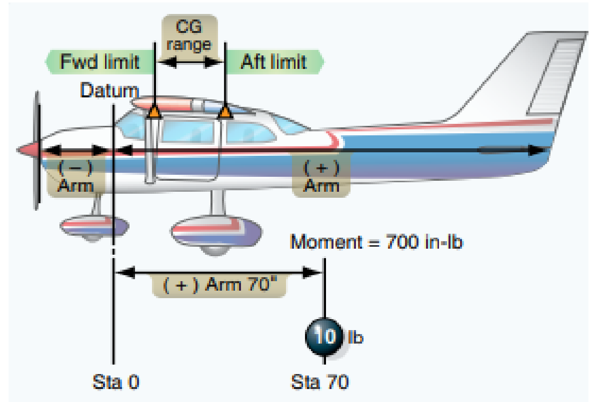
Airplane Weight and Balance

<table>
<tr><td colspan="1">Objective</td><td rowspan="4">
</td></tr>
<tr><td>To ensure the applicant learns the importance of airplane weight and balance and can properly calculate it for their airplane.</td></tr>
<tr><td>Purpose</td></tr>
<tr><td>Weight and balance is important because airplane performance and stability is heavily dependent on flying within the published limits. This lesson will introduce pilots to the concepts involved in weight and balance, and the proper methods for computing it.</td></tr>
<tr><td>Schedule</td><td>Equipment</td></tr>
<tr><td>● Ground Lesson: 30 minutes
● Student Q&A: 10 minutes</td><td>● Airplane POH
● Calculator
● Whiteboard / Markers (optional)
● Model Airplane (optional)</td></tr>
<tr><td>Student Actions</td><td>Instructor Actions</td></tr>
<tr><td>● Ask any questions, receive study material for the next lesson.
● Watch linked video.
● Review listed references.</td><td>● Deliver the ground lesson (below).
● Answer student questions.</td></tr>
<tr><td colspan="2">Completion Standards</td></tr>
<tr><td colspan="2">● Student can explain the following concepts:
○ Datum, weight, gross weight, arm, moment
○ How weight affects performance
○ How CG affects performance
○ How to compute weight and balance
○ Strategies for dealing with an airplane out of the allowable weight and balance envelope</td></tr>
</table>

References

- MzeroA Flight Training - "Aircraft Weight and Balance Part 1"
    - YouTube - https://www.youtube.com/watch?v=MlWUsiq_G90
- FAA-H-8083-3B (Airplane Flying Handbook) -
- FAA-H-8083-25B (Pilot's Handbook of Aeronautical Knowledge) - Chapter 5, Page 14-15 [Static and Dynamic Stability], Chapter 5, Page 15-17 [Longitudinal Stability], Chapter 5, Page 19-20 [Directional Stability], Chapter 5, Page 25-26 [Stalls], Chapter 10, Page 2 [Effects of Weight], Chapter 10, Page 2-4 [Balance, Stability, Center of Gravity], Chapter 10, Page 4-5 [Terms and Definitions], Chapter 10, Page 5-11 [Computing W&B]
- FAA-S-8081-6D (CFI PTS) - Area II Task F

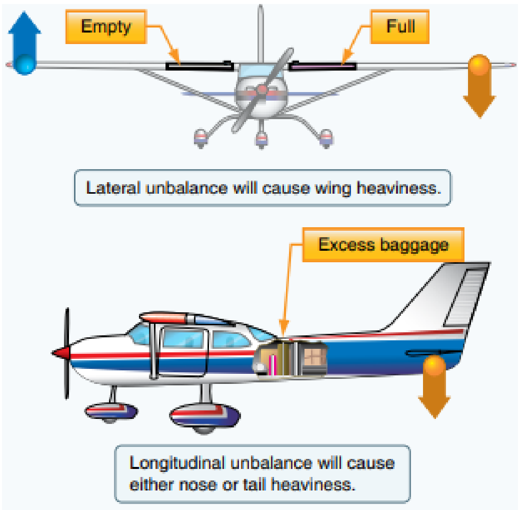
Ground Lesson Outline

- Importance of Weight and Balance
    - Dangers of Imbalance
- Weight and Balance Terms
    - Weight/Gross Weight/Basic Empty Weight
    - Arm/Station, Moment, Datum, CG
- Effect of Weight and Balance on Performance
    - Weight
        - Raises AoA for level flight
        - Affects stall speed, takeoff and landing distance, maneuvering speed
    - CG
        - Affects stall speed, stability
- Methods of Weight and Balance Control
    - Moving or reducing passengers or cargo
    - Adjusting fuel load
    - Ballast
- Computing Weight and Balance
    - How To Compute - Total Moment
    - Check Flight Envelope - Normal Category/Utility Category
    - Adding, Removing, and Shifting Loads

Common Errors

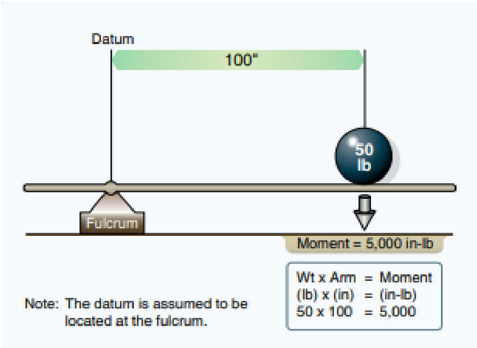
- **Failing to consider changes in passenger, cargo, or fuel load on weight and CG calculations.**
- Miscalculating the CG when loading changes.

Ground Lesson Content

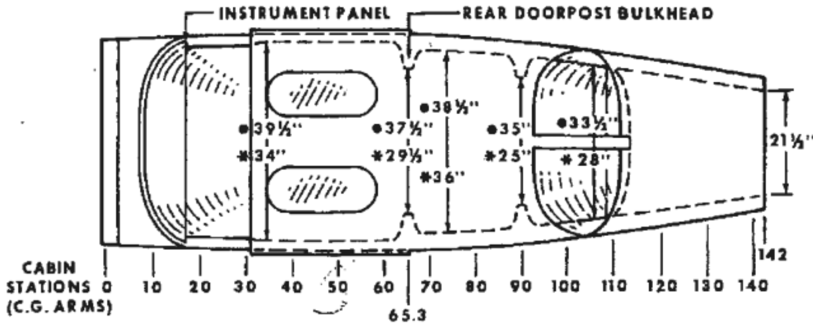


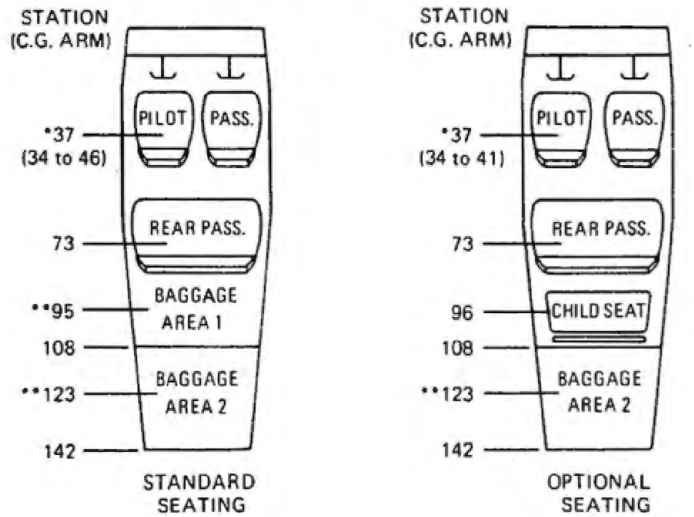
- **Importance of Weight and Balance -** It is quite intuitive that the heavier an airplane is, the more force is required to make it fly, or to maneuver it. Airplanes are extremely sensitive to weight, and are designed to operate only in specific ranges of minimum and maximum weights. Additionally, airplanes are quite sensitive to *balance*, which refers to the location of the Center of Gravity.
  - **Dangers of Imbalance -** Airplanes in flight rely on their flight control surfaces to produce sufficient forces to maneuver and control the airplane. Large imbalances in weight distribution can lead to situations where the airplane is excessively nose heavy, or tail heavy, or wants to roll one direction or another.

- **Weight and Balance Terms**
  - **Weight -** Simply, how heavy is the airplane overall (*gross weight*), or how heavy the individual object is, whether than be passengers, cargo, or even fuel or airplane parts.
    - **Maximum Gross Weight -** Maximum weight allowable for the airplane.
    - **Basic Empty Weight -** Weight of the airplane with all standard and optional equipment, plus any unusable fuel. Does *not* include weight of usable fuel, passengers, or cargo.
    - **Useful Load -** Difference between Maximum Gross Weight and Basic Empty Weight. Load usable for fuel, passengers, and cargo.
    - **Payload -** Load available after fuel is loaded.
  - **Datum -** A given point on the airplane from which all relative distances are measured. For instance, the position of all objects in the plane can be specified in the number of inches from the tip of the propeller spinner, or any other location. The datum can be imagined as the fulcrum in a balance or scale.

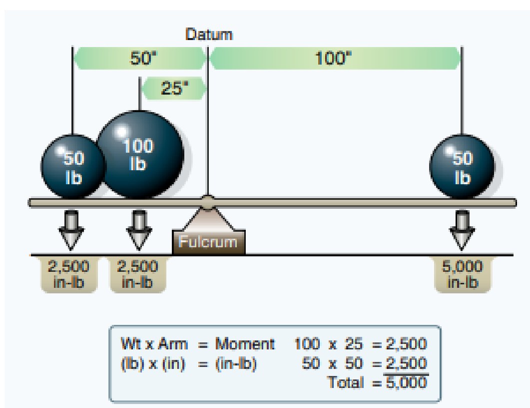


  - **Arm -** The *distance* from the datum. The further that an object is from the datum, the longer the arm. Arm is usually expressed as *inches aft of datum* (positive arm numbers) or *inches forward of datum* (negative arm numbers). **This is also sometimes called a *station* in some POHs.**

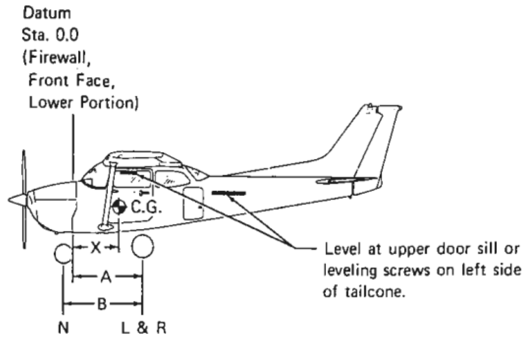




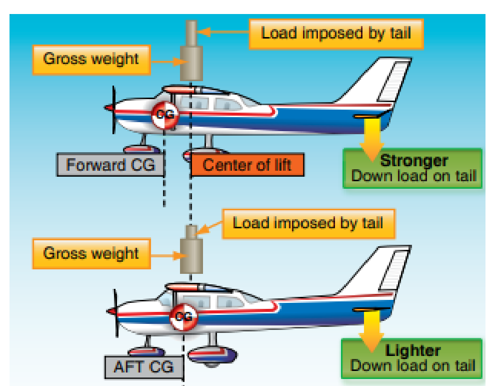
- **Moment -** In the 'balance scale' concept, moment simply describes the tendency of an object to rotate around the datum. A 50lb object 100 inches from the datum wants to rotate more than a 50lb object 50 inches from the datum. **This is intuitively experienced with levers: the longer the lever, the less force must be applied to achieve the same result.** When using a scale, a heavier object on one side can be balanced by lighter objects on the other, if those lighter objects are further away from the fulcrum. Moment is calculated by multiplying **`Weight x Arm`**, and is usually expressed in '*inch pounds*'.



- **CG -** Once all individual weights in an aircraft are considered, the *Center of Gravity* (CG) represents a sort of 'average position' of the weights. **When balancing an object by a fingertip, objects balance on their center of gravity.** When computing weight and balance for airplanes, the position of the CG is assumed to be some distance from the datum, represented as an *arm*, or *inches aft of datum*.

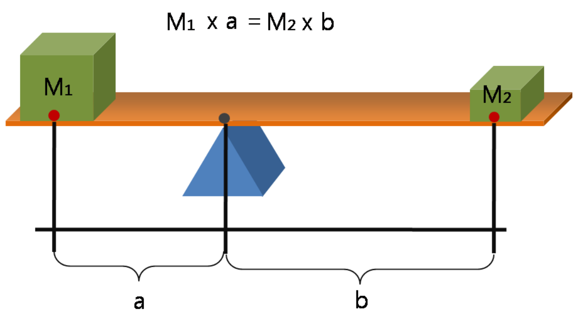


- **Effect of Weight and Balance on Performance**
  - **Weight**
    - **Takeoff and Landing Performance** - Heavier airplanes require **more runway to take off, and require more runway to land**.
    - **Stall Speed** - When flying at higher weights, the total load on the wing is higher, and the airplane must produce more lift to maintain straight and level flight. This requires a higher angle of attack for the same airspeed. Because airplanes always stall at the same angle of attack, and heavier weights increase angle of attack, it can be concluded that **heavier aircraft stall at a higher airspeed.**
    - **Load Factor** - Airplane load factors (maximum and minimum structural loads) are computed only for allowable ranges of airplane weights. **Exceeding these weights may cause structural failure in flight!** This is especially true when encountering turbulence, etc.
    - **Maneuvering Speed** - Likewise, flying at very light weights also affects performance, because it will require less flight control movement to produce the same forces. Recall that the wing will be flying at a lower angle of attack when the weight is lower, which means that the wing can produce more total lift before it stalls. **This can result in the airplane exceeding the limit load factor at lower airspeeds!**
  - **CG** - The position of the Center of Gravity affects many aspects of airplane performance and stability:
    - **Longitudinal Stability and Stall Recovery** - *Longitudinal stability* refers to an airplane's **stability in pitch**. Most airplanes are stable in pitch, and have a gentle up-down pitch oscillation over time. The most important factor in longitudinal stability is the location of the center of gravity relative to the center of lift.
      - **Center of Gravity and Center of Lift** - When conventionally designed airplanes fly, the center of gravity is always *in front of* the center of lift. You can think of the center of lift as a sort of pivot point in a seesaw. Because the horizontal stabilizer is far behind the center of lift, it produces *downward* force (essentially lift, but downward) to keep the nose of the airplane level. This downward force opposes the upward force of the main

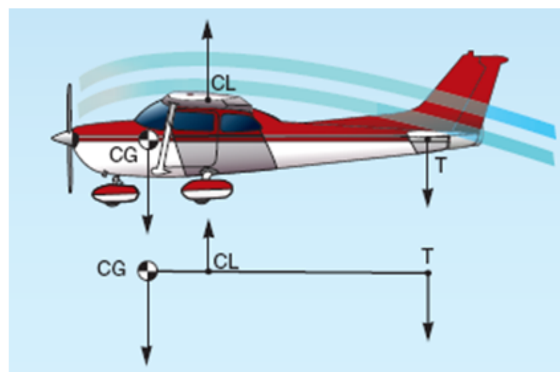


wing, requiring it to produce slightly more lift to compensate. Also, because any airfoil that produces lift also produces drag, the amount of drag caused by the horizontal stabilizer depends on the force it must produce.

- When the center of gravity is further forward, the horizontal stabilizer must produce more downward force to raise the nose, which adds to the loads placed on the Center of Lift pivot point (the main wing).



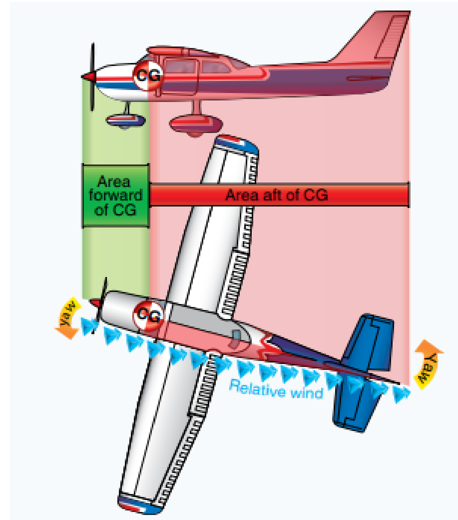
- Airplanes are designed so that they have a natural tendency to recover from a stall. **A well-designed airplane's Center of Gravity is always forward of the Center of Lift.**



- This design causes a natural tendency for the airplane to nose down, reducing the angle of attack. To counteract this, the horizontal stabilizer and elevator surfaces of an airplane are designed to produce a *downward* force, which 'holds up' the heavier nose area by pivoting the airplane around the Center of Lift. **When an airplane stalls, if the elevator pressure is relaxed, the Center of Gravity will fall naturally.**
- As the Center of Gravity moves closer to the Center of Lift, the natural nose-down stall-recovery tendency is weakened, and it requires less downward force by the tail to move the nose up or down. **In this configuration, relatively small movements of the elevator can cause large, rapid changes in pitch.** When an airplane Center of Gravity is too close to the Center of Lift, or even behind it, a very dangerous situation exists where there is no natural tendency to recover from a stall. **In fact, if the Center of Gravity is too far rearward (aft), the airplane may be uncontrollable in pitch and a stall may be unrecoverable!** This situation is called *longitudinal instability*.

- **Stall Speed** - Similar to the natural tendency for a forward CG to cause the airplane to recover from a stall, a forward CG requires the rear horizontal stabilizer to produce more downward force to keep the nose raised for level flight. This in turn adds more weight for the main wing to support, increasing its angle of attack, and therefore increasing stall speed.

- **Directional Stability** - *Directional stability* is stability in yaw. Airplane yaw is largely controlled by the vertical tail surface, and to a lesser extent, the fuselage itself. Due to the large distance from the center of gravity, the tail surface is very effective at maintaining directional stability. **When the CG moves rearwards, towards the tail, the tail surface is less effective and directional stability is reduced.**

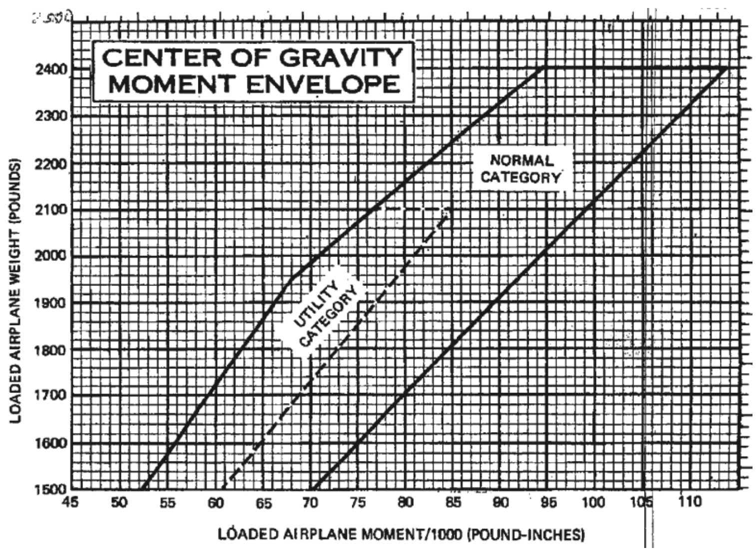


- **Methods of Weight and Balance Control** - Pilots have a few ways to manage the weight and balance of an airplane.
  - **Moving or reducing passengers or cargo** - If the weight is too much, the amount of passengers or cargo can be reduced. Similarly, if the issue is merely that of balance, it is possible that simply *moving* the passengers or cargo to another location can alleviate the problem.
  - **Adjusting fuel load** - Airplanes often carry significant amounts of fuel, which can be reduced to give a higher *payload* (weight carrying capability for passengers and cargo).
  - **Ballast** - If the issue is solely one of CG, it is often possible to add relatively small weights to baggage compartments to generate large changes in the CG, since baggage compartments are often far from the datum.

- **Computing Weight and Balance** - In order to determine the total weight and find the Center of Gravity for an airplane, the *Gross Weight* and *CG location* must be computed.
  - **How To Compute** - Computing weight and balance is fairly simple:
    - **Step 1**: Start with the *Airplane's Empty Weight and CG*. This can be found in the POH, and **represents the Gross Weight and CG location with no (usable) fuel, passengers, or cargo.**
    - **Step 2**: Add the weight of fuel, passengers, and cargo to the Airplane Empty Weight. This is the *gross weight*.
    - **Step 3**: Multiply the weight of each item (fuel, each passenger and item of cargo) by the *arm* for their location. This provides the *moment* for each item. Compute the moment of the empty airplane by multiplying the Airplane Empty Weight by the empty CG. (Some W&B sheets already provide this) This is the *empty moment*.
    - **Step 4**: Add each calculated moment to the empty moment to determine the *total moment*.
    - **Step 5**: Divide the *total moment* by the *gross weight*. **This provides the CG location, in terms of distance from the datum.**

Item	Weight	Arm	Moment
Aircraft Empty Weight	2,100	78.3	164,430
Front Seat Occupants	340	85.0	28,900
Rear Seat Occupants	350	121.0	42,350
Fuel	450	75.0	33,750
Baggage Area 1	80	150.0	12,000
Total	3,320		281,430
			281,430 ÷ 3,320 = 84.8

- **Check Flight Envelope -** Use the POH to find where the computed gross weight and CG lie within the envelope. Depending on the POH, you may need to use *total moment* or *CG (inches)*. **If the intersection between the weight and CG does not lie within the envelope, the airplane is not within the allowable CG range and weight must be added, removed, or moved to alter the CG!**
  - **Normal vs Utility Category -** Note that many airplanes may be operated in the *Utility Category* at certain ranges of weight and CG. If the maneuvers being planned require the airplane to be operated in this category, be sure to ensure the weight and CG are within limits for that area of the flight envelope.



- **Adding, Removing, and Shifting Loads -** It is also easy to compute what will happen to the weight or CG. The further from the datum (further towards the rear of the airplane) an object is placed, the more it will move the resulting CG rearwards.
  - For example, to simulate the adding of 10 lbs of ballast to the rear baggage area, simply multiply the weight of the ballast times the arm location of the baggage area, and add to the existing total moment, to see if the CG moves within limits. **Likewise, to simulate the removal of an item, compute a *negative* weight in the given location (giving a *negative* moment), and add it to the total moment.**