Aircraft Weight and Balance

Session Time: Five, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

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

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

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

ESSENTIAL QUESTIONS

1. How much can you load into an aircraft while still being able to fly safely?
2. How can the pilot ensure that the aircraft is within its weight and balance limits for takeoff and landing?
3. How does weight and balance shift during flight?

LEARNING GOALS

Students Will Know

- How the weight and balance of an aircraft affect its ability to fly safely
- How to determine if an aircraft is within safe weight and balance limits
- The method for efficiently shifting weight in an aircraft to bring it within safe limits

Students Will Be Able To

- *Explain* how an aircraft's operation is affected by weight and balance. (DOK-L2)
- *Calculate* the weight and balance of an aircraft using industry standard charts and graphs. (DOK-L2)
- *Solve* aircraft loading problems using the weight-shift equation. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students will examine an image related to an aircraft's weight and balance and discuss what is wrong, what could have led to the situation, and how it could be prevented.

Formative Assessment

In a three-part assessment, students define key terms and answer questions about the importance of weight and balance, perform calculations and analyze a loading scenario for a Cessna 172, and explain how adverse balance can affect flight characteristics.

Summative Assessment
Students will plan a trip in a Cessna 172. They will determine the weight and balance to safely start the trip and calculate changes to the aircraft's weight and balance during the course of the trip.

LESSON PREPARATION

MATERIALS/RESOURCES

- Aircraft Weight and Balance Presentation
- Aircraft Weight and Balance Student Activity 1
- Aircraft Weight and Balance Student Activity 2
- Aircraft Weight and Balance Student Activity 3
- Aircraft Weight and Balance Student Activity 4
- Aircraft Weight and Balance Student Activity 5
- Aircraft Weight and Balance Student Notes 1
- Aircraft Weight and Balance Student Notes 2
- Aircraft Weight and Balance Teacher Notes 1
- Aircraft Weight and Balance Teacher Notes 2
- Aircraft Weight and Balance Teacher Notes 3
- Aircraft Weight and Balance Teacher Notes 4
- Aircraft Weight and Balance Teacher Notes 5

Balancing Act Activity (per group)

- 12-inch ruler
- Three identical binder clips

Paper Airplane Balancing Activity (per group)

- 8 ” x 11” piece of paper
- Four paper clips

Flight Simulation Activity

- Flight simulation equipment

Recommended Student Reading

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

- Chapter Ten, Weight and Balance
  https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/12_phak_ch10.pdf

LESSON SUMMARY

Lesson 1: Aircraft Weight and Balance

Session one begins by introducing the concept of aircraft weight and balance and providing an overview of the underlying physics. Students will learn the definitions of weight, balance, and center of gravity and why it is important to operate aircraft within their weight and balance limitations. Students will perform an activity using a ruler and binder clips to demonstrate the two factors that affect the balance of a lever: the weight and how far it is from the fulcrum or balance point. Students will also discuss the flight characteristics of an aircraft when it is close to or outside the forward or aft CG range.

In the second session, students will experiment with weight, balance, and center of gravity (CG) in a paper airplane activity. The will learn very important terms related to weight and balance and will perform calculations to determine moment and center of gravity.

In the third session, students will learn to methods to calculate weight and balance for an aircraft. The computational method uses basic math compared against limits. The graph method uses calculations and manufacturers charts. The formative assessment will allow students to demonstrate their understanding of fundamental concepts from the lesson by defining key terms and answering questions about the importance of CG to safe flight. In the second part, students will perform calculations necessary to analyze a loading scenario for a Cessna 172. In the third part, students will explain how adverse balance can affect flight characteristics.

Students learn how to account and adjust for weight shift during flight in the fourth session. Students will also use a flight simulation activity to apply what they have learned about the effects of weight and balance during several in flight scenarios.

For the summative assessment, students will plan a trip in a Cessna 172. They will determine the weight and balance to safely start the trip and calculate changes to the aircraft's weight and balance during the course of the trip.

BACKGROUND

When most people watch an airplane takeoff, land, or fly overhead, they probably are not thinking about the airplane's center of gravity (CG), let alone whether the airplane is in balance. Yet weight, balance, and center of gravity are essential topics in aviation. Proper calculations are critical to safety of flight.

An aircraft's CG is the point along its longitudinal (lengthwise) axis where the aircraft would balance if it were placed on a fulcrum. (In this description, the aircraft is like a lever; a fulcrum is the point about which a lever turns.) Think of balancing a ruler on the back of one's finger. The ruler's CG is the point along its length where it will balance. Similarly, when an aircraft in flight is "balanced" about its CG, it will fly level.

To understand these concepts, students will need to learn the following terms:

- **Weight** - the force exerted by an aircraft from the pull of gravity
- **Center of gravity** - the point at which the aircraft would balance on a fulcrum
- **Center of lift** - the point where lift forces are considered to be concentrated
- **Reference datum (or simply datum)** - an arbitrarily chosen point from which all other locations are measured in inches fore (forward) or aft (behind); considered "station zero"

- **Station** - a location along an aircraft's longitudinal axis (e.g. the front seat station, the fuel tank station)
- **Arm** - the distance between the reference datum and a given station, measured in inches
- **Load moment (or simply moment)** - the product of weight (measured in pounds) and arm (measured in inches); a measure of the tendency of a mass to create a rotating force around a fixed point

One way to envision *moment* is if a person was to hold a 5-lb weight in their right hand next to their right shoulder. Think of the shoulder as the datum, the distance between the datum and the weight is very short. A person can probably hold the weight in this position for a long time because the weight has very little tendency to rotate around the shoulder toward the ground. Now imagine that same 5-lb weight held out at arm's length. This is more difficult and the person will probably tire more quickly. The weight is the same, but the *arm* (the weight's distance from the datum) has changed, which has changed the load moment.

Consider these calculations:

Example 1: a 5-lb weight is held at the shoulder (i.e., the datum)

5 lbs (weight) 3" (arm: i.e., the distance between the weight and the datum) = 15 inch-lbs

Example 2: a 5-lb weight is held out at arm's length

5 lbs (weight) 20" (arm) = 100 inch-lbs

These calculations show how the same weight has a dramatically different impact, depending on the length of the "arm." The longer the arm, the more difficult it is to support a weight. In other words, weight is not the only factor that affects CG; what really counts is load moment.

The study of aircraft weight and balance will give students a fascinating look into applied physics and teach them how to manage gravity to create safe, efficient flight. When loading an aircraft, two basic factors are paramount: 1) the amount of weight being loaded, and 2) the location (or *station*) on the aircraft (e.g., front seat, back seat, wings, baggage areas) where weight is being applied. Improperly loading an aircraft—either with too much total weight or too much weight at a given station—can create aerodynamic instability and even make the aircraft impossible to control.

Modern commercial airliners like the Boeing 747 or Airbus A380 have onboard computers that use passenger data and the aircraft's load profile to calculate weight and CG. However, this technology is expensive and not generally available to pilots of smaller aircraft, who must make the necessary calculations by hand (with the assistance of standardized tables and graphs). If the calculations show the aircraft is too heavy or out of balance, the pilot may need to remove cargo, passengers, or even fuel. Most aircraft are designed so that the CG can shift forward or aft within a limited range and still permit the airplane to safely fly.

MISCONCEPTIONS

Students may assume a four-seat aircraft can always take four passengers. This is true only if the passengers' combined weight adds up to less than the safe load for the aircraft. Otherwise, the aircraft may exceed its operational limitations due to weight and CG location. As a pilot, it is critical to conduct a weight and balance computation prior to taking off. Even if a fourth seat available, it may not be safe to have a passenger in it.

DIFFERENTIATION

To promote reflective thinking and guided inquiry in the small group discussion in the **EXPLORE** section of the lesson plan, circulate around the classroom and assist students who might have trouble coming up with problems that may be caused by an overloaded aircraft and an aircraft outside its CG limits. Ask questions that provoke their own ideas for possible answers.

To support metacognitive skills in the **EXPLAIN** and **EXTEND** sections of the lesson plan, provide multiple examples of the calculations that students are expected to perform by the end of this lesson. Walk through the examples and verbalize your thoughts and demonstrate what learners are expected to do in the assignment.

LEARNING PLAN

ENGAGE

Teacher Material: Aircraft Weight and Balance Presentation

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

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

Warm-Up

Ask students to examine the photograph. In a full class discussion, elicit responses to the following questions:

- What is wrong in this photograph?
- What might cause this to happen to an aircraft?
- How could accidents like this be prevented?

Possible answers: The tail of the airplane is touching the ground when it should be sitting level on its landing gear. This event seems like it occurred because the aircraft was not balanced and too much weight was added to the back of the aircraft. This accident could have been prevented if the aircraft's weight was balanced properly.

[DOK-L2; *infer, explain*]

EXPLORE

Teacher Material: Aircraft Weight and Balance Presentation

Slide 5: Use the video to introduce the importance of weight and balance. The aircraft was carrying heavy vehicles weighing nearly 80 tons, but they were not secured correctly. This caused a massive weight shift when the airplane took off and the aircraft became so unbalanced that the pilot could not recover. Be sure to watch this video before showing it to your class to ensure it is appropriate for your students.

- "National Air Cargo's Boeing 747-400 Freighter Crash in Afghanistan" (Length 0:30) http://video.link/w/kObe

Slide 6: Introduce the idea of weight and balance limitations. Help students recognize that operating within an aircraft's limitations is critical for safe flight. Emphasize that when it comes to aircraft balance, there is an acceptable range of values. This is necessary to allow for the fact that, depending on the mission, the aircraft could be loaded differently for every flight. Advise students that because of fuel burn, and sometimes the movement of people and baggage, the weight and balance of an aircraft changes over the course of a flight.

Slide 7: Remind students of the four forces of flight, and the definition of weight within this context.

Explain to students that it is surprisingly easy to overload most modern aircraft. Because even small aircraft must be flexible enough to perform a variety of missions, they are designed to give the pilot options when it comes to number of passengers and amount of cargo. An aircraft with four seats can't necessarily carry four passengers, depending on the weight of each passenger and the addition of baggage and fuel. By the same token, you can't necessarily fill all cargo spaces in an aircraft, depending on the amount and placement of fuel and passengers.

Questions

Working in small groups, ask students to list as many problems as they can think of that could be caused by an airplane that is overloaded. Suggest that they consider the factors they learned in the lift formula. Ask each group to share its answers and keep a list on the board. Use student responses to encourage discussion.

Possible answers: higher takeoff speeds, which requires a longer takeoff distance; longer landing roll because the landing speed is higher (higher weight requires more airspeed to produce required lift); rate and angle of climb are reduced; cruise speed is slower; range is shortened. More detailed answers will be provided on the following slide.

Slides 8-9: Now that students have had the chance to think about the hazards of overloading an aircraft, use this slide to talk about how excess weight adversely affects aircraft performance and what that might mean in practical terms. For example, a heavy aircraft will need to travel faster in order to take off. That will require more power, greater fuel burn, and a longer runway. What happens if the engine can't develop enough power to provide the necessary ground speed or if you run out of runway before becoming airborne? Ask the students to explain why each of these would happen using what they have learned so far in the course (e.g. air density, lift, etc.).

Slide 10: Balance is a state of physical equilibrium.

To demonstrate balance, ask students to extend their index finger and place a pen or pencil on top. Adjust the placement until the pen or pencil is level. The weight on either side of the finger is the same, so the object is balanced. The point at which the pen or pencil balances will most likely be toward the middle of the pen or pencil, but point out that not every object will balance on its middle—when an object is heavier on one end, the balance point will be closer to that end. Use this demonstration to explain that the point where the pen or pencil balances on their finger is the center of gravity, which is defined on the next slide.

Slide 11: Define center of gravity (CG) and use the illustration to show the CG. The CG is the point at which an airplane would balance if it were possible to suspend it at that point. (You can also think of it as the point where the airplane would balance if it were placed on a fulcrum as students just saw when balancing a pen or pencil on a finger.)

The CG also serves as the mass center of the airplane. This is the point at which the entire weight of the airplane is assumed to be concentrated for the purposes of weight and balance calculations.

The CG is often expressed as the number of inches from the reference datum, which is an arbitrary point chosen by the aircraft manufacturer. (Reference datum will be defined on a following slide.) For now, it is sufficient for students to know that CG is typically expressed as a number.

Manufacturers design aircraft so that they can be safely flown with slight variations in the location of the CG—a CG range. This is important to provide some flexibility when it comes to loading the aircraft. Make note that the acceptable CG range for an aircraft varies with its weight. Information about the CG range and its relationship to weight and loading configuration is provided by the aircraft manufacturer in the *Pilot's Operating Handbook*. Students will learn more about how to find and use this information later in this lesson.

Slide 12: This is a simple demonstration using a ruler and binder clips to show students the two factors that affect the balance of a lever: the weight and how far it is from the fulcrum or balance point. Divide into small groups and give each group a 12-inch ruler and three binder clips of equal size.

The first part of the demonstration will illustrate that equal sized weights placed at different distances from a fulcrum will result in an unbalanced situation. Have one student balance the ruler on the back of their index finger. Another student will hold the ruler steady while attaching one binder clip to the ruler 1 inch to the left of the balance point and one binder clip 5 inches to the right of the balance point. When released, the ruler should tip to the 5 inch side. Ask the students why, even though the clips were of the same size, that the ruler didn't balance?

Leaving the first two clips in place, have the students place the center of the ruler on the back of their index finger add a third clip to balance the ruler. Where did the third binder need to be placed? Ask the students to, based on their observations, identify what factors affected their ability to balance the ruler.

The combination of distance and weight need to be balanced on both sides of the ruler in order for it to be in equilibrium. Like the ruler, the loads in an airplane need to be balanced for if to fly safely.

Slide 13: Remind students that, like weight, CG is important for safe flight.

Questions

Working in small groups, ask students to list as many problems as they can think of that could be caused by an airplane that is outside its CG limits. Ask each group to share its answers and keep a list on the board. Use student responses to encourage discussion.

Possible answers: Many flight characteristics will change—how they change will depend on whether the CG is forward or aft of limits. Affected flight characteristics include speed, stall speed, pitch tendency, and flight control authority. More detailed answers will be provided on the next slide.

Slide 14: Remind students that CG limits fall within a range. This means that some acceptable CG values are forward (toward the front of the aircraft) and others are aft (toward the tail of the aircraft). Likewise, a CG outside of limitations may be either forward or aft of the acceptable range. How the aircraft behaves depends on where the CG is located along the longitudinal axis.

When the CG is forward of limits, the aircraft: won't fly as fast, will stall at a higher airspeed, and will tend to pitch nose down, which could make stall recovery easier.

When the CG is aft of limits, the aircraft: will fly faster, will stall at a lower airspeed, and will tend to pitch nose up, which could make it impossible to recover from a stall.

Regardless of whether the CG is forward or aft of limits, the aircraft will not fly as expected and could prove more difficult to control.

Slide 15: The illustrations on this slide show how a CG that is too far forward or too far aft can affect the aircraft's balance and limit control authority, particularly with regard to the elevator. With insufficient elevator authority, the pilot may not be able to raise or lower the nose enough to perform key functions like takeoff, landing flare, or stall recovery. This should conclude the first session.

EXPLAIN

Teacher Materials: Aircraft Weight and Balance Presentation, Aircraft Weight and Balance Teacher Notes 1, Aircraft Weight and Balance Teacher Notes 2, Aircraft Weight and Balance Teacher Notes 3, Aircraft Weight and Balance Teacher Notes 4
Student Materials: Aircraft Weight and Balance Student Activity 1, Aircraft Weight and Balance Student Activity 2, Aircraft Weight and Balance Student Activity 3, Aircraft Weight and Balance Student Activity 4, Aircraft Weight and Balance Student Notes 1

Slide 16: At the beginning of the second session, split students into small groups and distribute **Aircraft Weight and Balance Student Activity 1,** paper, and paper clips. Each group will fold a Nakamura Lock paper airplane.

Help students create their paper airplanes by modeling how to fold a Nakamura Lock paper airplane. You may wish to use this video to model how to fold the paper.

- "Nakamura Lock Paper Airplane" (Length 5:38)
  http://video.link/w/6Cce

Refer to **Aircraft Weight and Balance Teacher Notes 1** for answers and likely observations for this activity. When students have completed their work, discuss how this activity underscores the importance of taking great care when loading an actual airplane.

Slide 17: Calculating the weight and balance condition of their aircraft is one of the most fundamental skills a pilot must master. A pilot who attempts to fly an aircraft in either an overweight or out of balance condition is outside of the operating limits it was designed for and is risking the safety of the aircraft and all those aboard. Not only must the pilot in command ensure that the aircraft takes off within limits, they must ensure that it remains so as the flight progresses and fuel is burned, making the airplane lighter and possibly shifting the center of gravity. The aircraft's weight and location of the center of gravity also has performance implications that a pilot must understand.

Slide 18: Define the following key terms.

Center of Lift- The location along the chord line of an airfoil at which all the lift forces produced by the airfoil are considered to be concentrated. To maintain balance, the center of lift is located slightly aft (behind) of the CG. The center of lift is also known as the center of pressure. Unlike the CG, the center of lift is not impacted by the placement of weight.

Datum (Reference Datum) - An imaginary vertical plane or line from which all measurements of arm are taken. The datum is established by the manufacturer. Once the datum has been selected, all moment arms and the location of CG range are measured from this point. The datum location may be different on different aircraft. Be sure that students understand that the datum is arbitrary (i.e., it can be placed in any location), but once the datum is selected, all measurements should be taken from that same line. Connect the position of the datum with positive and /negative values of an arm.

Slide 19: Define the following key terms.

Arm (Moment Arm) - The horizontal distance in inches from the datum line to the CG of a weight or applied force. The algebraic sign is plus (+) if measured aft of the datum and minus (–) if measured forward of the datum. An arm measures the distance from the datum to any aircraft component or loaded object. Understanding how to measure a moment arm, including whether the value is positive or negative, is vital for weight and balance calculations.

Station - A location in the airplane that is identified by a number designating its distance in inches from the datum. The datum is, therefore, identified as station zero. An item located at station +50 would have an arm of 50 inches. In other words, the location of any component or object can be identified by its station. The components to be loaded on an aircraft are assigned a station, and it's important to make sure the aircraft is loaded this way so that its weight and CG are within safe limits. On the illustration on the slide, the arm for a backseat passenger is +70".

Slide 20: Define moment and explain the formula used to calculate a moment. Students need to understand that a moment is a force causing rotation. It's the concept used to determine how various forces interact with each other to achieve balance or rotation. When the sum of opposing forces equal zero, the system is in balance.

Moment - The product of the weight of an item multiplied by its arm. Moments are expressed in pound-inches (lb-in). Total moment is the weight of the airplane multiplied by the distance between the datum and the CG.

Moment (lb-in.) = Weight (lb) Arm (in.)

Referring to the diagram on the slide, have students use the formula to determine the moments for each of the three weights on the lever, add them, and determine mathematically whether the lever is balanced. Remind students that forces on one side of the fulcrum are positive, and those on the other are negative. In an aircraft, weights forward of the datum are negative and weights aft of the datum are positive.

Suggest students create a table to organize the steps.

Weight	Arm	Moment
50 lbs.	-50”	-2500 lb-in.
100 lbs.	-25”	-2500 lb-in.
50 lbs.	+100”	+5000 lb-in.

As a class, ask students if the lever in the example is balanced or unbalanced. They should find the sum of the moments on the left and right is –5,000 lb-in and 5,000 lb-in. Therefore, the lever is balanced.

Teaching Tips

Have students recall the activity they performed with balancing the ruler and binder clips during the last session. Why did they have to add a second binder clip to the side of the ruler where the clip was closest to the fulcrum? (*Because the moments weren’t in balance.*) How did adding a third binder clip create balance? (*It provided more moment to the side of the ruler.*)

If additional reinforcement of this concept is needed, show students the following video to support the explanation for calculating moment.

- “Law of the Lever” (Length 3:02)
  http://video.link/w/bTbe

Slide 21: Once again, refer back to the ruler-binder clip activity. When the ruler was balanced with the three clips, the student’s finger was the center of gravity.

It’s important to know where the CG is and needs to be so that an airplane can be safely loaded for flight.

Explain to students that the center of gravity - the point at which an airplane would balance if it were possible to suspend it at that point - is the point at which the sum of all positive and negative moments equal zero. The formula to determine CG is:

CG = total moment / total weight

Remind students that the datum is an arbitrary line. It can be any location as long as all measurements are taken from the same datum line. In this case, the datum is located on the far left edge of the lever.

Walk students through calculating the CG of the example illustrated on the slide. Suggest students create a table to organize the steps.

1. Determine the arm of each weight in inches from the datum
2. Determine the moment of each weight by multiplying the arm by the weight
3. Determine the total of all weights and the total off all moments
4. Divide the total moment by the total weight to determine the center of gravity

Item	Weight	Arm	Moment

A	100 lb.	+50 in.	+5000 lb-in.
B	100 lb.	+90 in.	+9000 lb-in.
C	200 lb.	+150 in.	+30,000 lb-in.
	400 lb. total		**+44,000 lb-in. total**

+44,000 lb-in. / 400 lb total = +110 in. CG

Point out to students that on the previous slide arm measurements were made from the fulcrum, or center of gravity, and on this slide they were made from a datum. Aircraft arms are measured from a datum. Ask students why they think aircraft arms are measured from a datum and not the center of gravity? Answer: Because the center of gravity can be in different places on an aircraft, which would make measurements difficult. Manufacturers therefore designate a stationary point to make arm measurements from called a datum.

This will likely conclude the second session.

Slide 22: To begin the third session, distribute **Aircraft Weight and Balance Student Activity 2.** The activity is a matching sheet of terms and definitions that will familiarize students with terms related to aircraft weight and balance. The activity sheet can be completed in small groups or individually, using the Internet or not. Not all terms have been previously introduced.

Answers can be found in **Aircraft Weight and Balance Teacher Notes 2.**

Slide 23: The *Pilot's Operating Handbook* contains the information necessary to determine an aircraft's weight and balance, including information specific to that particular aircraft such as its basic empty weight. Weights vary from aircraft to aircraft, even of the same model, depending on the equipment installed.

There are several methods for arriving at the weight and balance. We will use two, the computational method, which uses basic math compared against limits, and the graph method, which simplifies the calculations and provides a chart to visualize the result of the weight and CG calculations.

Walk students through how to perform weight and balance calculations using **Aircraft Weight and Balance Student Notes 3.** Answers can be found on **Aircraft Weight and Balance Teacher Notes 3.**

Slide 24: Complete the **Formative Assessment.** This will complete the third session.

Formative Assessment

Students will now follow the instructions in **Aircraft Weight and Balance Student Activity 4** to complete the formative assessment, which consists of three sections. In the first section, students will demonstrate their understanding of fundamental concepts from the lesson by defining key terms and answering questions about the importance of CG to safe flight. In the second section, students will perform calculations necessary to analyze a loading scenario for a Cessna 172. In the third section, students will explain how adverse balance can affect flight characteristics.

Each student will work individually on this assignment. Sample answers are provided in **Aircraft Weight and Balance Teacher Notes 4.** [DOK-L2; *explain*, DOK-L1; *calculate*]

EXTEND

Teacher Material: [Aircraft Weight and Balance Presentation]
Student Material: [Aircraft Weight and Balance Student Notes 2]

Slide 25: Explain to students the weight shift formula for change in weight or shifted weight. Weight shift could occur as a result of fuel burn, skydiving operations, or passengers moving in-flight. Have students think back to the video shown during the first session of this lesson where the massive weight shift on a cargo airplane caused it to become so unbalanced that the pilot could not recover.

If the pilot determines that the weight of the aircraft is not distributed properly, they can redistribute the weight on the aircraft in order to bring it back into operational limits. This slide shows what the pilot should consider when shifting weight.

- First, the total weight of the aircraft will stay the same if the weight is only being redistributed. If the aircraft is too heavy to fly, shifting weight will not help.
- When weight is moved around the aircraft, however, the total moment and the location of the center of gravity will change. When weight is moved forward, total moments decrease and when weight is moved aft, total moments increase. Emphasize to students, when a load is moved forward, subtract the moment from the total, when a load is moved aft, add the moment to the total. Depending on where the airplane weight is located on the moment envelope graph, the pilot should redistribute the weight appropriately.
- The more weight that is being moved, the more the moments will shift. If the aircraft is very far outside the moment envelope, they will have to redistribute a lot of weight compared to if the aircraft is already close to the envelope.

Slide 26: When a weight is moved from one place to another on an airplane, the total weight remains the same, but the moments and CG change.

To determine if the airplane remains loaded properly after a weight shift, or to determine how much and how far weight must be shifted to remain within CG limits, pilots can use the weight shift equation. The equation is a proportion:

Weight Shifted / Total Weight = Change in CG / Distance Weight is Shifted

Slide 27: Have students work individually to solve the weight shift example on the slide:

You are flying a Cessna 172 on an overnight trip. Your total aircraft weight is 2,492 lbs. You want to know how it will affect your CG if you move 50 lbs. of baggage from Baggage Area 1 to the front passenger seat, 58 inches forward.

The equation is: weight shifted divided by total weight is equal to the change in CG divided by the distance the weight is shifted.

Slide 28: Students should extract the following values from the paragraph:

Weight shifted: 50 lbs
Total weight: 2492 lbs
Change in CG: Unknown (this is what they're solving for)
Distance weight shifted: -58 inches (since the weight is moving forward, this value is negative)

Putting the values in the equation:
50/2492 = Change in CG/-58
Change in CG = -1.16 inches (forward)

Slide 29: Explain to students that when the total weight of the aircraft is above the operational limits, the only way to bring the aircraft back into limits is to remove weight. When weight is added or removed, the total weight of the aircraft changes and must be recalculated to make sure it is operating at or below the gross weight. The addition or removal of weight will change the center of gravity, which means that the CG and moment calculations need to be redone.

Slide 30: Students will now follow the instructions in **Aircraft Weight and Balance Student Notes 2** to complete the flight simulator activity.

Simulator Extension Powered by Redbird

Students will apply what they have learned about the effects of weight and balance on aircraft during takeoff and flight to make adjustments during several simulated scenarios. If possible, students should use a Cessna 172 to complete the various scenarios; if they have extra time, however, they may attempt the scenarios using other types of aircraft.

There are questions for students to answer in the activity. When an aircraft is overloaded, it will take more time, distance, and airspeed to take off. When it is loaded aft of the CG limit, the aircraft may pitch up on takeoff and climb, requiring forward pressure to keep the nose down. When an aircraft is loaded forward of the CG limit, it will be harder to raise the nose on takeoff, if it can be raised at all.

If there are limited simulators available, have some students complete the simulation activity while others are working on the summative assessment.

EVALUATE

Teacher Materials: Aircraft Weight and Balance Presentation, Aircraft Weight and Balance Teacher Notes 5
Student Material: Aircraft Weight and Balance Student Activity 5

Slide 31: Complete the **Summative Assessment.** Completing and reviewing the summative assessment will encompass the fifth day of the session.

Summative Assessment

Students will now follow the instructions in **Aircraft Weight and Balance Student Activity 5** to complete the summative assessment, which consists of a series of questions that requires students to plan a trip in a Cessna 172S for themselves (as pilot) and up to three friends. Students will determine how many friends they can safely bring with on the trip; they will also calculate changes to the aircraft's weight and balance during the course of the trip.

Each student will work individually on this assignment. Sample answers are provided in **Aircraft Weight and Balance Teacher Notes 5.**

[DOK-L2; *calculate*, DOK-L2; *solve*, DOK-L3; *interpret*]

Summative Assessment Scoring Rubric

Student is engaged in the activity

Student follows assignment instructions

Student work shows:

- Weight and balance calculations for various phases of the flight
- Weight and balance calculations for different numbers of friends on the trip
- Calculations using weight-shift equation

Contributions show understanding of the concepts covered in the lesson

Contributions show in-depth thinking, including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 Consistently demonstrates understanding of the material, including correct calculations for weight and balance, based on information in the relevant charts and graphs

7-8 Usually demonstrates criteria; most of the items can be accounted for except small errors in either the calculations or the reasoning

5-6 Sometimes demonstrates criteria; several of the weight and balance calculations are not correct and student draws incorrect conclusions that would create risks during an actual flight

0-4 Rarely to never demonstrates criteria; student demonstrates little to no understanding of the concepts or makes little to no effort to complete tasks

GOING FURTHER

We've gone far enough...

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-PS2-1 -** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass and its acceleration
    - Science and Engineering Practices
        - Analyzing and Interpreting Data
        - Using Mathematics and Computational Thinking
    - Disciplinary Core Ideas
        - PS2.A Forces and Motion
        - PS2.B Types of Interactions
    - Crosscutting Concepts
        - Cause and Effect
- **HS-PS2-2 -** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
    - Science and Engineering Practices
        - Analyzing and Interpreting Data
        - Using Mathematics and Computational Thinking
    - Disciplinary Core Ideas
        - PS2.A Forces and Motion

        - PS2.B Types of Interactions
    - Crosscutting Concepts
        - Cause and Effect

COMMON CORE STATE STANDARDS

- **W.9-10.1.B** - Develop claim(s) and counterclaims fairly, supplying evidence for each while pointing out the strengths and limitations of both in a manner that anticipates the audience's knowledge.
- **W.9-10.2** - Write informative/explanatory texts, including the narration of historical events, scientific procedures /experiments, or technical processes.
- **WHST.9-10.4** - Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **MP.4 -** Model with mathematics.
- **HSN.Q.A.1** - Use units as a way to understand problems and to guide the solution of multistep problems; choose and interpret units consistently in formulas; choose and interpret the scale and origin in graphs and data displays.
- **HSN.Q.A.2** - Define appropriate quantities for the purpose of descriptive modeling.
- **HSN.Q.A.3** - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
- **HSA.CED.A.1** - Create equations and inequalities in one variable and use them to solve problems.
- **HSA.CED.A.2** - Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.
- **HSS-IS.A.1** - Represent data with plots on the real number line (dot plots, histograms, and box plots).

REFERENCES

https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/media/FAA-H-8083-1.pdf

https://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Weight_and_Balance_Lesson_2.html

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