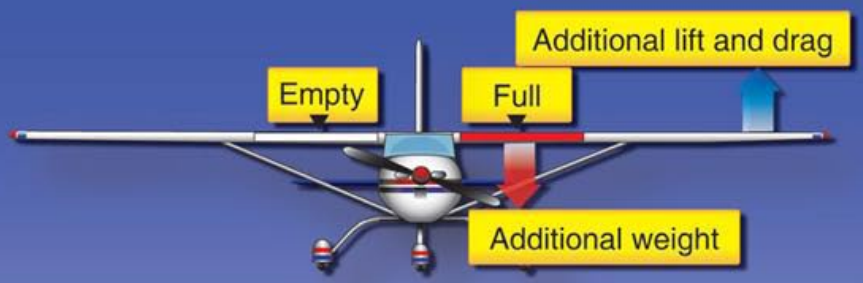
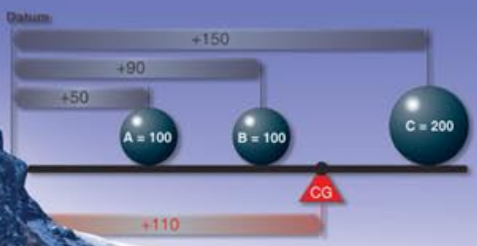
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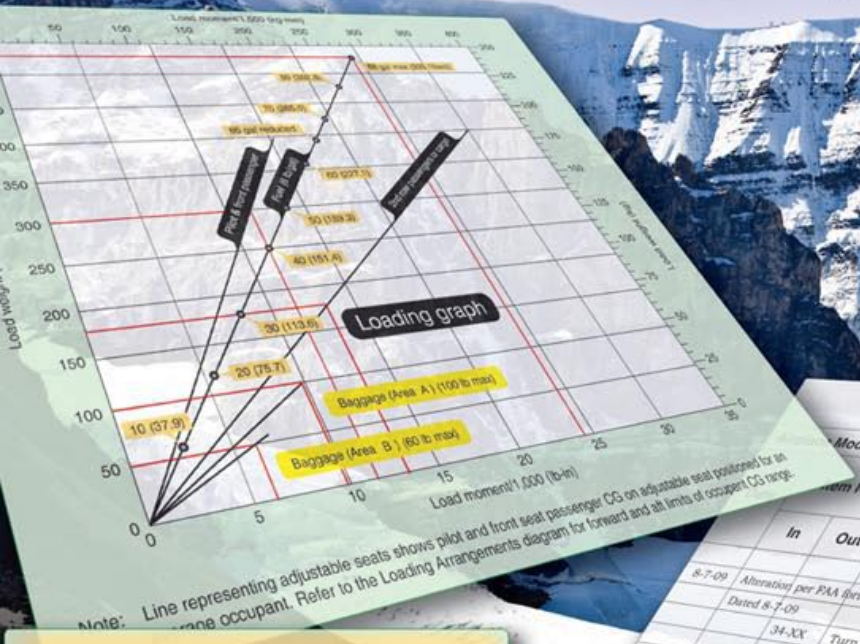
Aircraft Weight and Balance Handbook

U.S. Department of Transportation
Federal Aviation Administration





Item	Weight (lb)	Arm (in)	Moment	CG
Weight A	100	–100	–10,000	
Weight B	100	–60	–6,000	
	200		0	
			–16,000	–40



Weight and Balance Record

(Continuous history of changes in structure in structure or equipment affecting weight and balance)

Model Cessna 182L — Serial Number 18259080 — Page N

Item No. In	Item No. Out	Description of article or modification	Weight Change Added (+) Wt. (lb)	Added (+) Arm (in)	Added (+) Moment /1,000	Removed (–) Wt. (lb)	Removed (–) Arm (in)	Removed (–) Moment /1,000	W (lb)
8-7-09		As delivered							1,876
Alteration per FAA form 337 Dated 8-7-09									
	34-XX	Turn coordinator	7.38		.346				
34-XX		Directional gyro							1,883.4
22-XX		Auto pilot system	13.0	32.7	.425	-2.5	15.0	-.037	1,880.9
						-3.12	13.5	-.042	1,877.8
									1,890.8

$$\text{CG in \% MAC} = \frac{\text{CG in inches from LEMAC} \times 100}{\text{MAC}}$$

$$= \frac{22.37 \times 100}{61.6}$$

$$= 36.3\% \text{ MAC}$$

Aircraft Weight and Balance Handbook

2016

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U.S. Department of Transportation
FEDERAL AVIATION ADMINISTRATION
Flight Standards Service

Aircraft Weight and Balance Handbook
2016
FAA-H-8083-1B

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Preface

The Aircraft Weight and Balance Handbook has been prepared in recognition of the importance of weight and balance technology in conducting safe and efficient flight. The objective of this handbook is twofold: to provide the airframe and powerplant mechanic (A&P) with the method of determining the empty weight and empty weight center of gravity (EWCG) of an aircraft and to furnish the flight crew with information on loading and operating the aircraft to ensure its weight is within the allowable limit and the center of gravity (CG) is within the allowable range.

Any time there is a conflict between the information in this handbook and specific information issued by an aircraft manufacturer, the manufacturer's data takes precedence over information in this handbook. Occasionally, the word "must" or similar language is used where the desired action is deemed critical. The use of such language is not intended to add to, interpret, or relieve a duty imposed by Title 14 of the Code of Federal Regulations (14 CFR).

It is essential for persons using this handbook to become familiar with and apply the pertinent parts of 14 CFR. The current Flight Standards Service airman training and testing material and learning statements for all airman certificates and ratings can be obtained from www.faa.gov.

This handbook supersedes FAA-H-8083-1A, Aircraft Weight and Balance Handbook, dated 2007.

This handbook is available for download, in PDF format, from www.faa.gov.

This handbook is published by the United States Department of Transportation, Federal Aviation Administration, Airman Testing Standards Branch, AFS-630, P.O. Box 25082, Oklahoma City, OK 73125.

Comments regarding this publication should be sent, in email form, to the following address:

AFS630comments@faa.gov.



John S. Duncan
Director, Flight Standards Service

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Introduction

This handbook begins with the basic principle of aircraft weight and balance control, emphasizing its importance and including examples of documentation furnished by the aircraft manufacturer and by the FAA to ensure the aircraft weight and balance records contain the proper data.

Procedures for the preparation and the actual weighing of an aircraft are described, as are the methods of determining the location of the empty weight center of gravity (EWCG) relative to both the datum and the mean aerodynamic chord (MAC).

Loading computations for general aviation aircraft are discussed using both loading graphs and tables of weight and moment indexes.

Information is included that allows an FAA-certificated mechanic or repairman to determine the weight and center of gravity (CG) changes caused by repairs and alterations or removal and installation of equipment. This includes instructions for conducting adverse-loaded CG checks, also explaining the way to determine the amount and location of ballast needed to bring the CG within allowable limits.

The unique requirements for helicopter weight and balance control are discussed, including the determination of lateral CG and the way both lateral and longitudinal CG change as fuel is consumed.

One chapter includes the methods and examples of solving weight and balance problems using a hand-held electronic calculator, E6-B flight computer, and a dedicated electronic flight computer.

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Acknowledgments

The Aircraft Weight and Balance Handbook (FAA-H-8083-1B) was produced by the Federal Aviation Administration (FAA) with the assistance of Safety Research Corporation of America (SRCA). The FAA wishes to acknowledge the following contributors:

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Sporty's Pilot Shop, for image of an E6B Flight Computer used in Chapter 10

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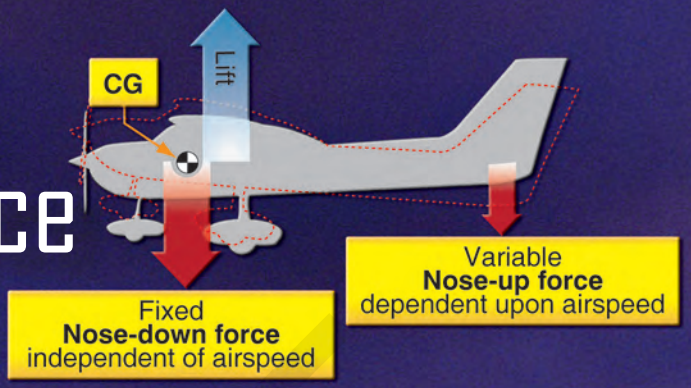
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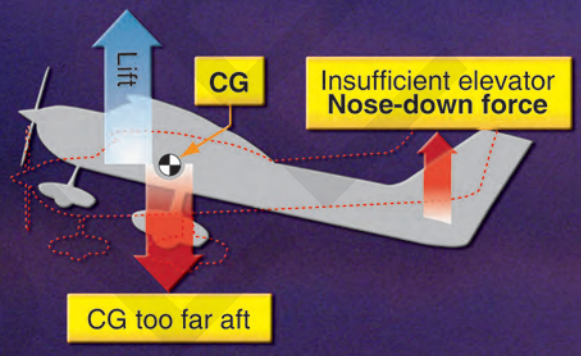
Chapter 1

Weight and Balance Control

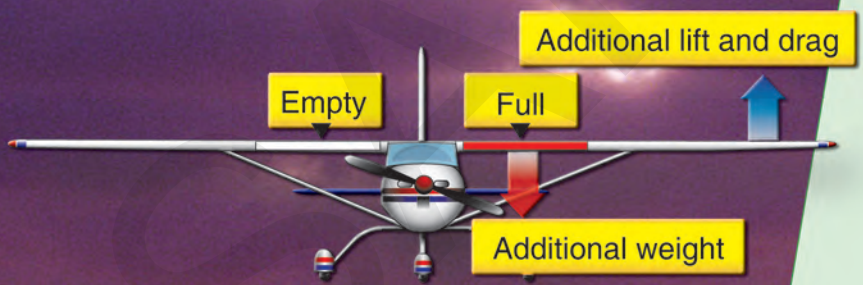


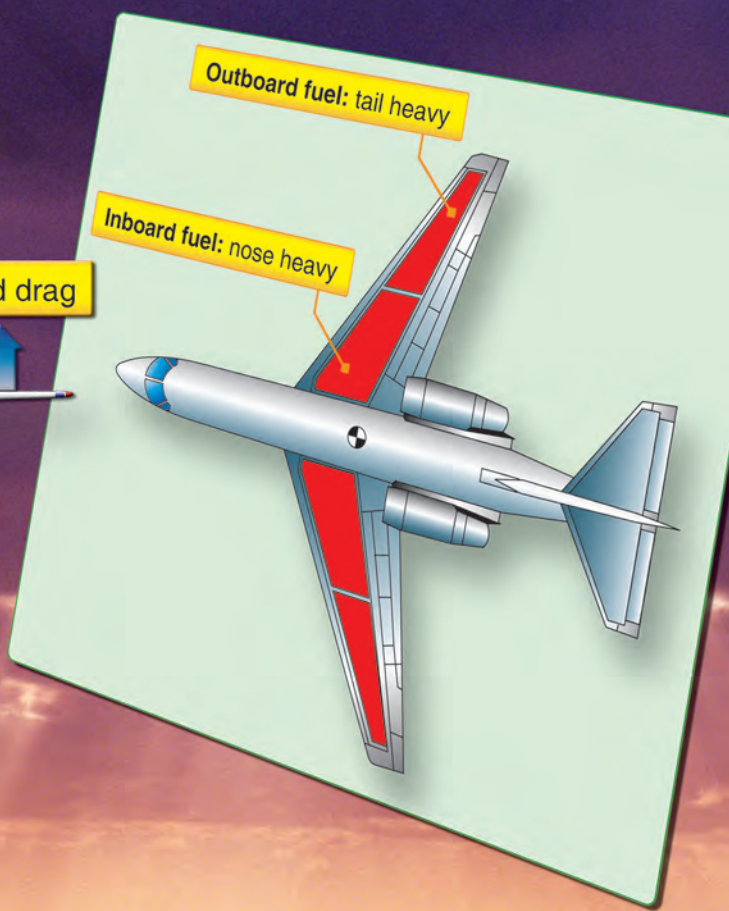
Introduction

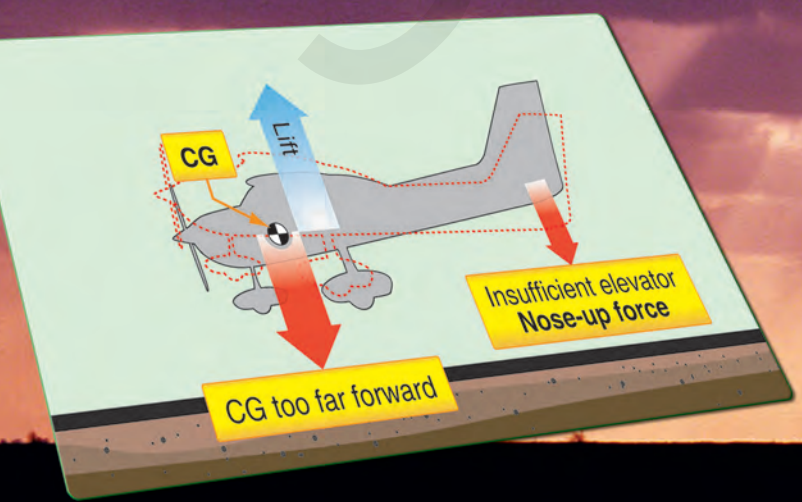
There are many factors in the safe and efficient operation of aircraft, including proper weight and balance control. The weight and balance system commonly employed among aircraft consists of three equally important elements: the weighing of the aircraft, the maintaining of the weight and balance records,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



Improper loading decreases the efficiency and performance 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.







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 how this is done.

Responsibility for Weight and Balance Control

The responsibility for proper weight and balance control begins with the engineers and designers and extends to the technicians who 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:

1. The designers of an aircraft set the maximum weight based on the amount of lift the wings or rotors can provide under the operational conditions for which the aircraft is designed. The structural strength of the aircraft also limits the maximum weight the aircraft can safely carry. The designers carefully determine the ideal center of gravity (CG) and calculate the maximum allowable deviation from this specific location.
2. 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.
3. The FAA-certificated 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.
4. The pilot in command (PIC) has the responsibility prior to every flight to know the maximum allowable weight of the aircraft and its CG limits. This allows the pilot to determine during the preflight inspection that the aircraft is loaded so that the CG is within the allowable limits.

Terminology

Pilots and FAA-certificated mechanics or repairmen must ensure they understand the terms as they relate to the aircraft in question. For small aircraft terminology, use the information found in sources associated with Civil Air Regulation (CAR) 3 certification or General Aviation Manufacturers Association (GAMA) Specification No. 1 for part 23 aircraft or part 27 for rotorcraft. For terminology applied to large part 25 aircraft, information can be found in Advisory Circular (AC) 120-27, Aircraft Weight and Balance Control. The glossary contains the most current terms and definitions. Current regulations are available from the Superintendent of Documents; U.S. Government Printing Office; Washington, DC 20402. They are also located on the FAA website at www.faa.gov. Earlier regulations may be available in libraries or in the Federal Register.

Weight Control

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

When an aircraft is designed, it is made as light as the required structural strength allows, 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. Every pound of weight added to a normal category aircraft requires that the structure be strong enough to support 3.8 pounds. An aircraft operated in the utility category must sustain a load factor of 4.4 times its weight, 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 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, when all seats are occupied, the baggage compartment is full, and all fuel tanks are full, the aircraft is grossly overloaded. This type of design requires the pilot to give great consideration to the requirements of each specific 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.

Overloading an aircraft can create a variety of problems:

- The aircraft needs a higher takeoff speed, which results in a longer takeoff run.
- Both the rate and angle of climb are reduced.
- The service ceiling is lowered.
- The cruising speed is reduced.
- The cruising range is shortened.
- Maneuverability is decreased.
- A longer landing roll is required because the landing speed is higher.
- Excessive loads are 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 if 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 may 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. Some helicopters 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 is 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 are noted by a placard, usually on the instrument panel, and they should be strictly followed.

As an aircraft ages, its weight usually increases due to debris and dirt collecting in hard-to-reach locations and moisture absorbed in the cabin insulation. This increase in weight is normally small, but it can be determined only 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, can cause the CG to shift, which must be computed and annotated in the weight and balance record.

Repairs and alterations are the major sources of weight changes. It is the responsibility of the FAA-certificated mechanic or repairman making any repair or alteration to know the weight and location of a change, to compute the CG, record the new empty weight and EWCG in the aircraft weight and balance record, and update the equipment lists.

If the newly calculated EWCG should happen to fall outside the EWCG range, it is necessary to perform an adverse-loading check. This requires 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. An adverse-loading check is a deliberate attempt to load an aircraft in a manner that creates the most critical balance condition and still remains within the design CG limits of the aircraft. If any of the checks fall outside the loaded CG range,

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the aircraft must be reconfigured or placarded to prevent the pilot from loading the aircraft improperly. It is sometimes possible to install a fixed ballast in order for the aircraft to operate again within the normal CG range.

The FAA-certificated 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 PIC 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 is a factor in flight safety. 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 to 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

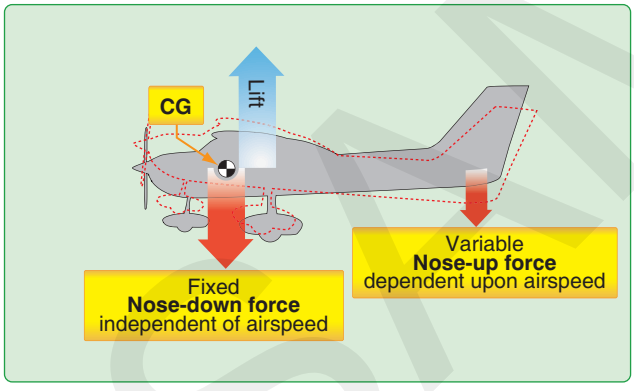


Figure 1-1. *Longitudinal forces acting on an airplane in flight.*

that varies directly with the airspeed. *[Figure 1-1]* If a rising air current should cause the nose to pitch up, the airplane slows and the downward force on the tail decreases. The weight concentrated at the CG pulls the nose back down. If the nose should drop in flight, the airspeed increases and the increased downward tail load brings the nose back up to level flight.

As long as the CG is maintained within the allowable limits for its weight, the airplane has adequate longitudinal stability

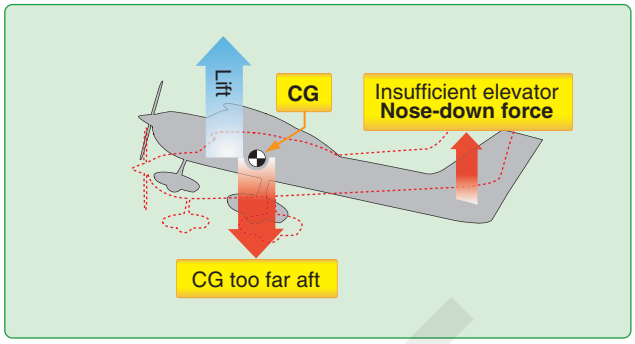


Figure 1-2. *If the CG is too far aft at the low stall airspeed, there might not be enough elevator nose-down authority to get the nose down for recovery.*

and control. If the CG is too far aft, it is too near the center of lift; the airplane is unstable and difficult to recover from a stall. *[Figure 1-2]* If the unstable airplane should enter a spin, the spin could become flat making recovery difficult or impossible. If the CG is too far forward, the downward tail load needs to be increased to maintain level flight. This increased tail load has the same effect as carrying additional weight; the aircraft must fly at a higher angle of attack and drag increases.

A more serious problem caused by the CG being too far forward is the lack of sufficient elevator authority. At low takeoff speeds, the elevator might not produce enough nose-up force to rotate; on landing there may not be enough elevator force to flare the airplane. *[Figure 1-3]* Both takeoff and landing runs are lengthened if the CG is too far forward. The basic aircraft design is such that lateral symmetry is assumed to exist. For each item of weight added to the left of the center line 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.

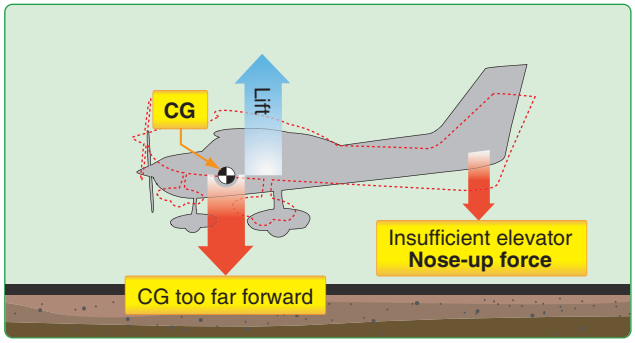


Figure 1-3. *If the CG is too far forward, there is not enough elevator nose-up force to flare the airplane for landing.*

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 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.

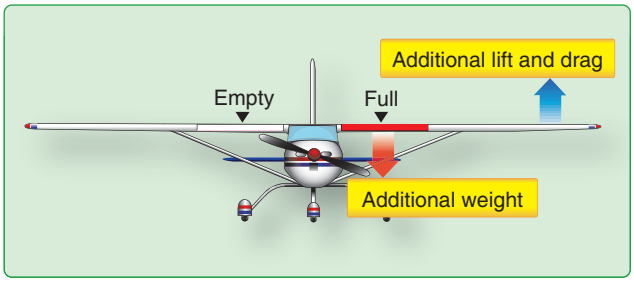


Figure 1-4. *Lateral imbalance causes wing heaviness, which may be corrected by deflecting the aileron. The additional lift causes additional drag, and the airplane flies inefficiently.*

Helicopters are more often affected by lateral imbalance 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 that requires large lateral displacement of the cyclic control to maintain level flight, the fore-and-aft cyclic control effectiveness is limited.

Swept-wing airplanes are more critical due to fuel imbalance because as the fuel is used from the outboard tanks, the CG shifts forward. As fuel is used from the inboard tanks, the CG shifts aft. *[Figure 1-5]* For this reason, fuel-use scheduling in swept-wing airplanes operation is critical.

Weight Control for Aircraft Other Than Fixed and Rotor-wing

Some light aircraft utilize different methods of determining weight and balance from the traditional fixed and rotor-wing aircraft. These aircraft achieve flight control by methods different from 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 EWCG or a CG 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.

Airplanes and WSC aircraft 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

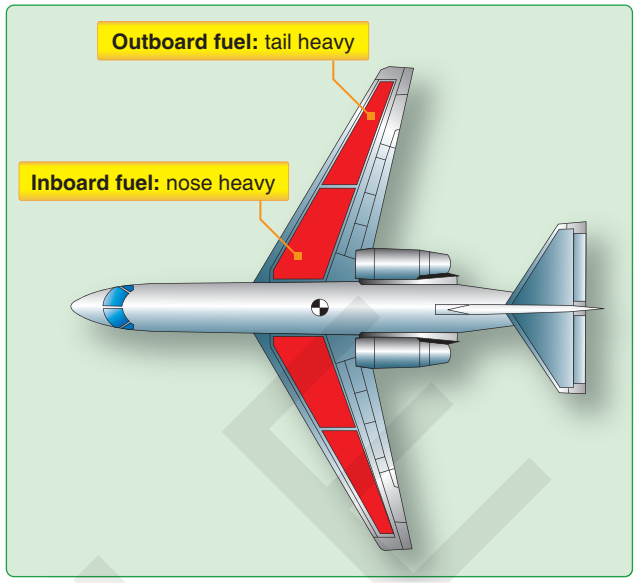


Figure 1-5. *Fuel in the tanks of a swept-wing airplane affects both lateral and longitudinal balance. As fuel is used from an outboard tank, the CG shifts forward.*

airplane requires an established weight and a known CG, whereas the WSC aircraft only requires the known weight.

The fixed-wing airplane has movable controls that alter lift on various airfoil surfaces to vary pitch, roll, and yaw. In turn, these changes in lift affect the characteristics of the flight parameters. Weight normally decreases in flight due to fuel consumption, and the airplane CG 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 CG changes. An airplane has a CG range or envelope within which it must remain if the flight controls are to remain effective and the airplane safely operated.

Weight-Shift Control Aircraft

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 by 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 reestablish the desired relationship between these forces; the wing flexes and alters its shape. As the shape is changed, lift is varied at different points on the wing to achieve the desired flight parameters.

SAMPLE

The flight controls primarily affect the pitch-and-roll axes. Since there is no vertical tail plane, there is minimal or no yaw control. Unlike in an airplane, the CG experienced by the WSC aircraft wing remains constant. Since the weight of the airframe acts through a single point (the wing attach point), the range over which the weight may act is fixed at the pendulum arm or length. Even though weight decreases as fuel is consumed, weight remains focused at the wing attach point. Because the range is fixed, there is no need to establish a calculated range. The pilot should consult the POH or Aircraft Operating Instructions (AOI) for maximum takeoff weight and minimum and maximum seat weight limits prior to each flight.

Powered Parachutes

The powered parachute is also a pendulum-style aircraft. Its airframe CG 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-airspeed aircraft. Once again, because the CG is fixed at the attach point to the wing, there is no CG range. As with WSC, the pilot should consult the POH or AOI for maximum takeoff weight and minimum and maximum seat weight limits prior to each flight.

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.

Balloons

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 CG of the gondola remains constant beneath the balloon envelope. As in WSC and powered-parachute aircraft, there is no CG limitation.

Underestimating the Importance of Weight and Balance

Many pilots, from sport pilot to commercial pilot, tend to underestimate the importance of proper weight and balance of their aircraft. Load sheets are taken for granted and hasty calculations are made of the aircraft's CG. Unfortunately, each year there are a number of accidents related to weight and balance issues. Many of these occurrences could have been avoided had more attention been given to weight and balance.

Every student pilot is taught how to work a weight and balance problem and that it is important to make sure every flight is loaded "within the envelope" (no more than maximum gross weight) for both takeoff and landing. But does he or she really understand just why this is so and the disastrous effect of being out of the envelope? Two examples of documented cases are provided below in an effort to indicate the serious nature of maintaining the proper weight and balance. In case studies when weight and balance was listed as the major factor of the accident, many were fatal.

For instance, a small aircraft was loaded with hunters, gear, and dogs (none of the dogs were secured inside the aircraft). During takeoff, all the dogs went to the aft of the airplane. This shifted the CG well aft of its allowable limit. The airplane stalled and crashed. The airplane was destroyed with casualties.

Another accident occurred when a group of skydivers were sitting on the floor toward the aft portion of the airplane (they were unsecured). During takeoff, the CG was again well beyond its aft limit. The airplane stalled and crashed. The airplane was destroyed with casualties.

There is a safety factor built into the formula for maximum gross weight. Any airplane can fly when it takes off at a weight greater than maximum gross weight if the runway is long enough and the density altitude is low enough. However, landing is a different matter. All airplanes are built to withstand an occasional hard landing, but what would happen if the hard landing were combined with a substantially overweight airplane? Something would probably break at that time or the structure would be weakened enough to break sometime in the future when everything might seem normal to a pilot unaware of the previous situation. Even more disastrous than an overweight, hard landing is reaching or exceeding the structural integrity of the metal and/or composite design values when maneuvering or when turbulence is encountered. Hidden damage could result, causing an unexpected catastrophic failure at some future time.

If an airplane is certificated with a maximum gross weight of 6,000 pounds (its weight on the ground) and is rolled into a 60° bank, the forces exerted make it feel as if it weighed 12,000 pounds. At its maximum certificated gross weight, there is no problem because the aircraft is operated within its certificated maneuvering loads. But loaded to 8,000 pounds with a 60° bank or an abrupt pullup, it suddenly weighs 16,000 pounds and might not be able to perform! Even if it could, there would probably be internal stress damage that would show up on future flights.