Chapter 1

Weight and Balance Control

Why is Weight and Balance Important?

Weight and balance is one of the most important factors affecting safety of flight. An overweight aircraft, or one whose center of gravity is outside the allowable limits, is inefficient and dangerous to fly. The responsibility for proper weight and balance control begins with the engineers and designers and extends to the pilot who operates and the Aviation Main-tenance Technician (AMT) who maintains the aircraft.

Modern aircraft are engineered utilizing state-of-the-art technology and materials to lift the maximum amount of weight and carry it the greatest distance at the highest speed. As much care and expertise must be exercised in operating and maintaining these efficient aircraft as was taken in their design and manufacturing.

Various types of aircraft have different load requirements. Transport aircraft must carry huge loads of passengers and cargo for long distances at high altitude and high speed. Military aircraft must be highly maneuverable and extremely sturdy. Corporate aircraft must carry a reasonable load at a high speed for long distances. Agricultural aircraft must carry large loads short distances and be extremely maneuverable. Trainers and private aircraft must be lightweight, low cost, simple, and safe to operate.

All aircraft regardless of their function have two characteristics in common: all are sensitive to weight, and the center of gravity of the aircraft must be maintained within a specified range.

The designers of an aircraft have determined the **maximum weight**, based on the amount of lift the wings or rotors can provide under the operating conditions for which the aircraft is designed. The structural strength of the aircraft also limits the maximum weight the aircraft can safely carry. The ideal location of the **center of gravity (CG)** was very carefully determined by the designers, and the maximum deviation allowed from this specific location has been calculated.

The manufacturer provides the aircraft operator with the **empty weight** of the aircraft and the location of its **empty-weight center of gravity (EWCG)** at the time the aircraft left the factory. The AMT who maintains the aircraft and performs the maintenance inspections keeps the weight and balance records current, recording any changes that have been made because of repairs or alterations.

The pilot in command of the aircraft has the responsibility on every flight to know the maximum allowable gross weight of the aircraft and its CG limits. This allows the pilot to determine on the preflight inspection that the aircraft is loaded in such a way that the CG is within the allowable limits.

Weight and balance technology, like all other aspects of aviation, has become more complex as the efficiency and capability of aircraft and engines have increased. Therefore, this requires all pilots and AMTs to understand weight and balance control, and to operate and maintain their aircraft so its weight and CG location are within the limitations established when the aircraft was designed, manufactured, and certified by the FAA.

Maximum weight: The maximum authorized weight of the aircraft and all of its equipment as specified in the Type Certificate Data Sheets (TCDS) for the aircraft.

Center of gravity (CG): The point at which an airplane would balance if suspended. Its distance from the reference datum is found by dividing the total moment by the total weight of the airplane.

Empty weight: The weight of the airframe, engines, and all items of operating equipment that have fixed locations and are permanently installed in the aircraft.

Empty-weight center of gravity (EWCG): The center of gravity of an aircraft, when the aircraft contains only the items specified in the aircraft empty weight.

Weight Control

Weight is a major factor in airplane construction and operation, and it demands respect from all pilots and particular diligence by all AMTs. **Excessive weight reduces the efficiency of an aircraft and the safety margin available if an emergency condition should arise.**

When an aircraft is designed, it is made as light as the required structural strength will allow, and the wings or rotors are designed to support the maximum allowable gross weight. When the weight of an aircraft is increased, the wings or rotors must produce additional lift and the structure must support not only the additional **static loads**, but also the **dynamic loads** imposed by flight maneuvers. For example, the wings of a 3,000-pound airplane must support 3,000 pounds in level flight, but when the airplane is turned smoothly and sharply using a bank angle of 60°, the dynamic load requires the wings to support twice this, or 6,000 pounds.

Severe uncoordinated maneuvers or flight into turbulence can impose dynamic loads on the structure great enough to cause failure. The structure of a normal category airplane must be strong enough to sustain a **load factor** of 3.8 times its weight; that is, every pound of weight added to an aircraft requires that the structure be strong enough to support an additional 3.8 pounds. An aircraft operating in the utility category must sustain a load factor of 4.4, and acrobatic category aircraft must be strong enough to withstand 6.0 times their weight.

The lift produced by a wing is determined by its airfoil shape, angle of attack, speed through the air, and the air density. When an aircraft takes off from an airport with a high **density altitude**, it must accelerate to a speed faster than would be required at sea level to produce enough lift to allow takeoff; therefore, a longer takeoff run is necessary. The distance needed may be longer than the available runway. When operating from a high density altitude airport, the **Pilot's Operating Handbook (POH)** or **Airplane Flight Manual (AFM)** must be consulted to determine the maximum weight allowed for the aircraft under the conditions of altitude, temperature, wind, and runway conditions.

Effects of Weight

Most modern aircraft are so designed that if all seats are occupied, all baggage allowed by the baggage compartment structure is carried, and all of the fuel tanks are full, the aircraft will be grossly overloaded. This type of design gives the pilot a great deal of latitude in loading the aircraft for a particular flight. If maximum range is required, occupants or baggage must be left behind, or if the maximum load must be carried, the range, dictated by the amount of fuel on board, must be reduced.

Some of the problems caused by overloading an aircraft are:

- The aircraft will need a higher takeoff speed, which results in a longer takeoff run.
- Both the rate and angle of climb will be reduced.
- The **service ceiling** will be lowered.
- The cruising speed will be reduced.
- The cruising range will be shortened.
- Maneuverability will be decreased.
- A longer landing roll will be required because the landing speed will be higher.
- Excessive loads will be imposed on the structure, especially the landing gear.

The POH or AFM includes tables or charts that give the pilot an indication of the performance expected for any gross weight. An important part of careful preflight planning includes a check of these charts to determine the aircraft is loaded so the proposed flight can be safely made.

High Density Altitude Airport Operations

Consult the POH or AFM to determine the maximum weight allowed for the aircraft under the conditions of altitude, temperature, wind, and runway conditions.

Your preflight planning must include a careful check of gross weight performance charts to determine the aircraft is loaded properly and the proposed flight can be safely made.

Static load: The load imposed on an aircraft structure due to the weight of the aircraft and its contents.

Dynamic load: The actual weight of the aircraft multiplied by the load factor, or the increase in weight caused by acceleration.

Load factor: The ratio of the maximum load an aircraft can sustain to the total weight of the aircraft. Normal category aircraft must have a load factor of at least 3.8, utility category aircraft 4.4, and acrobatic category aircraft, 6.0.

Density altitude: Pressure altitude corrected for nonstandard temperature.

Pilot's Operating Handbook (POH): An FAA-approved document published by the airframe manufacturer that lists the operating conditions for a particular model of aircraft and its engines.

Airplane Flight Manual (AFM): An FAA-approved document, prepared by the holder of a Type Certificate for an airplane or rotorcraft, that specifies the operating limitations and contains the required markings and placards and other information applicable to the regulations under which the aircraft was certificated.

Weight Changes

The maximum allowable gross weight for an aircraft is determined by design considerations. However, the maximum operational weight may be less than the maximum allowable due to such considerations as high density altitude or high-drag field conditions caused by wet grass or water on the runway. The maximum gross weight may also be limited by the departure or arrival airport's runway length.

One important preflight consideration is the distribution of the load in the aircraft. **Loading an aircraft so the gross weight is less than the maximum allowable is not enough. This weight must be distributed to keep the CG within the limits specified in the POH or AFM.**

If the CG is too far forward, a heavy passenger can be moved to one of the rear seats or baggage can be shifted from a forward baggage compartment to a rear compartment. If the CG is too far aft, passenger weight or baggage can be shifted forward. The fuel load should be **balanced laterally**: the pilot should pay special attention to the POH or AFM regarding the operation of the fuel system, in order to keep the aircraft balanced in flight.

Weight and balance of a helicopter is far more critical than for an airplane. A helicopter may be properly loaded for takeoff, but near the end of a long flight when the fuel tanks are almost empty, the CG may have shifted enough for the helicopter to be out of balance laterally or longitudinally. Before making any long flight, the CG with the fuel available for landing must be checked to ensure it will be within the allowable range.

Airplanes with tandem seating normally have a limitation requiring solo flight to be made from the front seat in some airplanes or the rear seat in others. Some of the smaller helicopters also require solo flight be made from a specific seat, either the right or the left. These seating limitations will be noted by a placard, usually on the instrument panel, and they should be strictly adhered to.

As an aircraft ages, its weight usually increases due to trash and dirt collecting in hard-to-reach locations, and moisture absorbed in the cabin insulation. This growth in weight is normally small, but it can only be determined by accurately weighing the aircraft.

Changes of fixed equipment may have a major effect upon the weight of the aircraft. Many aircraft are overloaded by the installation of extra radios or instruments. Fortunately, the replacement of older, heavy electronic equipment with newer, lighter types results in a weight reduction. This weight change, however helpful, will probably cause the CG to shift and this must be computed and annotated in the weight and balance data.

Repairs and alterations are the major sources of weight changes, and it is the responsibility of the AMT making any repair or alteration to know the weight and location of these changes, and to compute the new CG and record the new empty weight and EWCG in the aircraft weight and balance data.

The AMT conducting an annual or 100-hour inspection must ensure the weight and balance data in the aircraft records is current and accurate. It is the responsibility of the pilot in command to use the most current weight and balance data when operating the aircraft.

Has the Aircraft Gained Weight?

As an aircraft ages, its weight usually increases. Repairs and alterations are the major sources of weight change.

AMTs conducting an annual or 100-hour inspection must ensure the weight and balance data in the aircraft records is current and accurate. The pilot in command's responsibility is to use the most current weight and balance data when planning a flight.

Service ceiling: The highest altitude at which an aircraft can maintain a steady rate of climb of 100 feet per minute.

Balanced laterally: Balanced in such a way that the wings tend to remain level.

Stability and Balance Control

Balance control refers to the location of the CG of an aircraft. This is of primary importance to aircraft stability, which determines safety in flight.

The CG is the point at which the total weight of the aircraft is assumed to be concentrated, and the CG must be located within specific limits for safe flight. Both lateral and **longitudinal balance** are important, but the prime concern is longitudinal balance; that is, the location of the CG along the **longitudinal** or lengthwise **axis**.

An airplane is designed to have stability that allows it to be trimmed so it will maintain straight and level flight with hands off of the controls. Longitudinal stability is maintained by ensuring the CG is slightly ahead of the center of lift. This produces a fixed nose-down force independent of the airspeed. This is balanced by a variable nose-up force, which is produced by a downward aerodynamic force on the horizontal tail surfaces that varies directly with airspeed. [Figure 1-1]

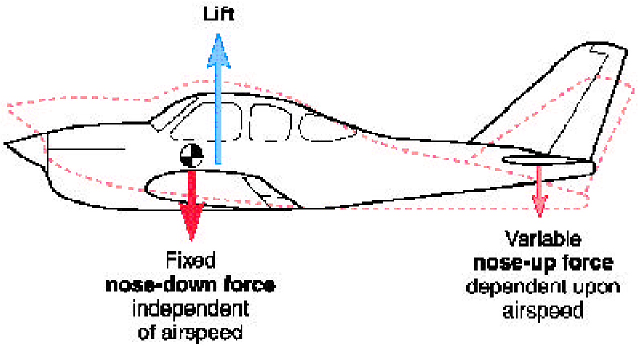

Figure 1-1. *Longitudinal forces acting on an airplane in flight.*

If a rising air current should cause the nose to pitch up, the airplane will slow down and the downward force on the tail will decrease. The weight concentrated at the CG will pull the nose back down. If the nose should drop in flight, the airspeed will increase and the increased downward tail load will bring the nose back up to level flight.

As long as the CG is maintained within the allowable limits for its weight, the airplane will have adequate longitudinal stability and control. If the CG is too far aft, it will be too near the **center of lift** and the airplane will be unstable, and difficult to recover from a stall. [Figure 1-2] If the unstable airplane should ever enter a spin, the spin could become flat and recovery would be difficult or impossible.

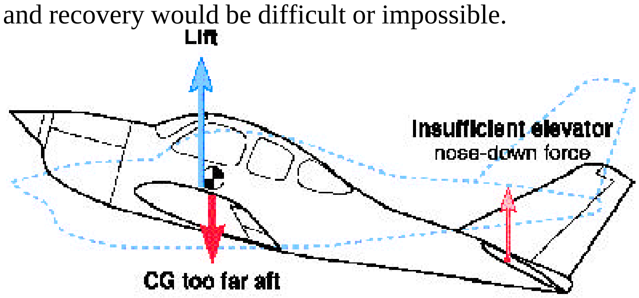

Figure 1-2. *If the CG is too far aft, at the low stall airspeed there might not be enough elevator nose-down force to get the nose down for recovery.*

If the CG is too far forward, the downward tail load will have to be increased to maintain level flight. This increased tail load has the same effect as carrying additional weight — the aircraft will have to fly at a higher angle of attack, and drag will increase.

A more serious problem caused by the CG being too far forward is the lack of sufficient elevator authority. At slow takeoff speeds, the elevator might not produce enough nose-up force to rotate and on landing there may not be enough elevator force to flare the airplane. [Figure 1-3] Both takeoff and landing runs will be lengthened if the CG is too far forward.

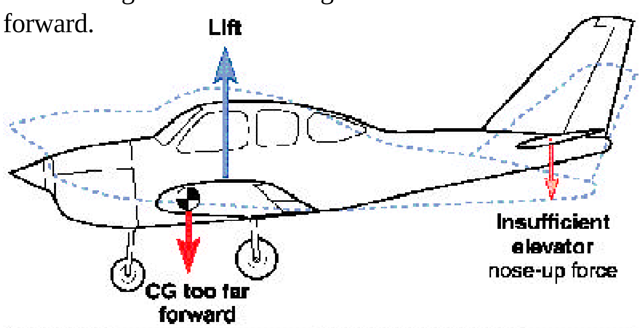

Figure 1-3. *If the CG is too far forward, there will not be enough elevator nose-up force to flare the airplane for landing.*

Longitudinal balance: Balance around the pitch, or lateral, axis.

Longitudinal axis: An imaginary line through an aircraft from nose to tail, passing through its center of gravity.

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.

The efficiency of some modern high-performance military fighter airplanes is increased by giving them neutral longitudinal stability. This is normally a very dangerous situation; but these aircraft are flown by autopilots which react far faster than a human pilot, and they are safe for their special operations.

The basic aircraft design assumes that lateral symmetry exists. For each item of weight added to the left of the centerline of the aircraft (also known as **buttock line zero**, or BL-0), there is generally an equal weight at a corresponding location on the right.

The **lateral balance** can be upset by uneven fuel loading or burnoff. The position of the lateral CG is not normally computed for an airplane, but the pilot must be aware of the adverse effects that will result from a laterally unbalanced condition. [Figure 1-4] This is corrected by using the aileron trim tab until enough fuel has been used from the tank on the heavy side to balance the airplane. The deflected trim tab deflects the aileron to produce additional lift on the heavy side, but it also produces additional drag, and the airplane flies inefficiently.

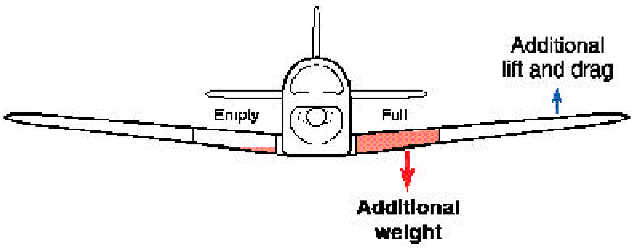

Figure 1-4. *Lateral imbalance causes wing heaviness, which may be corrected by deflecting the aileron. The additional lift causes additional drag and the airplane flies inefficiently.*

Helicopters are affected by lateral imbalance more than airplanes. If a helicopter is loaded with heavy occupants and fuel on the same side, it could be enough out of balance to make it unsafe to fly. It is also possible that if external loads are carried in such a position to require large lateral displacement of the cyclic control to maintain level flight, the fore-and-aft cyclic control effectiveness will be limited.

Sweptwing airplanes are more critical due to fuel imbalance because as the fuel is used from the outboard tanks the CG shifts forward, and as it is used from the inboard tanks the CG shifts aft. [Figure 1-5] For this reason, fuel-use scheduling in high-speed jet aircraft operation is critical.

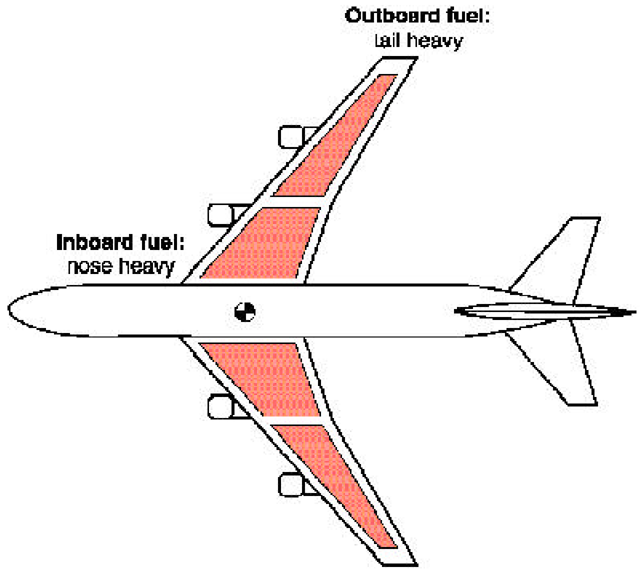

Figure 1-5. *Fuel in the tanks of a sweptwing airplane affects both lateral and longitudinal balance. As fuel is used from an outboard tank, the CG shifts forward.*

Aircraft can perform safely and achieve their designed efficiency only when they are operated and maintained in the way their designers intended. This safety and efficiency is determined to a large degree by holding the aircraft's weight and balance parameters within the limits specified for its design. The remainder of this book describes the way in which this is done.

Butt (or buttock) line zero: A line through the symmetrical center of an aircraft from nose to tail. It serves as the datum for measuring the arms used to find the lateral CG. Lateral moments that cause the aircraft to rotate clockwise are positive (+), and those that cause it to rotate counter-clockwise are negative (–).

Lateral balance: Balance around the roll, or longitudinal, axis.