**Airplane Weight and Balance**

References: FAA-H-8083-1; FAA-H-8083-3A pg 12-10; PHAK FAA-H-8083-25A Chap 9 pgs 1-11; Cessna POH/AFM

Ground Lesson

**Objectives:** The student should develop knowledge of weight and balance terms, effect of weight and balance on performance, methods to control weight and balance, adding or removing weight, weight shifting, determination of total weight and the center of gravity.

**Elements/Key Points/Schedule: Discussion 2:00**

1. Intro (5 min)
2. Terms (10 min)
3. Performance (10 min)
4. Weight and Balance Control (10 min)
5. Classroom break (10 min)
6. Calculating Weight and Balance (15 min)
7. Adding, Removing, and Shifting Weight (15 min)
8. Determination of total weight and Center of Gravity (10 min)
9. Objective review with questions (10 min)

Total (1.45 hr)

**Equipment:**

Classroom, chairs, ruler, pencil, coins, see-saw diagram, overhead projector, handout of terms, white board and markers, plain paper, references, model airplane, Cessna and Piper POH Weight & Balance section, quiz

**Instructors Actions:**

1. Discuss lesson objectives, present overview with w & b demo

2. Present lecture by using figures, charts

3. Ask and Answer Questions, help student do a sample w & b problem for 1 to 3 people in plane.

4. Assign homework

**Student Actions:**

1. Participate in discussion

2. Take notes

3. Ask and respond to questions

**Completion Standards:** The student understands the terms, factors, application of POH charts, relating to weight and balance and the airplane’s control. The student also can calculate the weight and balance for a given situation and make adjustments as necessary.

Airplane Weight and Balance

Instructors Notes:

**Introduction:**

**Attention**

The earliest airplanes of the Wright Bros. 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 for a safe flight.

**Overview**

Review Objectives and Elements/Key ideas

 1). Show student w&b presentation with ruler, pencil & coins

 2). Show student diagram (FIGURE 11) of a see-saw balanced and one that is not balanced

 3). Show student diagram of an airplanes basic empty weight, excludes fuel.

**What we are going to learn?**

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

**Why is it important to learn?**

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

**How this will be taught:**

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

[See Figure 1 & Figure 2]

B. Station -A location on the airplane fuselage usually given in terms of distance from the reference datum

 [See Figure 1 & Figure 2]

C. Arm – The horizontal distance, usually in inches, from the reference datum to the CG of an item

i. Arms ahead of the reference datum are negative and those behind the datum are positive

ii. If the datum is ahead of the nose, all of the arms are positive

[See Figure 1 & Figure 2]

D. Moment – A force that causes or tries to cause on object to rotate

i. It is the product of the weight of an item multiplied by its arm and expressed in pound-inches

[See Figure 1 & Figure 2]

E. Moment Index – The moment divided by a reduction number (100/1000) to get it smaller/reduce errors

F. 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

[See Figure 1 & Figure 2]

G. CG Limits – The extreme (forward/aft) CG locations within which the plane must be operated at a weight

 [See Figure 3]

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 equip, unusable fuel, and full operating fluids (including oil)

K. Payload – the weight of occupants, cargo and baggage

L. Useful Load – the difference between T/O weight (or ramp weight if applicable) and basic empty weight

M. Max Ramp Weight – the max weight approved for ground maneuvers (includes start, taxi, and run-up fuel)

N. Max T/O Weight – the max weight approved for the start of the T/O 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**

[See Figure 4]

A. Weight and Flight Performance

i. A heavier gross weight will result in:

a. Longer T/O/LDG roll, shallower climb, faster touchdown speed, slow accel/deceleration.

* Increased (drag and ground friction)

b. Climb and cruise performance is reduced which can lead to:.

* Overheating in climbs, added wear on engine, increased fuel, slower cruise, reduced range

B. Weight and Structure

 [See Figure 5]

i. Structural failures from overloading may be catastrophic

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 will add up and may result in failure later during normal operations

C. Weight and Stability

 [See Figure 5]

i. A stable and controllable plane may have very different characteristics when overloaded

a. Weight distribution has most effect, but gross weight adversely affects stability regardless of CG

ii. An airplane with forward loading

[See Figure 7]

a. Is heavier forward the CG .

* Nose up trim is required which requires the tail surfaces to produce a greater download adding to the wing loading and total lift required from the wing to maintain altitude

b. Requires a higher AOA, which results in more drag and, in turn, produces a higher stalling speed

c. The airplane is more controllable (Longer arm making the elevator more effective)

iii. With aft loading, the airplane requires less download 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 load, relieving the wing of loading and lift.

* Results in a lower stall speed

c. Recovery from a stall becomes progressively more difficult as it moves aft

D. Weight and Controllability

 [See Figure 5]

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.

* Recovery from a spin may be impossible if the CG moves aft only 1 or 2 inches (Flat spin)

a 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 AS (T/O, LDG, glides)

**3. Weight and Balance Control**

[See Figure 6]

A. The pilot is responsible for the management of weight and balance

B. There are various methods to determine weight and balance conditions:

i. CG calculations; CG graphs; CG tables

1. **Determining Weight and Balance**

[See Figure 6]

A. CG = Total Moment divided by Total Weight

 Formula : CG = TM / TW

i. Begin with the empty weight and make a list of everything that will be loaded in the airplane

a. People, items, and fuel

b. Be sure the 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 in 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.

* The weight/moment of the airplane are found in its weight and balance documents

iii. Then calculate the CG – (Total Moment/Total Weight)

iv. Use the chart in FIGURE 9 AND FIGURE 10 to determine whether the airplane is within limits

SAMPLE PROBLEM: IS AIRPLANE LOADED WITHIN LIMITS?

PILOT & COPILOT 375 LBS

PASSANGERS AFT 245 LBS

BAGGAGE 65 LBS

FUEL 70 GALS

Item weight x arm = moment/100

EMPTY WGHT 2110 78.29 165192

PILOT/CO PILOT 375 85.00 31875

PASSENGERS AFT 245 136.0 33320

BAGGAGE 65 150.00 9750

FUEL (1 GL=6 LB) 420 75.0 31500

 3,215 271637

CG=TM/TW 271637/3215= 84.49

B. Weight Change and/or CG Shift

 CG = TM/TW

a. Any weight added causes a + moment change (removed is -)

b. Weight shifted rearward (aft) causes a + moment change (forward is -)

c. A weight shift changes only the moment (change in weight = 0)

SAMPLE PROBLEM:

1). what would be the new CG location if 135 lbs of weight were added at Station 109.0?

 Aircraft weight 2340 lbs

 CG Location Station 103.0

Item weight x arm = moment

Aircraft 2340 103 241,020

Wt added +135 109 +14,715

 2,475 255,735

CG=TM/TW 255735/2475=103.3

Answer: New CG located at 103.3

**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:

PRIVATE/COMMERCIAL

To determine that the applicant:

1. Computes weight and balance. Determines the computed weight and center of gravity is within the airplane’s operating limitations and if the weight and center of gravity will remain within limits during all phases of flight.

**FIGURE 1**

**FIGURE 2**

**FIGURE 3**

**FIGURE 4**

**FIGURE 5**

**FIGURE 6**

**FIGURE 7**

**FIGURE 8**

**FIGURE 9**

**FIGURE 10**

In scenario A, the torque on both sides is mgL, so the people are balanced. In scenario B, the mass on the left side is the same as the right side but it is at half the distance, therefore the torque is greater on the right side and it rotates in that direction. In scenario C, the torque on the left side is 2mgL and mgL on the right. Now the torques are unbalanced in the opposite direction, so the see saw rotates the other way. In D, the mass on the left side is again doubled, but is only half as far from the pivot, so the torque is half that in C, thus the seesaw balances with no rotation.

**FIGURE 11**