# Task II.F: Airplane Weight and Balance

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## Lesson Overview

**Objective**

The student should develop knowledge of the elements related to weight and balance, and be able to properly calculate an airplane's weight and balance for a given situation.

**Reference**

- Airplane Flying Handbook (FAA-H-8083-3B, page(s) 12-11)
- Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-25B)
- Weight and Balance Handbook (FAA-H-8083-1B)
- POH/AFM

**Key Elements**

- Performance
- Calculating weight and balance
- Adding, removing, and shifting weight

**Elements**

- Terms
- Weight and flight performance
- Weight and balance control
- Determining weight and balance

**Equipment**

- White board
- Markers
- References

**Schedule**

1. Discuss objectives
2. Review material
3. Development
4. Conclusion

**Instructor Actions**

1. Discuss lesson objectives
2. Present lecture
3. Questions
4. Homework

**Student Actions**

- Participate in discussion Take notes

# Completion Standards

The student understands the factors related to weight and balance and the airplane’s control, stability, and performance.The student can calculate the weight and balance for a given situation and make adjustments as necessary.

# Instructor Notes

**Attention**

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.

# Lesson Details

In the Principles of Flight (2-D) lesson it was made clear that the balance around the center of gravity is crucial for flight control. This lesson discusses how that balance is calculated, and how correct weight and balance is confirmed. First, a few definitions are needed.

# Terms

**Reference datum**

An imaginary vertical plane from which all horizontal distances are measured for balance purposes. May be located anywhere the manufacturer chooses) nose, engine firewall, wing's leading edge, ahead of the nose,…)

**Station**

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

**Arm**

The horizontal distance (usually in inches) from reference datum to the CG of an item. Arms ahead of the reference datum are negative, arms behind the datum are positive. If the datum is ahead of the nose, all of the arms are positive.

**Moment**

Force that causes (or tries to cause) an object to rotate.

**Moment index**

The moment divided by a reduction number (100 or 1000) to get it smaller and reduce errors.

**Center of gravity**

- The point at which the airplane would balance if suspended.
- Distance of CG from reference datum = total moment/total weight.

**Limits**

Extreme locations (forward/aft) at which the CG can be to be operated at a given weight.

**Usable fuel**

The fuel available for flight planning.

**Unusable fuel**

The fuel in the tanks that cannot be safely used in flight or drained on the ground.

# Weight Terms

**Basic Empty Weight**

The weight of the standard airplane, optional equipment, unusable fuel, and full operating fluids (including oil).

**Basic Operating Weight**

This is the basic empty weight, plus crew. This is more commonly used in larger commercial aircraft and operations.

**Payload**

The weight of the occupants, cargo, and baggage.

**Useful Load**

The difference between takeoff weight (or ramp weight, if applicable) and the basic empty weight.

**Max Ramp Weight**

The maximum weight approved for ground maneuvers (includes start, taxi, run-up fuel).

**Max Takeoff Weight**

This is the maximum weight approved for the start of the takeoff run.

**Max Landing Weight**

This is the maximum weight approved for landing touchdown.

**Max Zero Fuel Weight**

The zero fuel weight (ZFW) of an aircraft is the total weight of the airplane and all its contents, minus the total weight of the usable fuel on board (unusable fuel is included in ZFW).

# Weight and flight performance

## Higher Gross Weight Causes

- Longer takeoff/landing roll
- Shallower climb
- Faster touchdown speed
- Slower acceleration/deceleration
- Increased retarding forces (drag, ground friction)

## Reduced climb/cruise performance concequences

- Overheating during climbs
- Added wear on engine
- Increased fuel consumption
- Slower cruise speed
- Reduced range

### Structure

- Overloading can result in catastrophic structural failures. However, often, structural failures affect the structure progressively, making it difficult to detect and repair.
- Airplanes are certified to withstand structural loads based on category. Total load remains in limits if gross weight and load factor limits are observed. Exceeding the max gross weight can cause damage even if the load factors are within weight limits.
- Cumulative results of routine overloading can result in failure later on during normal operations.

### Stability

#### Airplane with forward loading

- Slower
- Nose-up trim required, requires tail surfaces to produce a greater down load, adding to wing loading/total lift required from wing to maintain altitude.
- Requires a higher AOA, resulting in more drag, producing a higher stalling speed.
- More controllability—longer arm makes elevator more effective.

#### Airplane with aft loading

- Faster cruise.
- Reduced drag (smaller AOA, less down deflection on stabilizer)
- Tail surface produces less down load, relieving the wing of loading and lift.
- Lower stall speed.
- Recovery from stall becomes progressively more difficult as CG moves aft.

### Controllability

- Generally, aircraft becomes less controllable as CG moves aft.
- The elevator arm is shorter, requires greater deflection for the same result.
- Aft CG makes stall recovery harder—plane's tendency to pitch down is reduced. Moving the CG beyond the aft limit may make stall and spin recovery impossible.
- Moving the CG forward makes the airplane more nose-heavy, and the elevator may be unable to hold up the nose, especially at low airspeeds.

## Weight and balance control

The pilot is responsible for managing weight and balance, and determining weight and balance conditions via various methods:

- CG calculations

- CG graphs
- CG tables

# Determining weight and balance

CG = total moment/total weight

1. Beginning with the empty weight, list everything that will be loaded in the airplane (people, items, fuel).
2. Make sure the loaded weight is within limits. If too high, remove items/people.
3. Calculate moments of each item—use graph, or multiply weight by arm.
4. Calculate CG.
5. Determine if CG is within limits.

### Weight change, CG shift

**CG = (M+ΔM)/(W+ΔW)**

- Weight added causes a positive moment change.
- Weight shifted aft causes a positive moment change, weight shifted forward causes a negative moment change.

# Conclusion

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

# ACS Requirements

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.