Weight and Balance Control

Chapter 1

There are many factors that lead to efficient and safe operation of aircraft. Among these vital factors is proper weight and balance control. The weight and balance system commonly employed among aircraft consists of three equally important elements: the weighing of the aircraft, the maintaining of the weight and balance records, and the proper loading of the aircraft. An inaccuracy in any one of these elements nullifies the purpose of the whole system. The final loading calculations will be meaningless if either the aircraft has been improperly weighed or the records contain an error.

Improper loading cuts down the efficiency of an aircraft from the standpoint of altitude, maneuverability, rate of climb, and speed. It may even be the cause of failure to complete the flight, or for that matter, failure to start the flight. Because of abnormal stresses placed upon the structure of an improperly loaded aircraft, or because of changed flying characteristics of the aircraft, loss of life and destruction of valuable equipment may result.

The responsibility for proper weight and balance control begins with the engineers and designers, and extends to the aircraft mechanics that maintain the aircraft and the pilots who operate them.

Modern aircraft are engineered utilizing state-of-the-art technology and materials to achieve maximum reliability and performance for the intended category. As much care and expertise must be exercised in operating and maintaining these efficient aircraft as was taken in their design and manufacturing.

The designers of an aircraft have set the maximum weight, based on the amount of lift the wings or rotors can provide under the operation 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 certified aircraft leaves the factory. Amateur-built aircraft must have this information determined and available at the time of certification.

The airframe and powerplant (A&P) mechanic or repairman who maintains the aircraft 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 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 Control

Weight is a major factor in airplane construction and operation, and it demands respect from all pilots and particular diligence by all A&P mechanics and repairmen. **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 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. In accordance with Title 14 of the Code of Federal Regulations (14 CFR) part 23, 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 operated 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 is carried, and all of the fuel tanks are full, the aircraft will be grossly overloaded. This type of design requires the pilot to give great consideration to the requirements of the trip. 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 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.

Weight Changes

The maximum allowable weight for an aircraft is determined by design considerations. However, the maximum operational weight may be less than the maximum allowable weight due to such considerations as high-density altitude or high-drag field conditions caused by wet grass or water on the runway. The maximum operational 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 the 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. With some helicopters, they 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, left, or center. 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 record.

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

If the newly calculated EWCG should happen to fall outside the EWCG range, it will be necessary to perform adverse loading check. This will require a forward and rearward adverse-loading check, and a maximum weight check. These weight and balance extreme conditions represent the maximum forward and rearward CG position for the aircraft. Adverse loading checks are a deliberate attempt to load an aircraft in a manner that will create the most critical balance condition and still remain within the design CG limits of the aircraft. If any of the checks fall outside the loaded CG range, the aircraft must be reconfigured or placarded to prevent the pilot from loading the aircraft improperly. It is sometimes possible to install fixed ballast in order for the aircraft to again operate within the normal CG range.

The A&P mechanic or repairman conducting an annual or condition 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.

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 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 the airspeed. [Figure 1-1]

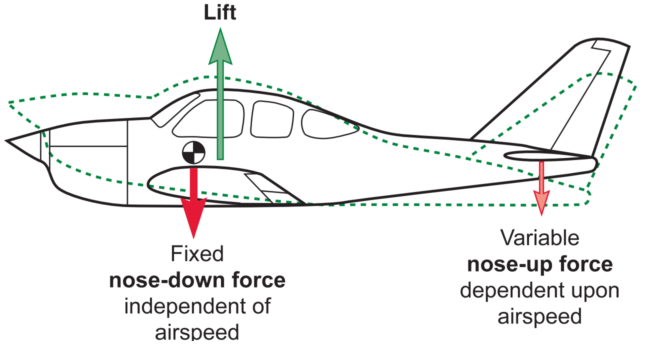

Figure 1-1. *Longitudinal forces acting on an airplane in flight.*

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.

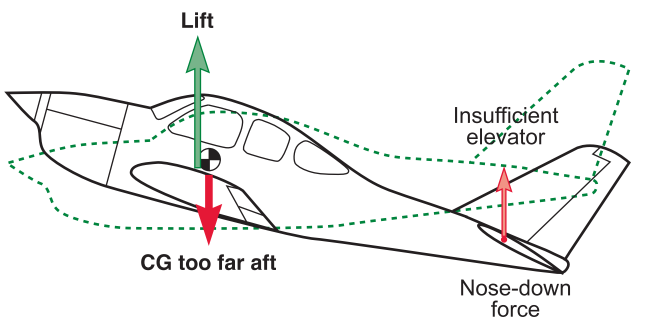

Figure 1-2. *If the CG is too far aft at the low stall airspeed, there might not be enough elevator nose-down authority to get the nose down for recovery.*

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.

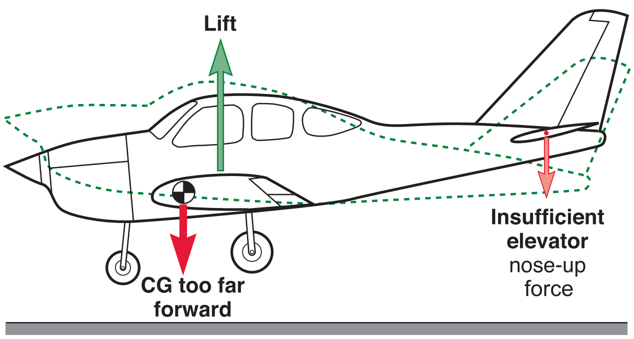

Figure 1-3. *If the CG is too far forward, there will not be enough elevator nose-up force to flare the airplane for landing.*

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.

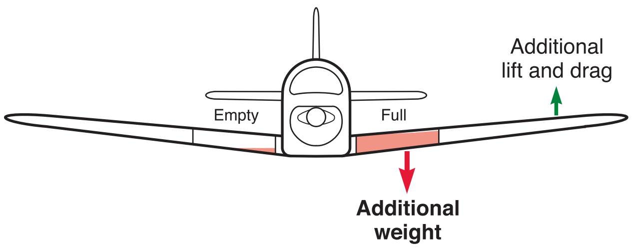

Figure 1-4. *Lateral imbalance causes wing heaviness, which may be corrected by deflecting the aileron. The additional lift causes additional drag and the airplane flies inefficiently.*

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 out of balance enough 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 sweptwing airplanes operation is critical.

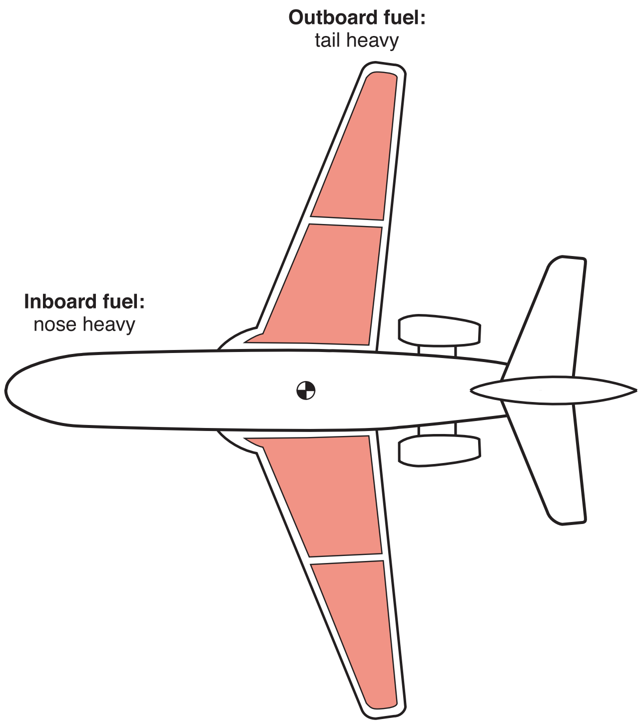

Figure 1-5. *Fuel in the tanks of a sweptwing airplane affects both lateral and longitudinal balance. As fuel is used from an outboard tank, the CG shifts forward.*

Weight Control for Aircraft other than Fixed and Rotorwing

Some light aircraft utilize different methods of determining weight and balance from the traditional fixed and rotorwing aircraft. These aircraft achieve flight control differently than the fixed-wing airplane or helicopter. Most notable of these are weight shift control (WSC) aircraft (also known as trikes), powered parachutes, and balloons.

These aircraft typically do not specify either an empty weight center of gravity or a center of gravity range. They require only a certified or approved maximum weight.

To understand why this is so, a look at how flight control is achieved is helpful.

As an example, airplanes and WSC aircraft both control flight under the influence of the same four forces (lift, gravity, thrust, and drag), and around the same three axes (pitch, yaw, and roll). However, each aircraft accomplishes this control in a very different manner. This difference helps explain why the fixed-wing airplane requires an established weight and a known center of gravity, whereas the WSC aircraft only requires the known weight.

The fixed-wing airplane has moveable controls that alter the lift on various airfoil surfaces to vary pitch, roll, and yaw. These changes in lift, in turn, change the characteristics of the flight parameters. Weight normally decreases in flight due to fuel consumption, and the airplane center of gravity changes with this weight reduction. An airplane utilizes its variable flight controls to compensate and maintain controllability through the various flight modes and as the center of gravity changes. An airplane has a center of gravity range or envelope within which it must remain if the flight controls are to remain effective and the airplane safely operated.

The WSC aircraft has a relatively set platform wing without a tail. The pilot, achieves control by shifting weight. In the design of this aircraft, the weight of the airframe and its payload is attached to the wing at a single point in a pendulous arrangement. The pilot through the flight controls, controls the arm of this pendulum and thereby controls the aircraft. When a change in flight parameter is desired, the pilot displaces the aircraft's weight in the appropriate distance and direction. This change momentarily disrupts the equilibrium between the four forces acting on the aircraft. The wing, due to its inherent stability, then moves appropriately to re-establish the desired relationship between these forces. This happens by the wing flexing and altering its shape. As the shape is changed, lift is varied at different points on the wing to achieve the desired flight parameters.

The flight controls primarily affect the pitch-and-roll axis. Since there is no vertical tail plane, minimal or no ability exists to directly control yaw. However, unlike the airplane, the center of gravity experienced by the wing remains constant. Since the weight of the airframe acts through the single point (wing attach point), the range over which the weight may act is fixed at the pendulum arm or length. Even though the weight decreases as fuel is consumed, the weight remains focused at the wing attach point. Most importantly, because the range is fixed, the need to establish a calculated range is not required.

The powered parachute also belongs to the pendulum-style aircraft. Its airframe center of gravity is fixed at the pendulum attach point. It is more limited in controllability than the WSC aircraft because it lacks an aerodynamic pitch control. Pitch (and lift) control is primarily a function of the power control. Increased power results in increased lift; cruise power amounts to level flight; decreased power causes a descent. Due to this characteristic, the aircraft is basically a one-air speed aircraft. Once again, because the center of gravity is fixed at the attach point to the wing, there can be no center of gravity range.

Roll control on a powered parachute is achieved by changing the shape of the wing. The change is achieved by varying the length of steering lines attached to the outboard trailing edges of the wing. The trailing edge of the parachute is pulled down slightly on one side or the other to create increased drag along that side. This change in drag creates roll and yaw, permitting the aircraft to be steered.

The balloon is controlled by the pilot only in the vertical dimension; this is in contrast to all other aircraft. He or she achieves this control through the use of lift and weight. Wind provides all other movement. The center of gravity of the gondola remains constant beneath the balloon envelope. As in WSC and powered-parachute aircraft, there is no center of gravity limitation.

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 handbook describes the way in which this is done.