II.F. Airplane Weight and Balance

References: FAA-H-8083-1; FAA-H-8083-3; FAA-H-8083-25; POH/AFM

Objectives	The student should develop knowledge of the elements related to weight and balance and have the ability to properly calculate an airplane's weight and balance for the given situation.
Key Elements	1. Performance 2. Calculating Weight and Balance 3. Adding, Removing, and Shifting Weight
Elements	1. Terms 2. Weight and Flight Performance 3. Weight and Balance Control 4. Determining Weight and Balance
Schedule	1. Discuss Objectives 2. Review material 3. Development 4. Conclusion
Equipment	1. White board and markers 2. References
IP's Actions	1. Discuss lesson objectives 2. Present Lecture 3. Ask and Answer Questions 4. Assign homework
SP's Actions	1. Participate in discussion 2. Take notes 3. Ask and respond to questions
Completion Standards	The student understands the factors relating to weight and balance and the airplane's control, stability and performance. The student also can calculate the weight and balance for a given situation and make adjustments as necessary.

Instructors Notes:

Introduction:

Attention

Interesting fact or attention grabbing story

The earliest airplanes could barely lift the pilot and enough fuel for a few minutes of flight. Many could not get airborne on a warm day. The first Wright flyer could only carry the pilot and a few ounces of fuel if the headwind was at least 11 mph! Planes have come a long way and pilots still need to balance the plane's load.

Overview

Review Objectives and Elements/Key ideas

What

Airplane weight and balance is basically, balancing the airplane within approved limits.

Why

Pilots need to keep weight within safe limits and balance the loads carried to maintain control of the airplane.

How:

1. **Terms**
   - A. Reference Datum (RD) - An imaginary vertical plane from which all horizontal distances are measured for balance purposes
     - i. The datum may be located anywhere the manufacturer chooses
     - ii. Common locations are the nose, the engine firewall, the wing's leading edge, or ahead of the nose
   - B. Station - A location on the airplane fuselage usually given in terms of distance from the reference datum
   - C. Arm – The horizontal distance, usually in inches, from the RD to the Center of Gravity of an item
     - i. Arms ahead of the reference datum are negative and those behind the RD are positive
     - ii. If the RD is ahead of the nose, all of the arms are positive
   - D. Moment – A force that causes or tries to cause an object to rotate
     - i. It is the product of the weight of an item multiplied by its arm and expressed in pound-inches
   - E. Moment Index – The moment divided by a reduction number (100/1000) to get it smaller/reduce errors
   - F. Center of Gravity (CG) – the point at which an airplane would balance if it were suspended at that point
     - i. The distance of the CG from the RD is found by dividing the total moment by total weight
   - G. CG Limits – The extreme (forward/aft) CG locations within which the plane must be operated at a weight
   - H. Usable Fuel – the fuel available for flight planning
   - I. Unusable Fuel – the fuel in the tanks that cannot be safely used in flight or drained on the ground
   - J. Basic Empty Weight – the weight of the standard airplane, optional equipment, unusable fuel, and full operating fluids (including oil)
   - K. Payload – the weight of the occupants, cargo and baggage
   - L. Useful Load –difference between takeoff weight (or ramp weight if applicable) and basic empty weight
   - M. Max Ramp Weight – the max weight approved for ground maneuvers (includes start, taxi, run-up fuel)
   - N. Max Takeoff Weight – the max weight approved for the start of the takeoff run
   - O. Max LDG Weight – The max weight approved for landing touchdown
   - P. Max Zero Fuel Weight – the max weight exclusive of usable fuel
   - Q. Standard Weights – Established for numerous items in weight and balance computations
     - i. Gas – 6lbs; Jet Fuel – 7 lbs; Oil – 7.5 lbs; Water – 8.35 lbs (All per gallon)

2. Weight and Flight Performance

A. Weight and Flight Performance
   i. A heavier gross weight will result in:
      a. Higher takeoff speed, longer takeoff run, reduced rate and angle of climb, lower maximum altitude, shorter range, reduced cruise speed, reduced maneuverability, higher stall speed, higher approach and landing, longer landing roll, excessive weight on the nose or tail wheel
      b. Climb and cruise performance is reduced which can lead to:
         - Overheating in climbs, added wear on engine, and increased fuel use

B. Weight and Structure
   i. Structural failures which result from overloading may be catastrophic but they often affect structure progressively making it difficult to detect or repair
   ii. An airplane is certified to withstand certain loads on its structure based on the category
      a. As long as gross weight and load factors limits are observed, the total load will remain in limits
      b. If the max gross weight is exceeded, load factors within the load factor limits can cause damage
   iii. The results of routine overloading are cumulative and may result in failure later during normal ops

C. Weight and Stability
   i. A stable and controllable plane may have very different characteristics when overloaded
      a. Weight distribution has the most effect, but gross weight also adversely affects stability
   ii. An airplane with forward loading
      a. "Heavier" and consequently slower than the same airplane with a further aft CG
         - Nose up trim is required which requires the tail surfaces to produce a greater down force which adds to the wing loading, increasing the total lift required from the wings
      b. Requires a higher AOA, which results in more drag and, in turn, produces a higher stalling speed
      c. The airplane is more controllable (the longer arm from the CG makes the elevator more effective)
   iii. With aft loading, the airplane requires less down force allowing for a faster cruise speed
      a. Faster cruise because of reduced drag (smaller AOA and less down deflection of stabilizer)
      b. The tail surface is producing less down force, relieving the wing of loading and lift
         - Results in a lower stall speed
      c. Although the stall speed is lower, recovery from a stall becomes progressively more difficult as the CG moves aft (more below)
   iv. The CG and the Lateral Axis
      a. Unbalanced lateral loading (more weight on the right or left side of the aircraft centerline) may result in adverse effects
         - This can be caused by: fuel imbalance, people, baggage, etc.
      b. Compensate for any imbalance with trim (if available), or constant control pressure
         - This places the aircraft in an out-of-streamline condition, increasing drag, and decreasing efficiency

D. Weight and Controllability
   i. Generally, an airplane becomes less controllable as the CG moves aft
      a. The elevator has a shorter arm and requires greater deflection for the same result
      b. Stall recovery is more difficult because the plane's tendency to pitch down is reduced
         - If the CG moves beyond the aft limit, stall and spin recovery may become impossible
   ii. As the CG moves forward, the airplane becomes more nose-heavy
      a. The elevator may no longer be able to hold up the nose, particularly at low airspeeds (takeoff, landing, glides)

- On landing the elevator may not be able to produce sufficient force to lift the nose wheel during the flare, in extreme cases a safe landing could be impossible

3. Weight and Balance Control

A. The pilot is responsible for the management of weight and balance
   i. Use the flight manual approved method and charts
   ii. Do not exceed the manufacturer's weights and CG ranges

B. There are various methods to determine weight and balance conditions:
   i. CG calculations; CG graphs; CG tables

4. Determining Weight and Balance

A. CG = Total Moment divided by Total Weight
   i. Begin with the empty weight and make a list of everything that will be loaded in the airplane
      a. People, items, and fuel (note the weights of everything as well)
      b. Be sure the total weight of what you want to load is within the max weight limits
         - If the total weight is too high, remove items/people to get within weight limits
   ii. Calculate the Moments of each item
      a. To find the moments, use the graph or multiply the weight by the arm in the POH
         - Use the method provided in the AFM
         - The weight/moment of the empty airplane are found in its weight and balance documents
   iii. Then calculate the CG – (Total Moment/Total Weight)
      a. For the DA20, compare the Total Weight and Total Moment on the graph in supplement 4
   iv. Use the chart in Supplement 4 to determine whether the airplane is within limits

B. Weight Change and/or CG Shift
   i. $CG = \frac{M^1 \pm \Delta M}{W^1 \pm \Delta W}$
      a. M1 and W1 are the original moment and weight
      b. Any weight added causes a + moment change (weight removed is -)
      c. Weight shifted rearward (aft) causes a + moment change (weight shifted forward is -)
      d. A weight shift changes only the moment (change in weight = 0)
   ii. EX: An airplane is to takeoff at 6,230 lbs with the CG at 79.0. What is the location of the CG after 50 gal (300lb) of fuel has been consumed from station 87.0?

$$\frac{(6{,}230)(79.0) - (300)(87)}{6{,}230 - 300} = 78.6\ in$$

   iii. EX: An airplane is to takeoff at 3,000lbs with CG at station 60. Since takeoff, 25 gallon (150lb) of fuel has been consumed. The fuel cell CG is station 65. After takeoff, a 200 lb. passenger moved from station 50 to 90. CG.

$$\frac{(3{,}000)(60) - (150)(65) + (200)(90-50)}{3{,}000 - 150} = 62.54\ in$$

   iv. EX: Gross weight of an airplane is 10,000 lbs. 500lbs of cargo is shifted 50 in. How far does CG shift?

$$\frac{500 \times 50}{10{,}000} = 2.5\ in$$

Conclusion:

Brief review of the main points

Weight and balance greatly affects flight and it is therefore very important we ensure that the airplane is correctly balanced before every flight.

PTS Requirements:

II.F. Airplane Weight and Balance

To determine that the applicant exhibits instructional knowledge of the elements of airplane weight and balance by describing:

1. Weight and balance terms.
2. Effect of weight and balance on performance.
3. Methods of weight and balance control.
4. Determination of total weight and center of gravity and the changes that occur when adding, removing, or shifting weight.