If an airplane exhibits positive dynamic stability, it will move through a series of “dampening” oscillations and eventually return to its original flight path; no input is necessary from the pilot. For example, imagine a skateboard on a halfpipe. The skateboard is neutrally stable when resting at the bottom of the halfpipe. If the skateboard is pulled up one side (displaced) and then released, it will move back down toward the neutral point, pass through it, and travel a similar distance up the other side of the half-tube; the skateboard will then reverse itself and move back through the neutral point. The cycle will then repeat—each time the skateboard will move a smaller distance up the halfpipe, a process called *dampening*—until the skateboard expends all its energy, returns to the neutral point, and stops.

If an airplane exhibits neutral dynamic stability, the oscillations will continue with no dampening—i.e., they will not reduce in frequency or amplitude over time. To return to the example of a skateboard on a halfpipe, if the skateboard had neutral dynamic stability it would continue moving back and forth along the halfpipe without stopping. Each movement up a side of the halfpipe would be the same distance. (Of course, on Earth a skateboard will not behave in this way, because it will always lose energy to gravity and friction.)

If an airplane exhibits negative dynamic stability, its movement away from the neutral point becomes greater with each oscillation. Left to itself, an airplane that was pitched up and then released would pitch down, then up, with increasingly large oscillations indefinitely. To return again to the skateboard, the distance it would travel up the halfpipe would increase with each cycle, moving farther and farther away from the neutral point over time. (Again, a skateboard on Earth could not behave in this way without receiving energy from an external source.)

Slide 12: Most civil (non-military) aircraft display positive static and positive dynamic stability, for several reasons:

- Positively stable aircraft are safer in the event of an upset.
- They are easier for pilots to control.
- They provide greater comfort for passengers.

Remind students that for there to be positive dynamic stability, there must first be positive static stability. Remember that static stability is the *first* motion after displacement, while dynamic stability is the motion of the aircraft over time (oscillations). It is impossible to have positive dynamic stability unless the first movement is also positive.

Slide 13: Students will complete exercises that require them to apply their understanding of stability using models to represent aircraft. Divide students into pairs and have each pair complete **Stability in Aircraft Design Student Activity 1**. Each pair will require a marble, a bowl, a key and a 10-inch length of string. The activity contains three parts. In each part one student should manipulate the marble or key and the other student should record answers to each question on the activity sheet. The exercises in this activity do not have to be completed in any particular order. Students can share supplies or rotate to stations, if necessary.

Sample answers are located in **Stability in Aircraft Design Teacher Notes 1**.

This activity will likely conclude the first session of this lesson.

EXPLAIN

Teacher Materials: Stability in Aircraft Design Presentation, Stability in Aircraft Design Teacher Notes 2
Student Material: Stability in Aircraft Design Student Activity 2

Slide 14: Students learned in the ninth grade courses that an airplane moves in a different way around each of its three axes:

- It pitches (moves its nose up and down) around its lateral axis, which runs from wingtip to wingtip.
- It rolls (tilts left and right) around its longitudinal axis, which runs horizontally through the center of the plane.
- It yaws (rotates left and right) around its vertical axis, which runs vertically through the center of the plane.

Engineers design an aircraft to achieve the amount of stability around each axis that is necessary to achieve the aircraft’s mission. Different parts affect stability in different ways.

Teaching Tips

Have students stand up and demonstrate pitch, roll and yaw. Instruct them to put their arms (“wings”) out to their sides and make a “T” shape.

To demonstrate “roll” - students stand with the feet planted and arms outstretched, then ask students to “tilt” their bodies at the waist to the left, keeping their right arm high and their left arm low. “Roll” back and have students “tilt” their bodies as the waist to the right but keeping their right arm low and left arm high.

To demonstrate “pitch” - students bend forward and then backwards at the waist while keeping their head upright and arms outstretched.

To demonstrate “yaw” - Have students stand with their feet planted and arms outstretched, then ask students to “twist” at the waist to the left and then to the right.

Slide 15: A pilot’s ability to control an aircraft’s pitch (its movement about the lateral axis) is very important. Of all three axes, pitch stability is also considered to be the most affected by variables introduced by the pilot, such as airplane loading and resultant CG.

Pitch stability is dependent on three factors: location of the wing with respect to the CG, location of the horizontal tail surfaces with respect to the CG, and size of the tail surfaces.

Consider a scenario in which an airplane is pitched upward by turbulence and the pilot does not take corrective action with the controls. As its pitch attitude increases, the airplane slows, passing less air over its lifting surfaces, which creates less lift. As lift decreases, the nose begins to change direction and tilt downward; eventually, the plane will have pitched down sufficiently to begin accelerating again. As the airplane speeds up, the lifting surfaces begin producing more lift, which pitches the nose back upward again. Each cycle in this series of climbs and descents (oscillations) gets smaller (i.e., there is less change in altitude), as energy is lost to friction and other forms of drag. Eventually, the airplane returns to its original orientation of level flight.

Slide 16: As students learned in the lesson on weight and balance, aircraft are designed to operate within a specific CG range; loading an aircraft so that its CG falls outside the intended range can make the aircraft unstable, resulting in seriouseven deadly—loss of control. Recall the video of the fatal crash of the Boeing 747 that had been improperly loaded. This video is of a similar incident in a Navy C-2 Greyhound that experienced a cargo shift on takeoff.

- “Navy C-2 Greyhound Crash” (Length 00:35)
  http://video.link/w/Il4e

Questions

After watching the video, ask students to explain what happened to the plane in terms of stability.

When the cargo weight shifted to its tail, the plane became unstable. As it took off, its stability became negative, resulting in a pitch up, stall and crash.

Slide 17: Both static and dynamic stability are affected by the location of an aircraft's CG. During flight testing when designing an aircraft, much time and effort is spent establishing that design's forward and aft CG limits. For most certified civil airplanes, it is critical that the plane remain both statically and dynamically stable throughout the allowable CG range.

Aircraft loaded toward the forward CG limit will exhibit greater stability than those loaded aft. This is due largely to the amount of downward force applied to the horizontal stabilizer to maintain level flight. In conventional aircraft, the center of lift is always behind the center of gravity, causing a torquing moment that pushes the tail upward. The downward force imposed on the horizontal stabilizer opposes this torque, contributing to stability around the pitch axis.

If displaced up, an aircraft loaded with a forward CG will have a tendency to pitch downward (static stability). An aircraft with a forward CG will begin its up and down oscillations more quickly, and the upward movements will dampen more quickly, due to the tendency of the nose to pitch down.

An aircraft loaded with a forward CG will also return to its original flight path with fewer oscillations, thus making it more dynamically stable. However, if the airplane is loaded with a CG outside the forward limit (i.e., too far forward), it may be impossible to pitch the nose sufficiently up when flaring to establish the proper landing attitude. This could result in the nose gear striking the runway first, which could damage the gear and potentially the propellers and engine.

Conversely, aircraft loaded with an aft (rearward) CG are less stable as the center of gravity moves closer to the center of lift. There is less tendency to pitch downward when displaced, which slows the recovery process. With an aft CG, the oscillations may display a longer wavelength (i.e., there is greater distance between the peaks of each oscillation) and greater amplitude (i.e., there is greater distance between the trough and peak of each oscillation).

Aft CGs are normally thought of as more dangerous, especially in the event of a stall. With an aft CG, should an aerodynamic stall occur, it may be impossible to push the nose down (i.e., decrease the angle of attack). Many fatal loss of control accidents have occured due to aircraft being loaded outside the aft CG limits, typically due to either fuel or cargo imbalance.

Slide 18: Positive stability around the longitudinal axis is achieved by the action of the wings—specifically, the design of the wings or the manner in which the wings are attached to the fuselage.

Many civil aircraft have their wings attached in such a manner as to create an upward tilt from the fuselage to the wingtips. To a person standing in front of such an airplane, viewing it head-on, the wings will appear to form a shallow "V' shape, with the fuselage at the base of the V. This upward tilt of the wings, called *dihedral*, is a major factor in roll stability.

When an airplane's roll axis is displaced during flight (one wing lowers and the other rises), dihedral will tend to lift the lower wing and bring the airplane back to wings-level flight by slightly changing the angle of attack on both wings.

In wings-level flight, dihedral causes both wings to attack the air at a slightly less than optimal angle. When a wing dips due to turbulence or pilot input, the angle of attack on that lowered wing increases slightly, and the angle of attack on the higher wing decreases by a similar amount. The increased angle of attack on the lower wing creates a little more lift on that surface, picking the wing back up toward a wings-level attitude. At the same time, the decreased angle of attack on the higher wing causes that wing to dip back toward wings-level flight, creating two sources of changing lift vectors and resulting in roll stability.

Slide 19: Some aircraft, such as commercial airliners and fighter jets, use swept wings instead of dihedral to foster positive stability around the roll axis. When a disturbance causes an aircraft with sweepback to drop a wing, the low wing presents its leading edge at an angle that is more perpendicular to the relative airflow. As a result, the the low wing acquires more lift, rises, and the aircraft is restored to its original flight attitude.

The placement of the wings on the fuselage also affects roll stability. Absent other factors, a high-wing airplane has greater roll stability than a low-wing airplane, due to the weight of the airplane being suspended below the wings and acting like a pendulum to correct any upset.

Slide 20: Positive yaw stability is largely the result of the vertical stabilizer (fin) providing a “feathering” effect.

When the pressure on both sides of the vertical stabilizer is the same, the aircraft flies straight (absent any other forces). Any yawing that takes place, on one side of the fin or the other, is countered by the opposite side pushing back and re-establishing directionally stable flight.

For example, as the vertical stabilizer moves right in an upset, the nose of the plane yaws to the left, with the pivot point being the center of gravity. This yawing motion exposes more of the right side of the fin to the slipstream, pushing the tail to the left and pivoting (yawing) the nose back right until the plane is again flying straight ahead; the vertical fin thus functions like the feathers on the tail of an arrow.

Slide 21: The placement of an aircraft’s engine affects pitch stability. For instance, in airplanes with the engine mounted below the center of gravity, adding power will cause the nose to pitch up and reducing power will cause the nose to pitch down.

In multi-engine aircraft, engine placement also affects yaw stability. With two engines mounted on opposite wings, the thrust of each engine balances the other in flight. If, however, one of the engines fails in flight, that balance is lost. As the good engine continues to create thrust, the airplane will yaw and roll in the direction of the dead engine, severely affecting stability around the longitudinal axis. Engineers may minimize the effect of this “asymmetric thrust” by placing the engines as close together (near the fuselage) as possible.

Slide 22: Stabilizers on the tail also affect both pitch and yaw stability.

Horizontal stabilizers provide the downward force on the tail to keep the aircraft’s nose up in flight. Engineers design horizontal stabilizers to provide just enough downward force to counterbalance the nose down tendency generated by the center of gravity.

Horizontal stabilizers that are too big will create too much drag or excessive down force; stabilizers that are too small will not provide enough down force, during a downward oscillation, to assist the wings in getting the nose back up. Either extreme will negatively affect stability.

Absent other factors, however, larger horizontal stabilizers provide more stability, as the increased area provides a larger stabilizing force.

Vertical stabilizers create the left-right yawing force that keeps the airplane flying straight or returns it to straight flight after an upset. Vertical stabilizers are also the attach points for the rudders, control surfaces that counter adverse yaw and give pilots an important tool when taking off or landing in crosswinds.

Like horizontal stabilizers, vertical stabilizers are designed to provide sufficient force to keep the aircraft flying straight without adding excessive weight or drag. If too small, the vertical stabilizer may be slow to correct an upset yaw condition. If too big, it may create too much drag and needless added weight.

Aircraft design is always a balancing act, creating just enough of one force to be effective without causing additional challenges elsewhere.

Slide 23: While stability in an aircraft is always an important consideration, maneuverability is also important — particularly if the aircraft is designed for specific purposes. Maneuverability describes an aircraft’s ability to change direction—it is the speed at which the airplane can change the rates of its roll, pitch, and yaw. The faster the airplane can change the orientation of these axes, the more maneuverable it is.

The ideal aircraft would turn instantly and climb or descend at lightning speed, while remaining safe and easy for a pilot to control, but real-world considerations (such as the laws of physics) won’t allow this. Instead, engineers determine how much maneuverability is required for an aircraft’s intended purpose, and then build this consideration into the design.

Both stability and maneuverability are influenced by wing design. Long wings provide stability around the roll axis, but they are slow and require more control input, making them difficult to bank (i.e., less maneuverable). Short wings can produce faster roll rates, but they have less stability (i.e., they are easily upset and potentially require pilot intervention in high winds and turbulence).

Slide 24: Airframe design also is important to stability and maneuverability.

Placing the horizontal and vertical stabilizers a large distance from the center of gravity tends to make the aircraft more stable and easier to control due to the added leverage applied across a longer distance. Conversely, placing the stabilizers closer to the center of gravity makes the controls more responsive (i.e., more maneuverable); however, the aircraft becomes less stable.

An airplane's center of gravity also affects it maneuverability.

An aft CG lessens the control force required to pitch up but requires additional force to pitch down. An aft CG also decreases the rudder force required to yaw the aircraft, improving lateral maneuverability. CG location has a negligible effect on roll rate.

A forward CG requires greater control force to yaw the aircraft, reducing lateral maneuverability. A forward CG also lessens the control force required to pitch down but requires additional force to pitch up.

Slide 25: Some advanced, mission-specific aircraft are so inherently unstable (e.g., B-2 Stealth Bomber, F-117 fighter) that it is impossible for the pilot to control them using conventional methods.

The stability of these aircraft relies on computers that quickly process data and respond to atmospheric conditions and adverse motion. The pilot still has the ability to control the aircraft, but pilot inputs pass through a computer that augments those inputs based on atmospheric conditions and other variables to determine proper control deflection.

Other advanced aircraft utilize multiple primary control surfaces (in addition to the standard configuration of ailerons, elevators, and rudders) to enhance both their controllability and stability.

Slide 26: As students have seen, stability can be thought of as an airplane's ability to self-correct when displaced from a flightpath, and it is affected by several aspects of aircraft design. Like a tightrope walker, the designer must balance multiple factors—including weight, drag, cost, overall efficiency, and performance—to achieve a practical and effective aircraft.

One of the factors in aircraft design is stability itself. Although students might assume that every aircraft should be positively stable, that isn't necessarily true. Some aircraft, such as aerobatic and fighter aircraft, must be neutrally stable to achieve their intended use. Stability must be traded off with maneuverability, as these two factors often work in opposition to each other. Often, the more stable the aircraft, the less maneuverable it is, and vice versa.

The intended use of the aircraft drives many of the design decisions. Where safety is the primary concern, airplane designers typically engineer the wings, fuselage, and stabilizers to maximize stability while minimizing weight and drag.

There is no aircraft design that will perform perfectly for every purpose. That is why engineers carefully tailor their designs to meet the demands of a specific purpose or mission.

- For large transport aircraft, stability, power, and efficiency tend to be dominant requirements.
- Small training aircraft need to be stable, easy to fly, and fuel efficient.
- Military combat aircraft must fly fast, "turn on a dime," and deliver a payload; these requirements prioritize maneuverability and speed.

Slide 27: Complete the **Formative Assessment**.

This assessment will likely conclude session 2 of this lesson and may extend into session 3.

Formative Assessment

Divide students into pairs and instruct each team to complete **Stability in Aircraft Design Student Activity 2**, which consists of a series of questions that will guide students to use their knowledge of aircraft stability and design features to help their team identify the type of stability issues that are encountered and potential solutions to the design of an airplane that can complete a specific mission. Students must choose the design features best suited to the given mission and explain their reasoning for each choice. Remind students that all aircraft designs must make trade-offs, balancing competing priorities in order to make the best aircraft for a particular mission.

Sample answers are located in **Stability in Aircraft Design Teacher Notes 2**.

[DOK 4; *apply concepts, DOK 2 explain*]

EXTEND

Teacher Materials: Stability in Aircraft Design Presentation, Stability in Aircraft Design Teacher Notes 3
Student Material: Stability in Aircraft Design Student Activity 3

Slide 28: Use a flight simulator to complete Stability in Aircraft Design Student Activity 3.

Simulator Extension Powered by Redbird

Divide students into pairs and have each pair complete **Stability in Aircraft Design Student Activity 3**. During this activity, partners will apply what they have learned about stability to work through several scenarios in a flight simulator.

- During the first simulation, one student should pilot the airplane and the other student should record observations and answer the questions in the worksheet.
- During the second simulation, partners should switch roles.

Sample observations and answers are included in **Stability in Aircraft Design Teacher Notes 3**.

EVALUATE

Teacher Materials: Stability in Aircraft Design Presentation, Stability in Aircraft Design Teacher Notes 4
Student Material: Stability in Aircraft Design Student Activity 4

Slide 29: Conduct the **Summative Assessment**.

Summative Assessment

Instruct each student to complete **Stability and Aircraft Design Student Activity 4**. Students will apply what they have learned about stability to complete both parts of the assessment:

- In Part 1, students will identify and explain various terminology and other features relevant to aircraft stability.

- In Part 2, students will read about a new aircraft design and identify the type of stability it exhibits and propose design alterations to improve stability.

Sample answers may be found in **Stability and Aircraft Design Teacher Activity 4**. To give students more time to process what they've learned, consider allowing students to complete this assessment as a homework assignment.

[DOK 2; cause/effect. DOK 3; draw conclusions]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Postings show evidence of one or more of the following:
    - Knowledge of the difference between static and dynamic stability
    - Knowledge of the control surfaces that contribute to aerodynamic stability around all three axes
    - Understanding of the effects weight distribution (CG) on longitudinal stability
- 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	Consistently demonstrates criteria
7-8	Usually demonstrates criteria
5-6	Sometimes demonstrates criteria
0-4	Rarely to never demonstrates criteria

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **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.9-10.2** - 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.

REFERENCES

http://www.boldmethod.com/learn-to-fly/aerodynamics/3-types-of-static-and-dynamic-stability-in-aircraft/
https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/airplane_handbook/
https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/07_phak_ch5.pdf