7.16 - AIRCRAFT WEIGHT AND BALANCE

SECTON A

CENTER OF GRAVITY/BALANCE LIMITS CALCULATIONS AND RELEVANT DOCUMENTS

AIRCRAFT WEIGHT AND BALANCE

The weight of an aircraft and its balance are extremely important for operating an aircraft in a safe and efficient manner. When a manufacturer designs an aircraft and it is certified, the specifications identify the aircraft's maximum weight and the limits within which it must balance.

The maximum allowable weight is based on the surface area and shape of the wing, and how much lift it will generate at a safe and appropriate airspeed. If a small general aviation airplane, for example, required a takeoff speed of 200 miles per hour to generate enough lift to support its weight, that would not be safe. Taking off and landing at lower airspeeds is certainly safer than doing so at higher speeds.

Where an aircraft balances is also a significant factor in determining if the aircraft is safe to operate. An aircraft that does not have good balance can exhibit poor maneuverability and controllability, making it difficult or impossible to fly. This could result in an accident, causing damage to the aircraft and injury to the people on board. Safety is the primary reason for concern about an aircraft's weight and balance.

A secondary reason for concern about weight and balance, but also a very important one, is the efficiency of the aircraft. Improper loading reduces the efficiency of an aircraft from the standpoint of ceiling, maneuverability, rate of climb, speed, and fuel consumption. If an airplane is loaded in such a way that it is extremely nose heavy, higher than normal forces will need to be exerted at the tail to keep the airplane in level flight. The higher than normal forces at the tail will create additional drag, which will require additional engine power and therefore additional fuel flow in order to maintain airspeed.

The most efficient condition for an aircraft is to have the point where it balances fall very close to, or perhaps exactly at, the aircraft's center of lift. If this were the case, little or no flight control force would be needed to keep the aircraft flying straight and level. In terms of stability and safety, however, this perfectly balanced condition might not be desirable. All of the factors that affect aircraft safety and efficiency, in terms of its weight and balance, are discussed in detail in this chapter.

NEED AND REQUIREMENTS FOR AIRCRAFT WEIGHING

Every aircraft type certificated, before leaving the factory for delivery to its new owner, receives a weight and balance report as part of its required aircraft records. The weight and balance report identifies the empty weight of the aircraft and the location at which the aircraft balances, known as the center of gravity. If the manufacturer chooses to do so, it can weigh every aircraft it produces and issue the weight and balance report based on that weighing. As an alternative, the manufacturer is permitted to weigh an agreed upon percentage of a particular model of aircraft produced, perhaps 10 to 20 percent, and apply the average to all the aircraft.

After the aircraft leaves the factory and is delivered to its owner, the need or requirement for placing the aircraft on scales and reweighing it varies depending on the type of aircraft and how it is used. For a small general aviation airplane being used privately, such as a Cessna 172, there may be a requirement that it be periodically reweighed. There is, however, a requirement that the airplane always have a current and accurate weight and balance report. If the weight and balance report for an aircraft is lost, the aircraft must be weighed and a new report must be created. If the airplane has new equipment installed, such as a radio or a global positioning system, a new weight and balance report must be created.

If the installer of the equipment wants to place the airplane on scales and weigh it after the installation, that is a perfectly acceptable way of creating the new report. If the installer knows the exact weight and location of the new equipment, it is also possible to create a new report by doing a series of mathematical calculations.

Over a period of time, almost all aircraft have a tendency to gain weight. Examples of how this can happen include an airplane being repainted without the old paint being removed, and the accumulation of dirt, grease, and oil in parts of the aircraft that are not easily accessible for cleaning. When new equipment is installed, and its weight and location are mathematically accounted for, some miscellaneous weight might be overlooked, such as wire and hardware. For this reason, it is a good practice to periodically place an aircraft on scales and confirm its actual empty weight and empty weight center of gravity. Some aircraft are required to be weighed and have their center of gravity calculated on a periodic basis, typically every 3 years. Examples of aircraft that may fall under this requirement are:

1. Air taxi and charter twin-engine airplanes.
2. Airplanes with a seating capacity of 20 or more passengers or a maximum payload of 6 000 pounds or more. This applies to most airplanes operated by the airlines, both main line and regional, and to many of the privately operated business jets.

WEIGHT AND BALANCE TERMINOLOGY

Datum

The datum is an imaginary vertical plane from which all horizontal measurements are taken for balance purposes, with the aircraft in level flight attitude. If the datum was viewed on a drawing or photograph of an aircraft, it would appear as a vertical line which is perpendicular (90 degrees) to the aircraft's horizontal axis. For each aircraft make and model, the location of all items is identified in reference to the datum. For example, the fuel in a tank might be 60 inches (60") behind the datum, and a radio on the flight deck might be 90" forward of the datum.

There is no fixed rule for the location of the datum, except that it must be a location that will not change during the life of the aircraft. For example, it would not be a good idea to have the datum be the tip of the propeller spinner or the front edge of a seat, because changing to a new design of spinner or moving the seat would cause the datum to change. It might be located at or near the nose of the aircraft, a specific number of inches forward of the nose, at the engine firewall, at the center of the main rotor shaft of a helicopter, or any place that can be imagined.

The manufacturer has the choice of locating the datum where it is most convenient for measurement, equipment location, and weight and balance computation. ***Figure 16-1*** shows an aircraft with the leading edge of the wing being the datum.

For American manufactured aircraft, the location of the datum is identified in the Aircraft Specifications or Type Certificate Data Sheet. Aircraft certified prior to 1958 fell under the Civil Aeronautics Administration, and had their weight and balance information contained in a document known as Aircraft Specifications.

Aircraft certified since 1958 fall under the FAA and have their weight and balance information contained in a document known as a Type Certificate Data Sheet. The Aircraft Specifications typically included the aircraft equipment list. For aircraft with a Type Certificate Data Sheet, the equipment list is a separate document.

Arm

The arm is the horizontal distance that a part of the aircraft or a piece of equipment is located from the datum. The arm's distance is always given or measured in inches, and, except for a location which might be exactly on the datum, it is preceded by the algebraic sign for positive (+) or negative (–). The positive sign indicates an item is located aft of the datum and the negative sign indicates an item is located forward of the datum. If the manufacturer chooses a datum that is at the most forward location on an aircraft (or some distance forward of the aircraft), all the arms will be positive numbers. Location of the datum at any other point on the aircraft will result in some arms being positive numbers, or aft of the datum, and some arms being negative numbers, or forward of the datum.

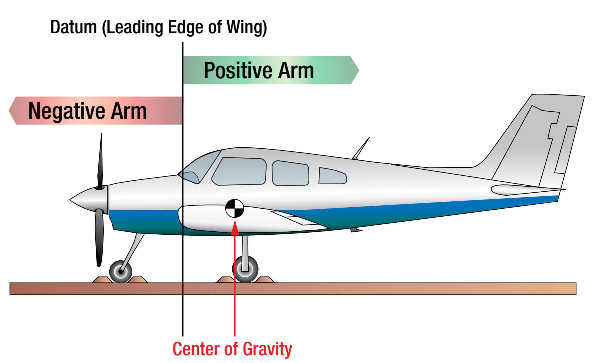

Figure 16-1. Datum location and its effect on positive and negative arms.

AIRCRAFT WEIGHT AND BALANCE

Figure 16-1 shows an aircraft where the datum is the leading edge of the wing. For this aircraft, any item (fuel, seat, radio, and so forth) located forward of the wing leading edge will have a negative arm, and any item located aft of the wing leading edge will have a positive arm. If an item was located exactly at the wing leading edge, its arm would be zero, and mathematically it would not matter whether its arm was considered to be positive or negative.

The arm of each item is usually included in parentheses immediately after the item's name or weight in the Aircraft Specifications, Type Certificate Data Sheet, or equipment list for the aircraft. In a Type Certificate Data Sheet, for example, the fuel quantity might be identified as 150 gallons (gal) (+138) and the nose baggage limit as 200 pounds (lbs) (–55). These numbers indicate that the fuel is located 138" aft of the datum and the nose baggage is located 55" forward of the datum. If the arm for a particular piece of equipment is not known, its exact location must be accurately measured. When the arm for a piece of equipment is being determined, the measurement is taken from the datum to the piece of equipment's own center of gravity.

Moment

A moment is the product of a weight multiplied by its arm. The moment for a piece of equipment is in fact a torque value, measured in units of inch-pounds (in-lbs). To obtain the moment of an item with respect to the datum, multiply the weight of the item by its horizontal distance from the datum. Likewise, the moment of an item with respect to the center of gravity (CG) of an aircraft can be computed by multiplying its weight by the horizontal distance from the CG.

A 5 lb radio located 80" from the datum would have a moment of 400 inch-pounds (in-lbs) (5 lbs × 8"). Whether the value of 400 in-lbs is preceded by a positive (+) or negative (–) sign depends on whether the moment is the result of a weight being removed or added and its location in relation to the datum. This situation is shown in *Figure 16-2*, where the moment ends up being a positive number because the weight and arm are both positive.

The algebraic sign of the moment, based on the datum location and whether weight is being installed or removed, would be as follows:

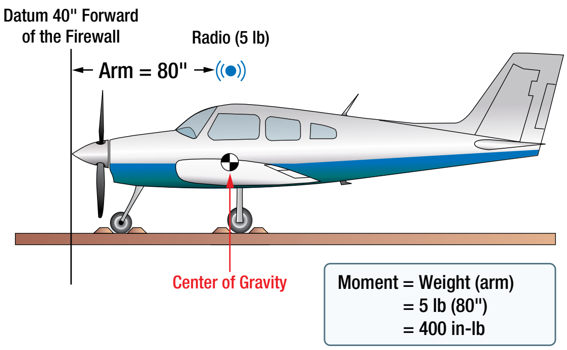

Figure 16-2. Moment of a radio located aft of the datum.

- Weight being added aft of the datum produces a positive moment (+ weight, + arm).
- Weight being added forward of the datum produces a negative moment (+ weight, – arm).
- Weight being removed aft of the datum produces a negative moment (– weight, + arm).
- Weight being removed forward of the datum produces a positive moment (– weight, – arm)

When dealing with positive and negative numbers, remember that the product of like signs produces a positive answer and the product of unlike signs produces a negative answer.

Center Of Gravity

The center of gravity (CG) of an aircraft is a point about which the nose heavy and tail heavy moments are exactly equal in magnitude. It is the balance point for the aircraft. An aircraft suspended from this point would have no tendency to rotate in either a nose-up or nose-down attitude. It is the point about which the weight of an airplane or any object is concentrated.

Figure 16-3 shows a first class lever with the pivot point (fulcrum) located at the center of gravity for the lever. Even though the weights on either side of the fulcrum are not equal, and the distances from each weight to the fulcrum are not equal, the product of the weights and arms (moments) are equal, and that is what produces a balanced condition.

Maximum Weight

The maximum weight is the maximum authorized weight of the aircraft and its contents, and is indicated in the Aircraft Specifications or Type Certificate Data Sheet. For many aircraft, there are variations to the maximum allowable weight, depending on the purpose

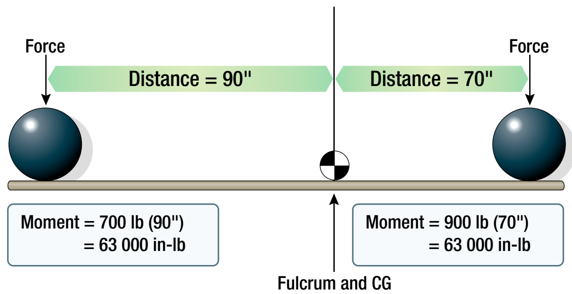

Figure 16-3. Center of gravity and a first class lever.

and conditions under which the aircraft is to be flown. For example, a certain aircraft may be allowed a maximum gross weight of 2 750 lbs when flown in the normal category, but when flown in the utility category, which allows for limited aerobatics, the same aircraft's maximum allowable gross weight might only be 2 175 lbs. There are other variations when dealing with the concept of maximum weight, as follows:

- Maximum Ramp Weight—the heaviest weight to which an aircraft can be loaded while it is sitting on the ground. This is sometimes referred to as the maximum taxi weight.
- Maximum Takeoff Weight—the heaviest weight an aircraft can have when it starts the takeoff roll. The difference between this weight and the maximum ramp weight would equal the weight of the fuel that would be consumed prior to takeoff.
- Maximum Landing Weight—the heaviest weight an aircraft can have when it lands. For large wide body commercial airplanes, it can be 100 000 lbs less than maximum takeoff weight, or even more.
- Maximum Zero Fuel Weight—the heaviest weight an aircraft can be loaded to without having any usable fuel in the fuel tanks. Any weight loaded above this value must be in the form of fuel.

Empty Weight

The empty weight of an aircraft includes all operating equipment that has a fixed location and is actually installed in the aircraft. It includes the weight of the airframe, powerplant, required equipment, optional or special equipment, fixed ballast, hydraulic fluid, and residual fuel and oil. Residual fuel and oil are the fluids that will not normally drain out because they are trapped in the fuel lines, oil lines, and tanks. They must be included in the aircraft's empty weight. For most aircraft certified after 1978, the full capacity of the engine oil system is also included in the empty weight. Information regarding residual fluids in aircraft systems that must be included in the empty weight, and whether or not full oil is included, will be indicated in the Aircraft Specifications or Type Certificate Data Sheet.

Other terms that are sometimes used when describing empty weight include basic empty weight, licensed empty weight, and standard empty weight. The term "basic empty weight" typically applies when the full capacity of the engine oil system is included in the value. The term "licensed empty weight" typically applies when only the weight of residual oil is included in the value, so it generally involves only aircraft certified prior to 1978. Standard empty weight would be a value supplied by the aircraft manufacturer, and it would not include any optional equipment that might be installed in a particular aircraft. For most people working in the aviation maintenance field, the basic empty weight of the aircraft is the most important one.

Empty Weight Center Of Gravity

The empty weight center of gravity for an aircraft is the point at which it balances when it is in an empty weight condition. The concepts of empty weight and center of gravity were discussed earlier in this chapter, and now they are being combined into a single concept.

One of the most important reasons for weighing an aircraft is to determine its empty weight center of gravity. All other weight and balance calculations, including loading the aircraft for flight, performing an equipment change calculation, and performing an adverse condition check, begin with knowing the empty weight and empty weight center of gravity. This crucial information is part of what is contained in the aircraft weight and balance report.

Useful Load

To determine the useful load of an aircraft, subtract the empty weight from the maximum allowable gross weight. For aircraft certificated in both normal and utility categories, there may be two useful loads listed in the aircraft weight and balance records. An aircraft with an empty weight of 900 lbs will have a useful load of 850 lbs, if the normal category maximum weight is listed as 1 750 lbs. When the aircraft is operated in the utility category, the maximum gross weight may be reduced to 1 500 lbs, with a corresponding decrease in the useful load to 600 lbs. Some aircraft have the same useful load regardless of the category in which they are certificated.

The useful load consists of fuel, any other fluids that are not part of empty weight, passengers, baggage, pilot, copilot, and crew members. Whether or not the weight of engine oil is considered to be a part of useful load depends on when the aircraft was certified, and can be determined by looking at the Aircraft Specifications or Type Certificate Data Sheet. The payload of an aircraft is similar to the useful load, except it does not include fuel.

A reduction in the weight of an item, where possible, may be necessary to remain within the maximum weight allowed for the category in which an aircraft weights is called a weight check.

Minimum Fuel

There are times when an aircraft will have a weight and balance calculation done, known as an extreme condition check. This is a pencil and paper check in which the aircraft is loaded in as nose heavy or tail heavy a condition as possible to see if the center of gravity will be out of limits in that situation. In a forward adverse check, for example, all useful load in front of the forward CG limit is loaded, and all useful load behind this limit is left empty. An exception to leaving it empty is the fuel tank. If the fuel tank is located behind the forward CG limit, it cannot be left empty because the aircraft cannot fly without fuel. In this case, an amount of fuel is accounted for, which is known as minimum fuel. Minimum fuel is typically that amount needed for 30 minutes of flight at cruise power.

For a piston engine powered aircraft, minimum fuel is calculated based on the METO (maximum except take-off) horsepower of the engine. For each METO horsepower of the engine, one-half pound of fuel is used. This amount of fuel is based on the assumption that the piston engine in cruise flight will burn 1 lb of fuel per hour for each horsepower, or ½ lb for 30 minutes. The piston engines currently used in small general aviation aircraft are actually more efficient than that, but the standard for minimum fuel has remained the same. Minimum fuel is calculated as follows:

$$\text{Minimum Fuel (pounds)} = \text{Engine METO Hp} \div 2$$

For example, if a forward adverse condition check was being done on a piston engine powered twin, with each engine having a METO horsepower of 500, the minimum fuel would be 250 lbs (500 METO Hp ÷ 2).

For turbine engine powered aircraft, minimum fuel is not based on engine horsepower. If an adverse condition check is being performed on a turbine engine powered aircraft, the aircraft manufacturer would need to supply information on minimum fuel.

Tare Weight

When aircraft are placed on scales and weighed, it is sometimes necessary to use support equipment to aid in the weighing process. For example, to weigh a tail dragger airplane, it is necessary to raise the tail in order to get the airplane level. To level the airplane, a jack might be placed on the scale and used to raise the tail. Unfortunately, the scale is now absorbing the weight of the jack in addition to the weight of the airplane. This extra weight is known as tare weight, and must be subtracted from the scale reading. Other examples of tare weight are wheel chocks placed on the scales and ground locks left in place on retractable landing gear.

Standard Weights Used for Aircraft Weight And Balance

Unless the specific weight for an item is known, the standard weights used in aircraft weight and balance are as follows:

- Aviation gasoline 6 lbs/gal
- Turbine fuel 6.7 lbs/gal
- Lubricating oil 7.5 lbs/gal
- Water 8.35 lbs/gal
- Crew and passengers 170 lbs per person

PROCEDURES FOR DETERMINING WEIGHT AND BALANCE

The most important reason for weighing an aircraft is to find out its empty weight (basic empty weight), and to find out where it balances in the empty weight condition. When an aircraft is to be flown, the pilot in command must know what the loaded weight of the aircraft is, and where its loaded center of gravity is. In order for the loaded weight and center of gravity to be calculated, the pilot or dispatcher handling the flight must first know the empty weight and empty weight center of gravity.

Earlier in this chapter it was identified that the center of gravity for an object is the point about which the nose heavy and tail heavy moments are equal. One method that could be used to find this point would involve lifting an object off the ground twice, first suspending it from a point near the front, and on the second lift suspending it from a point near the back. With each lift, a perpendicular line (90 degrees) would be drawn from the suspension point to the ground. The two perpendicular lines would intersect somewhere in the object, and the point of intersection would be the center of gravity.

This concept is shown in ***Figure 16-4***, where an irregular shaped object is suspended from two different points. The perpendicular line from the first suspension point is shown in red, and the new suspension point line is shown in blue. Where the red and blue lines intersect is the center of gravity.

If an airplane were suspended from two points, one at the nose and one at the tail, the perpendicular drop lines would intersect at the center of gravity the same way they do for the object in ***Figure 16-4***. Suspending an airplane from the ceiling by two hooks, however, is clearly not realistic. Even if it could be done, determining where in the airplane the lines intersect would not be possible.

A more realistic way to find the center of gravity for an object, especially an airplane, is to place it on a minimum of two scales and to calculate the moment value for each scale reading. In ***Figure 16-5***, there is a plank that is 200" long, with the left end being the datum (zero arm), and 6 weights placed at various locations along the length of the plank. The purpose of ***Figure 16-5*** is to show how the center of gravity can be calculated when the arms and weights for an object are known.

To calculate the center of gravity for the object in ***Figure 16-5***, the moments for all the weights need to be calculated and then summed, and the weights need to be summed. In the four column table in ***Figure 16-6***, the item, weight, and arm are listed in the first three columns, with the information coming from ***Figure 16-5***.

The moment value in the fourth column is the product of the weight and arm. The weight and moment columns are summed, with the center of gravity being equal to the total moment divided by the total weight. The arm column is not summed. The number appearing at the bottom of that column is the center of gravity. The calculation would be as shown in ***Figure 16-6***.

For the calculation shown in ***Figure 16-6***, the total moment is 52 900 in-lbs, and the total weight is 495 lb. The center of gravity is calculated as follows:

Center of Gravity = Total Moment ÷ Total Weight
= 52 900 in-lbs ÷ 495 lb
= 106.9" (106.87 rounded off to tenths)

An interesting characteristic exists for the problem presented in ***Figure 16-5***, and the table showing the center of gravity calculation. If the datum (zero arm)

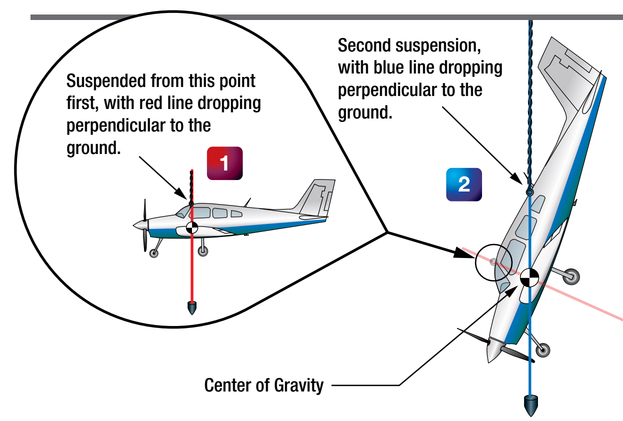

Figure 16-4. Center of gravity determined by two suspension points.

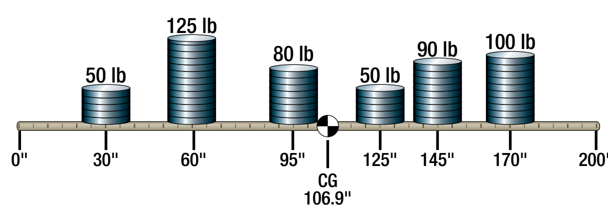

Figure 16-5. Center of gravity for weights on a plank, datum at one end.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
50 pound weight	50	+30	1 500
125 pound weight	125	+60	7 500
80 pound weight	80	+95	7 600
50 pound weight	50	+125	6 250
90 pound weight	90	+145	13 050
100 pound weight	100	+170	17 000
Total	495	+106.9	52 900

Figure 16-6. Center of gravity calculation for weights on a plank with datum at one end.

for the object was in the middle of the 200" long plank, with 100" of negative arm to the left and 100" of positive arm to the right, the solution would show the center of gravity to be in the same location. The arm for the center of gravity would not be the same number, but its physical location would be the same. ***Figure 16-7*** and ***Figure 16-8*** show the new calculation.

Center of Gravity = Total Moment ÷ Total Weight
= 3 400 in-lb ÷ 495 lb
= 6.9" (6.87 rounded off to tenths)

In ***Figure 16-7***, the center of gravity is 6.9" to the right of the plank's center. Even though the arm is not the same number, in ***Figure 16-5*** the center of gravity is also 6.9" to the right of center (CG location of 106.9 with the center being 100). Because both problems are the same in these two figures, except for the datum location, the center of gravity must be the same.

The definition for center of gravity states that it is the point about which all the moments are equal. We can prove that the center of gravity for the object in ***Figure 16-7*** is correct by showing that the total moments on either side of this point are equal. Using 6.87 as the CG location for slightly greater accuracy, instead of the rounded off 6.9 number, the moments to the left of the CG would be as shown in ***Figure 16-9***.

The moments to the right of the CG, as shown in ***Figure 16-7***, would be as shown in ***Figure 16-10***. Disregarding the slightly different decimal value, the moment in both of the previous calculations is 10 651 in-lb. Showing that the moments are equal is a good way of proving that the center of gravity has been properly calculated.

WEIGHT AND BALANCE DATA

In order to weigh an aircraft and calculate its empty weight and empty weight center of gravity, a technician must have access to weight and balance information about the aircraft. Possible sources of weight and balance data are as follows:

- Aircraft Specifications—applies primarily to aircraft certified under the Civil Aeronautics Administration, when the specifications also included a list of equipment with weights and arms.
- Aircraft Operating Limitations—supplied by the aircraft manufacturer.
- Aircraft Flight Manual—supplied by the aircraft manufacturer.
- Aircraft Weight and Balance Report—supplied by the aircraft manufacturer when the aircraft is new, and by the technician when an aircraft is reweighed in the field.

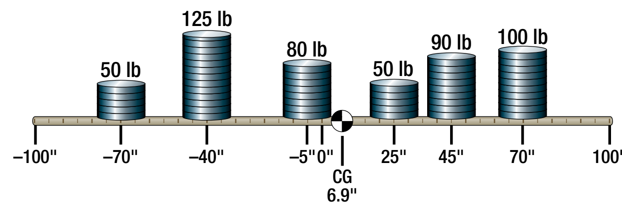

Figure 16-7. Center of gravity for weights on a plank, datum in the middle.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
50 pound weight	50	–70	–3 500
125 pound weight	125	–40	–5 000
80 pound weight	80	–5	–400
50 pound weight	50	+25	1 250
90 pound weight	90	+45	4 050
100 pound weight	100	+70	7 000
Total	495	+6.9	3 400

Figure 16-8. Center of gravity calculation for weights on a plank with datum in the middle.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
50 pound weight	50	76.87	3 843.50
125 pound weight	125	46.87	5 858.75
80 pound weight	80	11.87	949.60
Total	255	135.61	10 651.85

Figure 16-9. Moments to the left of the center of gravity.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
50 pound weight	50	18.13	906.50
90 pound weight	90	38.13	3 431.70
100 pound weight	100	63.13	6 313.00
Total	240	119.39	10 651.25

Figure 16-10. Moments to the right of the center of gravity.

- Aircraft Type Certificate Data Sheet—applies where the equipment list with weights and arms is a separate document.

The document in ***Figure 16-11*** is a Type Certificate Data Sheet (TCDS) for a Piper twin-engine airplane known as the Seneca (PA-34-200). The main headings for the information typically contained in a TCDS are included, but much of the information contained under these headings has been removed if it did not directly pertain to weight and balance. Information on only one model of Seneca is shown, because to show all the different models would make the document excessively long. The portion of the TCDS that has the most direct application to weight and balance is highlighted in yellow. Some of the important weight and balance information found in a Type Certificate Data Sheet is as follows:

1. Center of gravity range
2. Maximum weight
3. Leveling means
4. Number of seats and location
5. Baggage capacity
6. Fuel capacity
7. Datum location
8. Engine horsepower
9. Oil capacity
10. Amount of fuel in empty weight
11. Amount of oil in empty weight

CENTER OF GRAVITY RANGE

The center of gravity range for an aircraft is the limits within which the aircraft must balance. It is identified as a forward most limit (arm) and an aft most limit (arm).

In the Type Certificate Data Sheet for the Piper Seneca airplane, shown earlier in this chapter, the range is given as follows:

CG Range:
(Gear Extended)

S/N 34-E4, 34-7250001 through 34-7250214
(See NOTE 3):
(+86.4") to (+94.6") at 4 000 lb
(+82.0") to (+94.6") at 3 400 lb
(+80.7") to (+94.6") at 2 780 lb
Straight line variation between points given.
Moment change due to gear retracting landing gear (–32 in-lb).

Because the Piper Seneca is a retractable gear airplane, the specifications identify that the range applies when the landing gear is extended, and that the airplane's total moment will be decreased by 32 when the gear retracts. To know how much the center of gravity will change when the gear is retracted, the moment of 32 in-lbs would need to be divided by the loaded weight of the airplane. For example, if the airplane weighed 3 500 lbs, the center of gravity would move forward 0.009" (32 ÷ 3 500).

Based on the numbers given, up to a loaded weight of 2 780 lbs, the forward CG limit is +80.7" and the aft CG limit is +94.6". As the loaded weight of the airplane increases to 3 400 lbs and eventually to the maximum of 4 000 lbs, the forward CG limit moves aft. In other words, as the loaded weight of the airplane increases, the CG range gets smaller. The range gets smaller as a result of the forward limit moving back, while the aft limit stays in the same place.

The data sheet identifies that there is a straight line variation between the points given. The points being referred to are the forward and aft center of gravity limits. From a weight of 2 780 lbs to a weight of 3 400 lbs, the forward limit moves from +80.7" to +82.0", and if plotted on a graph, that change would form a straight line. From 3 400 lbs to 4 000 lbs, the forward limit moves from +82 to +86.4", again forming a straight line. Plotted on a graph, the CG limits would look like what is shown in ***Figure 16-12***. When graphically plotted, the CG limits form what is known as the CG envelope.

In ***Figure 16-12***, the red line represents the forward limit up to a weight of 2 780 lbs. The blue and green lines represent the straight line variation that occurs for the forward limit as the weight increases up to a maximum of 4 000 lbs. The yellow line represents the maximum weight for the airplane, and the purple line represents the aft limit.

Empty Weight Center Of Gravity Range

For some aircraft, a center of gravity range is given for the aircraft in the empty weight condition. This practice is not very common with airplanes, but is often done for helicopters. This range would only be listed for an airplane if it was very small and had limited positions for people and fuel. If the empty weight CG of an aircraft falls within the empty weight CG limits, it is known

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

TYPE CERTIFICATE DATA SHEET NO. A7SO – REVISION 14

PIPER
PA-34-200
PA-34-200T
PA-34-220T

June 1, 2001

This data sheet, which is a part of type certificate No. A7SO, prescribes conditions and limitations under which the product for which the type certificate was issued meets the airworthiness requirements of the Federal Aviation Regulations.

Type Certificate Holder:
The New Piper Aircraft, Inc.
2926 Piper Drive
Vero Beach, Florida 32960

I. Model PA-34-200 (Seneca), 7 PCLM (Normal Category), Approved 7 May 1971.

Engines
S/N 34-E4, 34-7250001 through 34-7250214:
1 Lycoming LIO-360-C1E6 with fuel injector,
Lycoming P/N LW-10409 or LW-12586 (right side); and
1 Lycoming IO-360-C1E6 with fuel injector,
Lycoming P/N LW-10409 or LW 12586 (left side).
S/N 34-7250215 through 34-7450220:
1 Lycoming LIO-360-C1E6 with fuel injector,
Lycoming P/N LW-12586 (right side); and
1 Lycoming IO-360-C1E6 with fuel injector,
Lycoming P/N LW-12586 (left side).

Fuel
100/130 minimum grade aviation gasoline

Engine Limits
For all operations, 2,700 RPM (200 hp)

Propeller and Propeller Limits
Left Engine
1 Hartzell, Hub Model HC-C2YK-2 ( ) E, Blade Model C7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) EU, Blade Model C7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) EF, Blade Model FC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) EFU, Blade Model FC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2CG (F), Blade Model (F) C7666A
(This model includes the Hartzell damper); or
1 Hartzell, Hub Model HC-C2YK-2CGU (F), Blade Model (F) C7666A
(This model includes the Hartzell damper).
Note: HC-( )2YK-( ) may be substituted for HC-( )2YR-( ) per Hartzell Service Advisory 61.

Right Engine
1 Hartzell, Hub Model HC-C2YK-2 ( ) LE, Blade Model JC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) LEU, Blade Model JC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) LEF, Blade Model FJC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) LEFU, Blade Model FJC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2CLG (F), Blade Model (F) JC7666A
(This model includes the Hartzell damper); or
1 Hartzell, Hub Model HC-C2YK-2CLGU (F), Blade Model (F) JC7666A
(This model includes the Hartzell damper.)
Note: HC-( )2YK-( ) may be substituted for HC-( )2YR-( ) per Hartzell Service Advisory 61.
Pitch setting: High 79° to 81°, Low 13.5° at 30" station.
Diameter: Not over 76", not under 74". No further reduction permitted.

Spinner: Piper P/N 96388 Spinner Assembly and P/N 96836 Cap Assembly, or P/N 78359-0 Spinner Assembly and P/N 96836-2 Cap Assembly (See NOTE 4)

Governor Assembly:
1 Hartzell hydraulic governor, Model F-6-18AL (Right);
1 Hartzell hydraulic governor, Model F-6-18A (Left).
Avoid continuous operation between 2,200 and 2,400 RPM unless aircraft is equipped with Hartzell propellers which incorporate a Hartzell damper on both left and right engine as noted above.

Airspeed Limits

VNE (Never exceed)	217 mph	(188 knots)
VNO (Maximum structural cruise)	190 mph	(165 knots)
VA (Maneuvering, 4,200 lb)	146 mph	(127 knots)
VA (Maneuvering, 4,000 lb)	146 mph	(127 knots)
VA (Maneuvering, 2,743 lb)	133 mph	(115 knots)
VFE (Flaps extended)	125 mph	(109 knots)
VLO (Landing gear operating)		
Extension	150 mph	(130 knots)
Retract	125 mph	(109 knots)
VLE (Landing gear extended)	150 mph	(130 knots)
VMC (Minimum control speed)	80 mph	(69 knots)

CG Range (Gear Extended)
S/N 34-E4, 34-7250001 through 34-7250214 (See NOTE 3):
(+86.4) to (+94.6) at 4,000 lb
(+82.0) to (+94.6) at 3,400 lb
(+80.7) to (+94.6) at 2,780 lb
S/N 34-7250215 through 34-7450220:
(+87.9) to (+94.6) at 4,200 lb
(+82.0) to (+94.6) at 3,400 lb
(+80.7) to (+94.6) at 2,780 lb
Straight line variation between points given.
Moment change due to gear retracting landing gear (-32 in-lb)

Empty Weight CG Range
None

Maximum Weight
S/N 34-E4, 34-7250001 through 34-7250214:
4,000 lb – Takeoff
4,000 lb – Landing
See NOTE 3.

Maximum Weight
S/N 34-7250215 through 34-7450220:
4,200 lb – Takeoff
4,000 lb – Landing

No. of Seats
7 (2 at +85.5, 3 at +118.1, 2 at +155.7)

Maximum Baggage
200 lb (100 lb at +22.5, 100 lb at +178.7)

Fuel Capacity
98 gallons (2 wing tanks) at (+93.6) (93 gallons usable)
See NOTE 1 for data on system fuel.

Oil Capacity
8 qt per engine (6 qt per engine usable)
See NOTE 1 for data on system oil.

Control Surface Movements

Ailerons	(±2°)	Up 30°	Down 15°	
Stabilator		Up 12.5° (+0,-1°)	Down 7.5° (±1°)	
Rudder (±1°)		Left 35°	Right 35°	
Stabilator Trim Tab (Stabilator neutral)	(±1°)	Down 10.5°	Up 6.5°	
Wing Flaps	(±2°)	Up 0°	Down 40°	
Rudder Trim Tab (Rudder neutral)	(±1°)	Left 17°	Right 22°	
Nosewheel	S/N 34-E4, 34-7250001 through 34-7350353:			
Travel	(±1°)	Left 21°	Right 21°	
Nosewheel	S/N 34-7450001 through 34-7450220:			
Travel	(±1°)	Left 27°	Right 27°	

Manufacturer's Serial Numbers
3449001 and up.

DATA PERTINENT TO ALL MODELS

Datum
78.4" forward of wing leading edge from the inboard edge of the inboard fuel tank.

Leveling Means
Two screws left side fuselage below window.

Certification Basis
Type Certificate No. A7SO issued May 7, 1971, obtained by the manufacturer under the delegation option authorization. Date of Type Certificate application July 23, 1968.

<u>Model PA-34-200 (Seneca I):</u>
14 CFR part 23 as amended by Amendment 23-6 effective August 1, 1967; 14 CFR part 23.959 as amended by Amendment 23-7 effective September 14, 1969; and 14 CFR part 23.1557(c)(1) as amended by Amendment 23-18 effective May 2, 1977. Compliance with 14 CFR part 23.1419 as amended by Amendment 23-14 effective December 20, 1973, has been established with optional ice protection provisions.

Production Basis
Production Certificate No. 206. Production Limitation Record issued and the manufacturer is authorized to issue an airworthiness certificate under the delegation option provisions of 14 CFR part 21.

Equipment
The basic required equipment as prescribed in the applicable airworthiness regulations (see Certification Basis) must be installed in the aircraft for certification. In addition, the following items of equipment are required:

MODEL	AFM/POH	REPORT #	APPROVED	SERIAL EFFECTIVITY
PA-34-200(Seneca)	AFM	VB-353	7/2/71	34-E4, 34-7250001 through 34-7250214
	AFM	VB-423	5/20/72	34-7250001 through 34-7250189 when Piper Kit 760-607 is installed; 34-7250190 through 34-7250214 when Piper Kit 760-611 is installed; and 34-7250215 through 34-7350353
	AFM	VB-563	5/14/73	34-7450001 through 34-7450220
	AFM Supp.	VB-588	7/20/73	34-7250001 through 34-7450039 when propeller with dampers are installed
	AFM Supp.	VB-601	11/9/73	34-7250001 through 34-745017 when ice protection system is installed

<u>NOTES</u>

NOTE 1 Current Weight and Balance Report, including list of equipment included in certificated empty weight, and loading instructions when necessary, must be provided for each aircraft at the time of original certification. The certificated empty weight and corresponding center of gravity locations must include undrainable system oil (not included in oil capacity) and unusable fuel as noted below:

Fuel: 30.0 lb at (+103.0) for PA-34 series, except Model PA-34-220T (Seneca V), S/N 3449001 and up
Fuel: 36.0 lb at (+103.0) for Model PA-34-220T (Seneca V), S/N 3449001 and up
Oil: 6.2 lb at (+ 39.6) for Model PA-34-200
Oil: 12.0 lb at (+ 43.7) for Models PA-34-200T and PA-34-220T

NOTE 2 All placards required in the approved Airplane Flight Manual or Pilot's Operating Handbook and approved Airplane Flight Manual or Pilot's Operating Handbook supplements must be installed in the appropriate location.

NOTE 3 The Model PA-34-200; S/N 34-E4, 34-7250001 through 34-7250189, may be operated at a maximum takeoff weight of 4,200 lb when Piper Kit 760-607 is installed. S/N 34-7250190 through 34-7250214 may be operated at a maximum takeoff weight of 4,200 lb when Piper Kit 760-611 is installed.

NOTE 4 The Model PA-34-200; S/N 34-E4, 34-7250001 through 34-7250189, may be operated without spinner domes or without spinner domes and rear bulkheads when Piper Kit 760-607 has been installed. --
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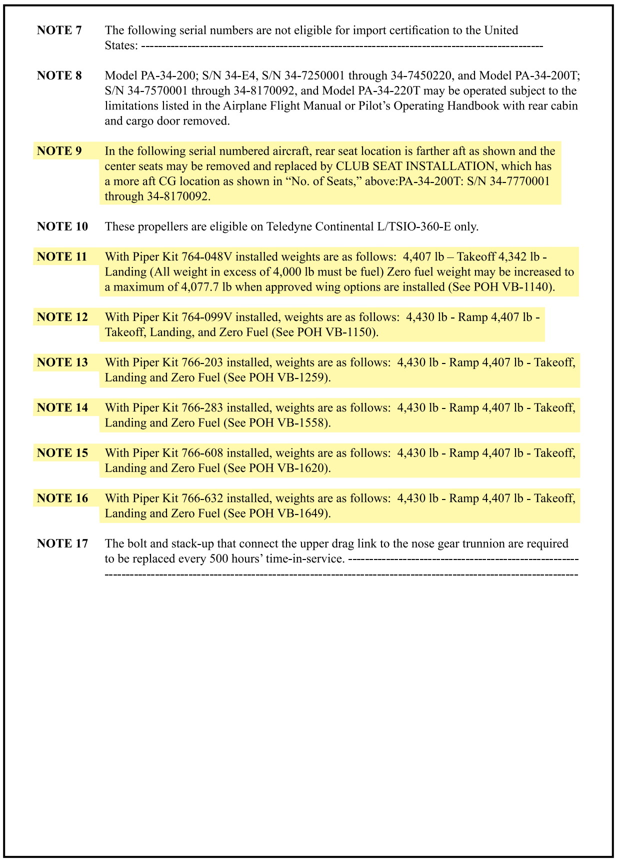
NOTE 5 The Model PA-34-200 may be operated in known icing conditions when equipped with spinner assembly and the following kits: --

NOTE 6 Model PA-34-200T; S/N 34-7570001 through 34-8170092, may be operated in known icing conditions when equipped with deicing equipment installed per Piper Drawing No. 37700 and spinner assembly.

Figure 16-11. Type Certificate Data Sheet.



NOTE 7 The following serial numbers are not eligible for import certification to the United States: --

NOTE 8 Model PA-34-200; S/N 34-E4, S/N 34-7250001 through 34-7450220, and Model PA-34-200T; S/N 34-7570001 through 34-8170092, and Model PA-34-220T may be operated subject to the limitations listed in the Airplane Flight Manual or Pilot's Operating Handbook with rear cabin and cargo door removed.

NOTE 9 In the following serial numbered aircraft, rear seat location is farther aft as shown and the center seats may be removed and replaced by CLUB SEAT INSTALLATION, which has a more aft CG location as shown in "No. of Seats," above:PA-34-200T: S/N 34-7770001 through 34-8170092.

NOTE 10 These propellers are eligible on Teledyne Continental L/TSIO-360-E only.

NOTE 11 With Piper Kit 764-048V installed weights are as follows: 4,407 lb – Takeoff 4,342 lb - Landing (All weight in excess of 4,000 lb must be fuel) Zero fuel weight may be increased to a maximum of 4,077.7 lb when approved wing options are installed (See POH VB-1140).

NOTE 12 With Piper Kit 764-099V installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing, and Zero Fuel (See POH VB-1150).

NOTE 13 With Piper Kit 766-203 installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing and Zero Fuel (See POH VB-1259).

NOTE 14 With Piper Kit 766-283 installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing and Zero Fuel (See POH VB-1558).

NOTE 15 With Piper Kit 766-608 installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing and Zero Fuel (See POH VB-1620).

NOTE 16 With Piper Kit 766-632 installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing and Zero Fuel (See POH VB-1649).

NOTE 17 The bolt and stack-up that connect the upper drag link to the nose gear trunnion are required to be replaced every 500 hours' time-in-service. --

Figure 16-11. Type Certificate Data Sheet. (continued)

that the loaded CG of the aircraft will be within limits if standard loading is used. This information will be listed in the Aircraft Specifications or Type Certificate Data Sheet, and if it does not apply, it will be identified as "none."

Operating Center Of Gravity Range

All aircraft will have center of gravity limits identified for the operational condition, with the aircraft loaded and ready for flight. If an aircraft can operate in more than one category, such as normal and utility, more than one set of limits might be listed. As shown earlier for the Piper Seneca airplane, the limits can change as the weight of the aircraft increases. In order to legally fly, the center of gravity for the aircraft must fall within the CG limits.

EXAMPLE WEIGHT AND BALANCE COMPUTATIONS

In ***Figure 16-13***, a tricycle gear airplane is being weighed by using three floor scales. The specifications on the airplane and the weighing specific data are as follows:

- Aircraft Datum: Leading edge of the wing
- Leveling Means: Two screws, left side of fuselage below window
- Wheelbase: 100"
- Fuel Capacity: 30 gals aviation gasoline at +95"
- Unusable Fuel: 6 lbs at +98"
- Oil Capacity: 8 qts at –38"
- Note 1: Empty weight includes unusable fuel and full oil
- Left Main Scale Reading: 650 lbs
- Right Main Scale Reading: 640 lbs
- Nose Scale Reading: 225 lbs
- Tare Weight: 5 lb chocks on left main, 5 lb chocks on right main, 2.5 lb chock on nose

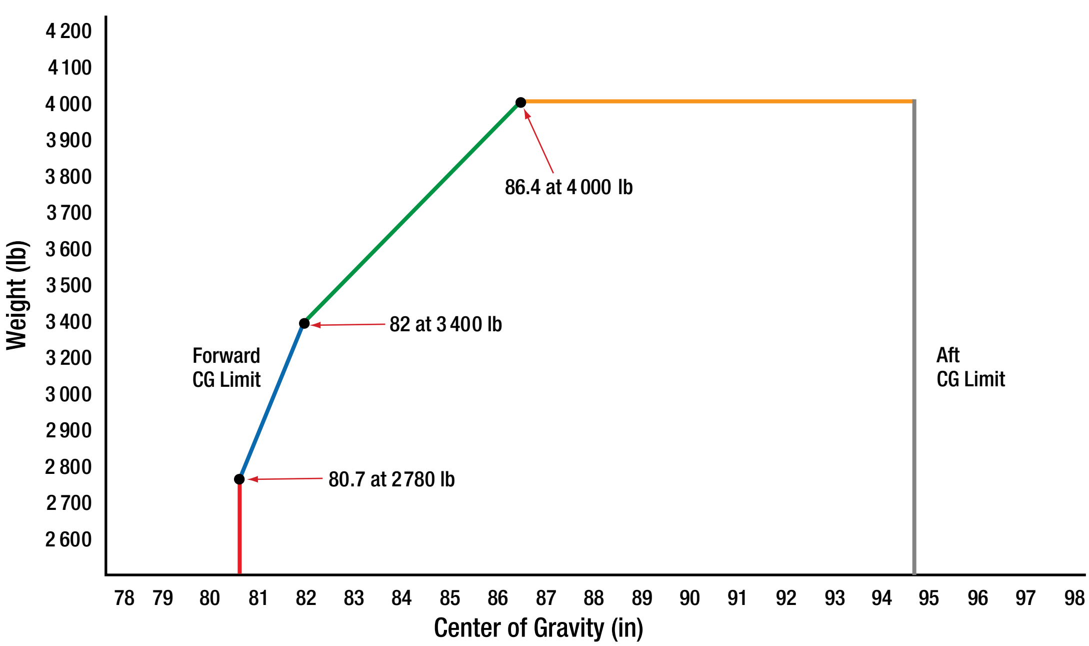


Figure 16-12. Center of gravity envelope for the Piper Seneca.

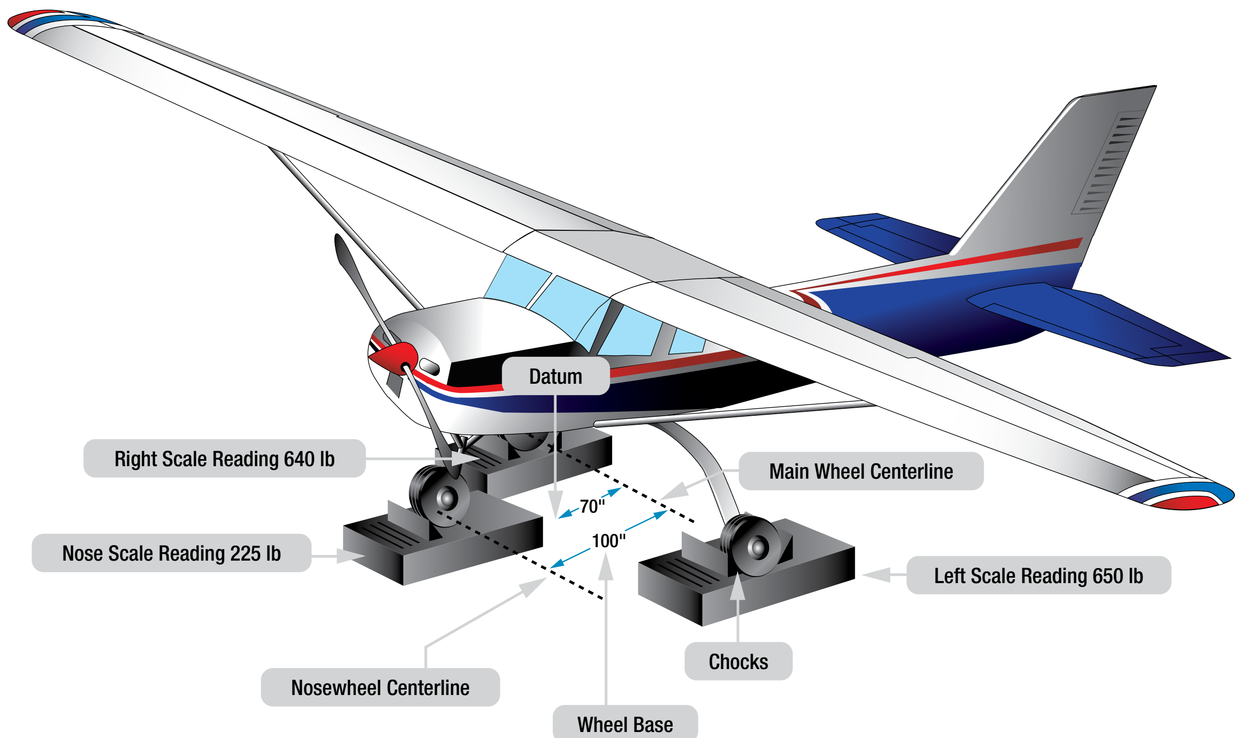


Figure 16-13. Example airplane being weighed.

- During Weighing: Fuel tanks full and oil full; Hydrometer check on fuel shows 5.9 lbs/gal

By analyzing the data identified for the airplane being weighed in ***Figure 16-13***, the following needed information is determined.

- Because the airplane was weighed with the fuel tanks full, the full weight of the fuel must be subtracted and the unusable fuel added back in. The weight of the fuel being subtracted is based on the pounds per gallon determined by the hydrometer check (5.9 lbs/gal).
- Because wheel chocks are used to keep the airplane from rolling off the scales, their weight must be subtracted from the scale readings as tare weight.
- Because the main wheel centerline is 70" behind the datum, its arm is a +70".
- The arm for the nosewheel is the difference between the wheelbase (100") and the distance from the datum to the main wheel centerline (70"). Therefore, the arm for the nosewheel is –30".

To calculate the airplane's empty weight and empty weight center of gravity, a six column chart is used. ***Figure 16-14*** shows the calculation for the airplane in ***Figure 16-13***.

Based on the calculation shown in the chart, the center of gravity is at +50.1", which means it is 50.1" aft of the datum. This places the center of gravity forward of the main landing gear, which must be the case for a tricycle gear airplane. This number is the result of dividing the total moment of 66 698 in-lbs by the total weight of 1 331.5 lbs.

EWCG Formulas

The EWCG can be quickly calculated by using the following formulas. There are four possible conditions and formulas that relate the location of the CG to the datum. Notice that the formula for each condition first determines the moment of the nose $\frac{F \times L}{W}$ wheel or tail $\frac{R \times L}{W}$ wheel and then divides it by the total weight of the airplane. The arm is then added to or subtracted from the distance between the main wheels and the datum (distance D).

Formula 1 Nosewheel airplanes with datum forward of the main wheels.

$$CG = D - \left(\frac{F \times L}{W}\right)$$

Item	Weight (lb)	Tare (lb)	Net Wt. (lb)	Arm (inches)	Moment (in-lb)
Nose	225	–2.5	222.5	–30	–6 675
Left Main	650	–5	645	+70	45 150
Right Main	640	–5	635	+70	44 450
Subtotal	1 515	–12.5	1 502.5		82 925
Fuel Total			–177	+95	–16 815
Fuel Unuse			+6	+98	588
Oil			Full		
Total			1 331.5	+50.1	66 698

Figure 16-14. Example airplane being weighed.

Formula 2 Nosewheel airplanes with the datum aft of the main wheels.

$$CG = -\left(D + \frac{F \times L}{W}\right)$$

Formula 3 Tail wheel airplanes with the datum forward of the main wheels.

$$CG = D + \left(\frac{R \times L}{W}\right)$$

Formula 4 Tail wheel airplanes with the datum aft of the main wheels.

$$CG = -D + \left(\frac{R \times L}{W}\right)$$

Datum Forward Of The Airplane–Nosewheel Landing Gear

The datum of the airplane in ***Figure 16-15*** is 100" forward of the leading edge of the wing root, or 128" forward of the main-wheel weighing points. This is distance (D). The weight of the nosewheel (F) is 340 lb, and the distance between main wheels and nosewheel (L) is 78". The total weight of the airplane (W) is 2 006 lb. The location of the CG may be determined by using this formula:

$$CG = D - \left(\frac{F \times L}{W}\right)$$

$$= 128 - \left(\frac{340 \times 78}{2\ 006}\right)$$

$$= 114.8$$

The CG is 114.8" aft of the datum. This is 13.2" forward of the main-wheel weighing points, which proves the location of the datum has no effect on the location of the CG so long as all measurements are made from the same location.

Datum Aft Of The Main Wheels–Nosewheel Landing Gear

The datum of some aircraft may be located aft of the main wheels. The airplane in this example is the same one just discussed, but the datum is at the intersection of the trailing edge of the wing with the fuselage. The distance (D) between the datum of the airplane in ***Figure 16-16*** and the main-wheel weighing points is 75", the weight of the nosewheel (F) is 340 lb, and the distance between main wheels and nosewheel (L) is 78". The total net weight of the airplane (W) is 2 006 lb. The location of the CG may be determined by using this formula:

$$CG = -\left(D + \frac{F \times L}{W}\right)$$

$$= -\left(75 + \frac{340 \times 78}{2\ 006}\right)$$

$$= 88.2$$

The CG location is a negative value, which means it is 88.2" forward of the datum. This places it 13.2" forward of the main wheels, the same location as it was when it was measured from other datum locations.

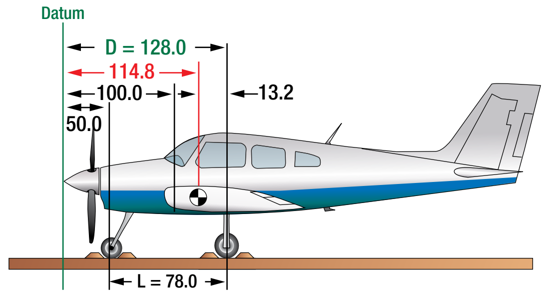


Figure 16-15. The datum is 100" forward of the wing root leading edge.

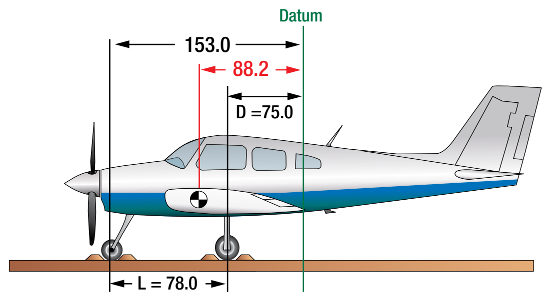


Figure 16-16. The datum is aft of the main wheels at the wing trailing edge.

Location Of Datum

It makes no difference where the datum is located if all measurements are made from the same location.

Datum Forward Of The Main Wheels–Tail Wheel Landing Gear

Locating the CG of a tail wheel airplane is done in the same way as locating it for a nosewheel airplane except the formulas use $\frac{R \times L}{W}$ rather than $\frac{F \times L}{W}$.

The distance (D) between the datum of the airplane in ***Figure 16-17*** and the main-gear weighing points is 7.5", the weight of the tail wheel (R) is 67 lb, and the distance (L) between the main-wheel and the tail wheel weighing points is 222". The total weight of the airplane (W) is 1 218 lb. Determine the CG by using this formula:

$$CG = D + \left(\frac{R \times L}{W}\right)$$

$$= 7.5 + \left(\frac{67 \times 222}{1\ 218}\right)$$

$$= 19.7$$

The CG is 19.7 inches behind the datum.

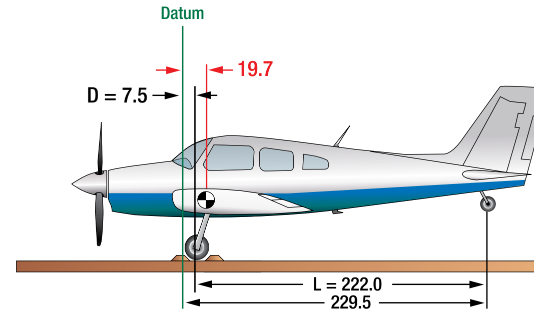


Figure 16-17. The datum of this tail wheel airplane is the wing root leading edge.

Datum Aft Of The Main Wheels–Tail Wheel Landing Gear

The datum of the airplane in ***Figure 16-18*** is located at the intersection of the wing root trailing edge and the fuselage. This places the arm of the main gear (D) at –80". The net weight of the tail wheel (R) is 67 lb, the distance between the main wheels and the tail wheel (L) is 222", and the total net weight (W) of the airplane is 1 218 lb. Since the datum is aft of the main wheels, use the formula:

$$CG = -D + \left(\frac{R \times L}{W}\right)$$

$$= -80 + \left(\frac{67 \times 222}{1\ 218}\right)$$

$$= 67.8$$

The CG is 67.8" forward of the datum, or 12.2" aft of the main-gear weighing points. The CG is in the same location relative to the main wheels, regardless of where the datum is located.

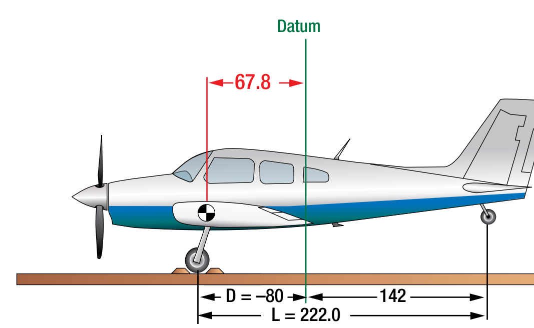


Figure 16-18. The datum is aft of the main wheels, at the intersection of the wing trailing edge and the fuselage.

LOADING AN AIRPLANE FOR FLIGHT

The ultimate test of whether or not there is a problem with an airplane's weight and balance is when it is loaded and ready to fly. The only real importance of an airplane's empty weight and empty weight center of gravity is how it affects the loaded weight and balance of the airplane, since an airplane doesn't fly when it is empty. The pilot in command is responsible for the weight and balance of the loaded airplane, and he or she makes the final decision on whether or not the airplane is safe to fly.

Example Loading Of An Airplane For Flight

As an example of an airplane being loaded for flight, the Piper Seneca twin will be used. The Type Certificate Data Sheet for this airplane was shown earlier in this chapter, and its center of gravity range and CG envelope were also shown. The information from the Type Certificate Data Sheet that pertains to this example loading is as follows:

CG Range (Gear Extended)	S/N 34-7250215 – 34-7450220: (+87.9") to (+94.6") at 4 200 lb (+82.0") to (+94.6") at 3 400 lb (+80.7") to (+94.6") at 2 780 lb Straight line variation between points given. –32 in-lb moment change due to gear retracting landing gear
Empty Weight CG Range	None
Maximum Weight	S/N 34-7250215 – 34-7450220: 4 200 lb—Takeoff 4 000 lb—Landing
No. of Seats	7 (2 at +85.5", 3 at +118.1", 2 at +155.7")
Maximum Baggage	200 lb (100 lb at +22.5, 100 lb at +178.7)
Fuel Capacity	98 gal (2 wing tanks) at (+93.6") (93 gal usable). See NOTE 1 for data on system fuel.

For the example loading of the airplane, the following information applies:

- Airplane Serial Number: 34-7250816
- Airplane Empty Weight: 2 650 lb
- Airplane Empty Weight CG: +86.8"

For today's flight, the following useful load items will be included:

- 1 pilot at 180 lbs at an arm of +85.5"
- 1 passenger at 160 lbs at an arm of +118.1"
- 1 passenger at 210 lbs at an arm of +118.1"
- 1 passenger at 190 lbs at an arm of +118.1"
- 1 passenger at 205 lbs at an arm of +155.7"
- 50 lbs of baggage at +22.5"
- 100 lbs of baggage at +178.7"
- 80 gals of fuel at +93.6"

To calculate the loaded weight and CG of this airplane, a four column chart will be used. (***Figure 16-19***)

Based on the information in the Type Certificate Data Sheet, the maximum takeoff weight of this airplane is 4 200 lbs, and the aft-most CG limit is +94.6". The loaded airplane in the chart above is 25 lbs too heavy, and the CG is 1.82" too far aft. To make the airplane safe to fly, the load needs to be reduced by 25 lbs and some of the load needs to be shifted forward.

For example, the baggage can be reduced by 25 lbs, and a full 100 lbs of it can be placed in the more forward compartment. One passenger can be moved to the forward seat next to the pilot, and the aft-most passenger can then be moved forward. If these changes are made, the four column calculation will be as shown in ***Figure 16-20***.

With the changes made, the loaded weight is now at the maximum allowable of 4 200 lbs, and the CG has moved forward 4.41". The airplane is now safe to fly.

Adverse-Loaded CG Checks

Many modern aircraft have multiple rows of seats and often more than one baggage compartment. After any repair or alteration that changes the weight and balance, the A&P mechanic or repairman must ensure that no legal condition of loading can move the CG outside of its allowable limits. To determine this, adverse-loaded CG checks must be performed and the results noted in the weight and balance revision sheet.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	2 650	+86.80	230 020.0
Pilot	180	+85.50	15 390.0
Passenger	160	+118.10	18 896.0
Passenger	210	+118.10	24 801.0
Passenger	190	+118.10	22 439.0
Passenger	205	155.70	31 918.5
Baggage	50	+22.50	1 125.0
Baggage	100	+178.70	17 870.0
Fuel	480	+93.60	44 928.0
Total	4 255	+96.42	407 387.5

Figure 16-19. Center of gravity calculation for Piper Seneca.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	2 650	+86.8	230 020.0
Pilot	180	+85.5	15 390.0
Passenger	210	+85.5	17 955.0
Passenger	160	+118.1	24 801.0
Passenger	190	+118.1	22 439.0
Passenger	205	+118.1	24 210.5
Baggage	100	+22.5	2 250.0
Baggage	25	+178.7	4 467.5
Fuel	480	93.6	44 928.0
Total	4 200	+92.0	386 461.0

Figure 16-20. Center of gravity calculation for Piper Seneca with weights shifted.

During a forward adverse-loaded CG check, all useful load items in front of the forward CG limit are loaded and all useful load items behind the forward CG limit are left empty. So, if there are two seats and a baggage compartment located in front of the forward CG limit, two people weighing 170 lb each are seated and the maximum allowable baggage is placed in the baggage compartment. Any seat or baggage compartment located behind the forward CG limit is left empty. If the fuel is located behind the forward CG limit, minimum fuel will be shown in the tank. Minimum fuel is calculated by dividing the engine's METO Hp by 2.

During an aft adverse-loaded CG check, all useful load items behind the aft CG limit are loaded and all useful load items in front of the aft CG limit are left empty. Even though the pilot's seat will be in front of the aft CG limit, the pilot's seat cannot be left empty. If the fuel tank is located forward of the aft CG limit, minimum fuel will be shown.

WEIGHT AND BALANCE EXTREME CONDITIONS

A weight and balance extreme condition check, sometimes called an adverse condition check, involves loading the aircraft in as nose heavy or tail heavy a condition as possible, and seeing if the center of gravity falls outside the allowable limits. This check is done with pencil and paper. In other words, the aircraft is not actually loaded in an adverse way and an attempt made to fly it.

On what is called a forward extreme condition check, all useful load items in front of the forward CG limit are loaded, and all useful load items behind the forward CG limit are left empty. So if there are two seats and a baggage compartment located in front of the forward CG limit, two people weighing 170 lbs each will be put in the seats, and the maximum allowable baggage will be put in the baggage compartment. Any seat or baggage compartment located behind the forward CG limit will be left empty. If the fuel is located behind the forward CG limit, minimum fuel will be shown in the tank. Minimum fuel is calculated by dividing the engine's METO horsepower by 2.

On an aft extreme condition check, all useful load items behind the aft CG limit are loaded, and all useful load items in front of the aft CG limit are left empty. Even though the pilot's seat will be located in front of the aft CG limit, the pilot's seat cannot be left empty. If the fuel tank is located forward of the aft CG limit, minimum fuel will be shown.

EQUIPMENT CHANGE AND AIRCRAFT ALTERATION

When the equipment in an aircraft is changed, such as the installation of a new radar system or ground proximity warning system, or the removal of a radio or seat, the weight and balance of an aircraft will change. An alteration performed on an aircraft, such as a cargo door being installed or a reinforcing plate being attached to the spar of a wing, will also change the weight and balance of an aircraft. Any time the equipment is changed or an alteration is performed, the new empty weight and empty weight center of gravity must be determined.

This can be accomplished by placing the aircraft on scales and weighing it, or by mathematically calculating the new weight and balance. The mathematical calculation is acceptable if the exact weight and arm of all the changes are known.

Example Calculations After An Equipment Change

A small twin-engine airplane has some new equipment installed, and some of its existing equipment removed.

The details of the equipment changes are as follows:

Airplane Empty Weight:	2 350 lb
Airplane Empty Weight CG:	+24.7"
Airplane Datum:	Leading edge of the wing
Radio Installed:	5.8 lb at an arm of –28"
Global Positioning System Installed:	7.3 lb at an arm of –26"
Emergency Locater Transmitter Installed:	2.8 lb at an arm of +105"
Strobe Light Removed:	1.4 lb at an arm of +75"
Automatic Direction Finder (ADF) Removed:	3 lb at an arm of –28"
Seat Removed:	34 lb at an arm of +60"

To calculate the new empty weight and empty weight center of gravity, a four column chart is used. The calculation would be as shown in ***Figure 16-21***.

In evaluating the weight and balance calculation shown in ***Figure 16-21***, the following key points should be recognized.

- The weight of the equipment needs to be identified with a plus or minus to signify whether it is being installed or removed.
- The sign of the moment (plus or minus) is determined by the signs of the weight and arm.
- The strobe and the ADF are both being removed (negative weight), but only the strobe has a negative moment. This is because the arm for the ADF is also negative, and two negatives multiplied together produce a positive result.
- The total arm is the airplane's center of gravity, and is found by dividing the total moment by the total weight.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	2 350.0	+24.70	58 045.0
Radio Install	+5.8	–28.00	–162.4
GPS Install	+7.3	–26.00	–189.8
ELT Install	+2.8	+105.00	294.0
Strobe Remove	–1.4	+75.00	–105.0
ADF Remove	–3.0	–28.00	84.0
Seat Remove	–34.0	+60.00	–2 040.0
Total	2 327.5	24.03	55 925.8

Figure 16-21. Center of gravity calculation after equipment change.

- The result of the equipment change is that the airplane's weight was reduced by 22.5 lbs and the center of gravity has moved forward 0.67".

THE USE OF BALLAST

Ballast is used in an aircraft to attain the desired CG balance, when the center of gravity is not within limits or is not at the location desired by the operator. It is usually located as far aft or as far forward as possible to bring the CG within limits, while using a minimum amount of weight. Ballast that is installed to compensate for the removal or installation of equipment items and that is to remain in the aircraft for long periods is called permanent ballast.

It is generally lead bars or plates bolted to the aircraft structure. It may be painted red and placarded:

- PERMANENT BALLAST—DO NOT REMOVE. The installation of permanent ballast results in an increase in the aircraft empty weight, and it reduces the useful load.

Temporary ballast, or removable ballast, is used to meet certain loading conditions that may vary from time to time. It generally takes the form of lead shot bags, sand bags, or other weight items that are not permanently installed. Temporary ballast should be placarded:

- BALLAST, XX LB. REMOVAL REQUIRES WEIGHT AND BALANCE CHECK. The baggage compartment is usually the most convenient location for temporary ballast.

Whenever permanent or temporary ballast is installed, it must be placed in an approved location and secured in an appropriate manner. If permanent ballast is being bolted to the structure of the aircraft, the location must

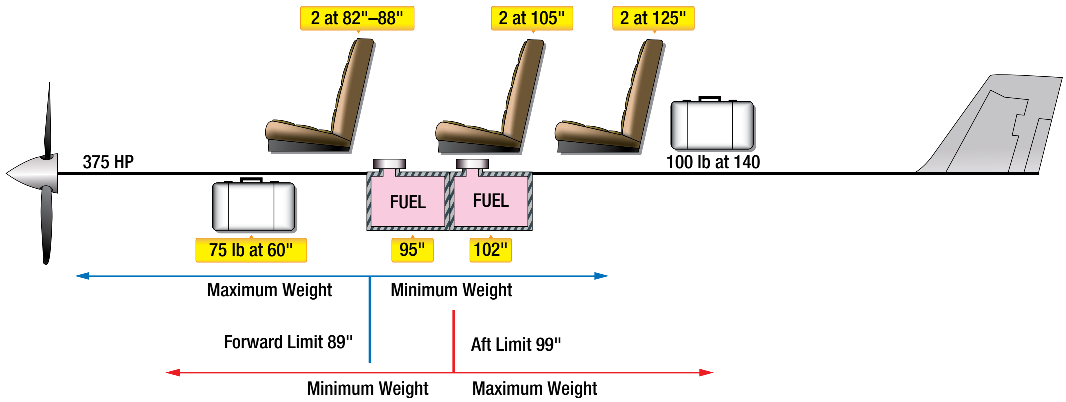


Figure 16-22. Example airplane for extreme condition checks.

be one that was previously approved and designed for the installation, or it must be approved by the FAA as a major alteration before the aircraft is returned to service. When temporary ballast is placed in a baggage compartment, it must be secured in a way that prevents it from becoming a projectile if the aircraft encounters turbulence or an unusual flight attitude. To calculate how much ballast is needed to bring the center of gravity within limits, the following formula is used.

$$\text{ballast needed} = \frac{\text{loaded weight of aircraft (distance CG is out of limits)}}{\text{arm from ballast location to affected limit}}$$

Figure 16-22 and ***Figure 16-23*** show an aft extreme condition check being performed on an airplane. In this previously shown example, the airplane's center of gravity was out of limits by 0.6". If there were a need or a desire to fly the airplane loaded this way, one way to make it possible would be the installation of temporary ballast in the front of the airplane. The logical choice for placement of this ballast is the forward baggage compartment.

The center of gravity for this airplane is 0.6" too far aft. If the forward baggage compartment is used as a temporary ballast location, the ballast calculation will be as follows:

$$\text{ballast needed} = \frac{\text{loaded weight of aircraft (distance CG is out of limits)}}{\text{arm from ballast location to affected limit}}$$

$$= \frac{3\ 034 \text{ lb } (0.6")}{39"}$$

$$= 46.68 \text{ lbs}$$

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	1 850	+92.45	171 032.5
Pilot	170	+88.00	14 960.0
2 Passengers	340	+105.00	35 700.0
2 Passengers	340	+125.00	42 500.0
Baggage	100	+140.00	14 000.0
Fuel	234	+102.00	23 868.0
Total	3 034	+99.60	302 060.5

Figure 16-23. Extreme condition check.

When ballast is calculated, the answer should always be rounded up to the next higher whole pound, or in this case, 47 lbs of ballast would be used. To ensure the ballast calculation is correct, the weight of the ballast should be plugged back into the four column calculation and a new center of gravity calculated.

The aft limit for the airplane was 99", and the new CG is at 98.96", which puts it within acceptable limits. The new CG did not fall exactly at 99" because the amount of needed ballast was rounded up to the next higher whole pound. If the ballast could have been placed farther forward, such as being bolted to the engine firewall, less ballast would have been needed. That is why ballast is always placed as far away from the affected limit as possible. (***Figure 16-24***.) In evaluating the ballast calculation shown above, the following key points should be recognized.

- The loaded weight of the aircraft, as identified in the formula, is what the airplane weighed when the CG was out of limits.
- The distance the CG is out of limits is the difference between the CG location and the CG limit, in this case 99.6" minus 99".

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Loaded Weight	3 034	+99.60	302 060.5
Ballast	47	+60.00	2 820.0
Total	3 081	+98.96	304 880.5

Figure 16-24. Ballast calculation.

- The affected limit identified in the formula is the CG limit which has been exceeded. If the CG is too far aft, it is the aft limit that has been exceeded.
- The aft limit for this example airplane is 99", and the ballast is being placed in the baggage compartment at an arm of 60". The difference between the two is 39", the quantity divided by in the formula.

Viewed as a first class lever problem, ***Figure 16-25*** shows what this ballast calculation would look like. A ballast weight of 46.68 lbs on the left side of the lever multiplied by the arm of 39" (99 minus 60) would equal the aircraft weight of 3 034 lb multiplied by the distance the CG is out of limits, which is 0.6" (99.6 minus 99).

LOADING GRAPHS AND CG ENVELOPES

The weight and balance computation system, commonly called the loading graph and CG envelope system, is an excellent and rapid method for determining the CG location for various loading arrangements. This method can be applied to any make and model of aircraft, but is more often seen with small general aviation aircraft.

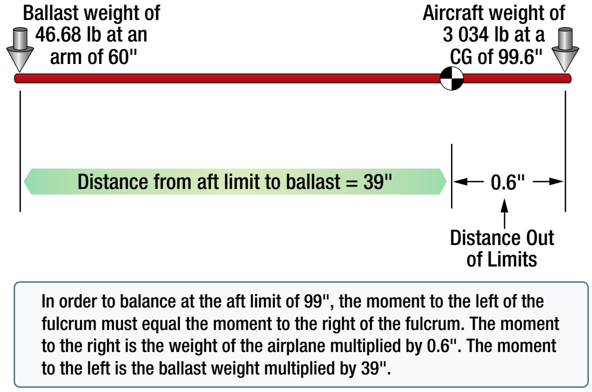


Figure 16-25. Ballast calculation as a first class lever.

Aircraft manufacturers using this method of weight and balance computation prepare graphs similar to those shown in ***Figure 16-26 and Figure 16-27*** for each make and model aircraft at the time of original certification. The graphs become a permanent part of the aircraft records, and are typically found in the Airplane Flight Manual or Pilot's Operating Handbook (AFM/POH). These graphs, used in conjunction with the empty weight and empty weight CG data found in the weight and balance report, allow the pilot to plot the CG for the loaded aircraft.

The loading graph illustrated in ***Figure 16-26*** is used to determine the index number (moment value) of any item or weight that may be involved in loading the aircraft. To use this graph, find the point on the vertical scale that represents the known weight. Project a horizontal line to the point where it intersects the proper diagonal weight line (i.e., pilot, copilot, baggage). Where the

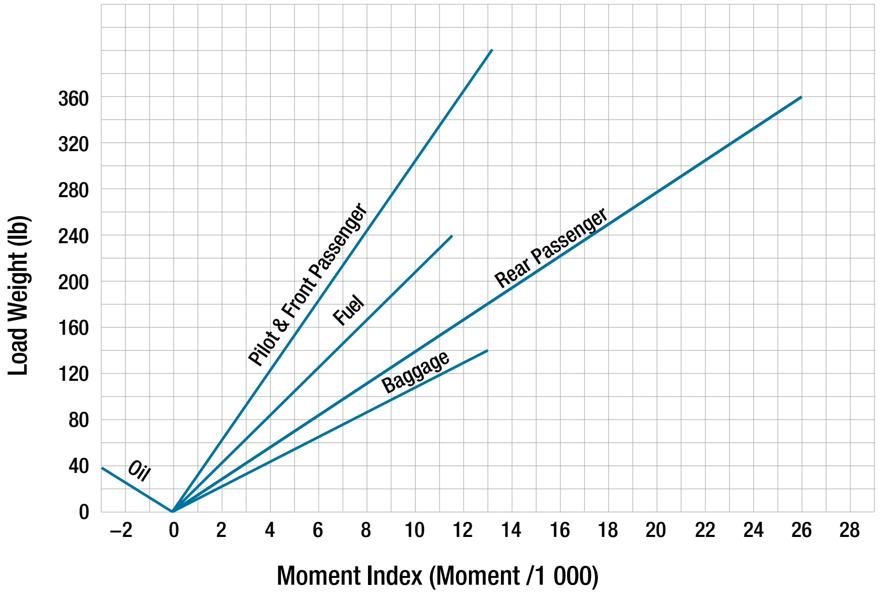


Figure 16-26. Aircraft loading graph.

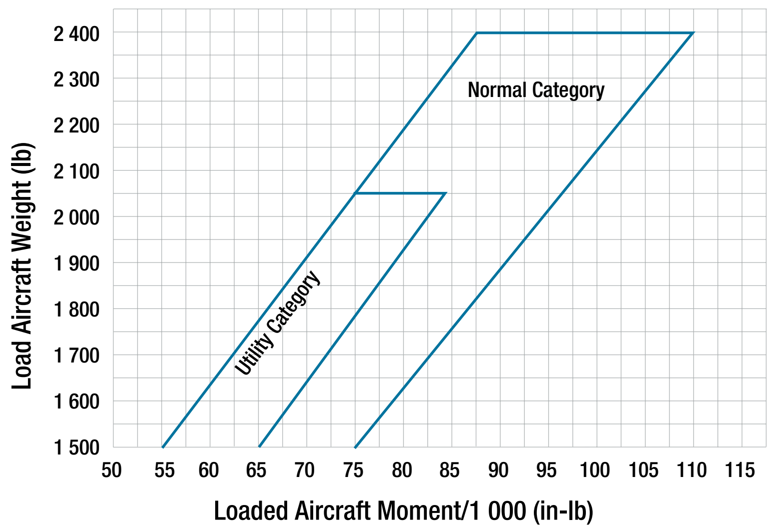


Figure 16-27. CG envelope.

horizontal line intersects the diagonal, project a vertical line downward to determine the loaded moment (index number) for the weight being added.

After the moment for each item of weight has been determined, all weights are added and all moments are added. The total weight and moment is then plotted on the CG envelope. (***Figure 16-27***) The total weight is plotted on the vertical scale of the graph, with a horizontal line projected out from that point. The total moment is plotted on the horizontal scale of the graph, with a vertical line projected up from that point. Where the horizontal and vertical plot lines intersect on the graph is the center of gravity for the loaded aircraft. If the point where the plot lines intersect falls inside the CG envelope, the aircraft CG is within limits.

In ***Figure 16-27***, there are actually two CG envelopes, one for the aircraft in the Normal Category and one for the aircraft in the Utility Category.

The loading graph and CG envelope shown in ***Figures 16-26 and 16-27*** are for an airplane with the following specifications and weight and balance data.

Number of Seats:	4
Fuel Capacity (Usable):	38 gal of Av Gas
Oil Capacity: (included in empty weight)	8 qt
Baggage:	120 lb
Empty Weight:	1 400 lb
Empty Weight CG:	38.5"
Empty Weight Moment:	53 900 in-lb

An example of loading the airplane for flight and calculating the total loaded weight and the total loaded moment is shown in ***Figures 16-28 and 16-29***. The use of the loading graph to determine the moment for each of the useful load items is shown in ***Figure 16-29***. The color used for each useful load item in ***Figure 16-28*** matches the color used for the plot on the loading graph. The total loaded weight of the airplane is 2 258 pounds and the total loaded moment is 99 400 in-lbs. These two numbers can now be plotted on the CG envelope to see if the airplane is within CG limits.

Figure 16-30 shows the CG envelope, with the loaded weight and moment of the airplane plotted. The CG location shown falls within the normal category envelope, so the airplane is within CG limits for this category. It is interesting to note that the lines that form the CG envelope are actually graphic plots of the forward and aft CG limits. In ***Figure 16-30***, the red line is a graphic plot of the forward limit, and the blue and green lines are graphic plots of the aft limit for the two different categories.

Item	Weight (lb)	Moment (in-lb)
Aircraft Empty Wt.	1 400	53 900
Pilot	180	6 000
Front Passengers	140	4 500
Rear Passengers	210	15 000
Baggage	100	9 200
Fuel	228	10 800
Total	2 258	99 400

Figure 16-28. Aircraft load chart.

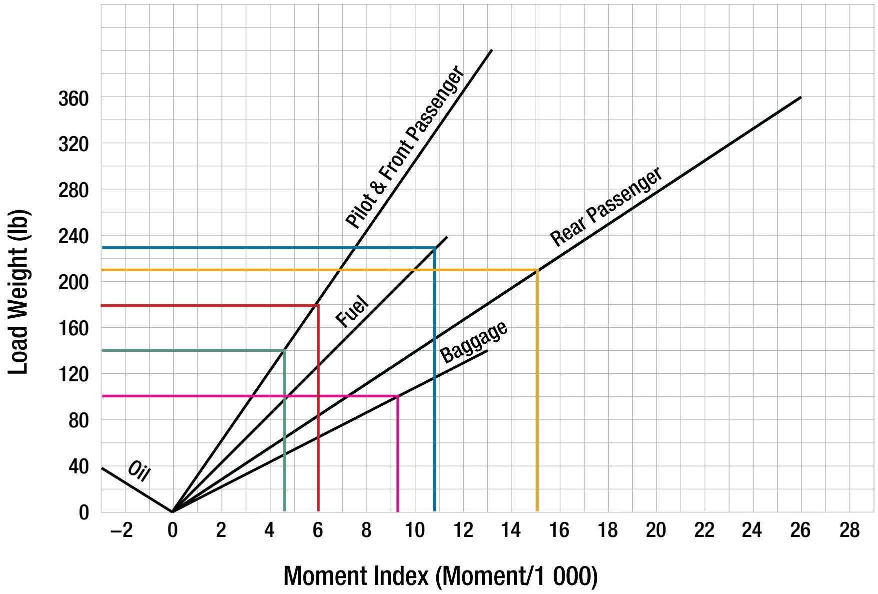


Figure 16-29. CG envelope.

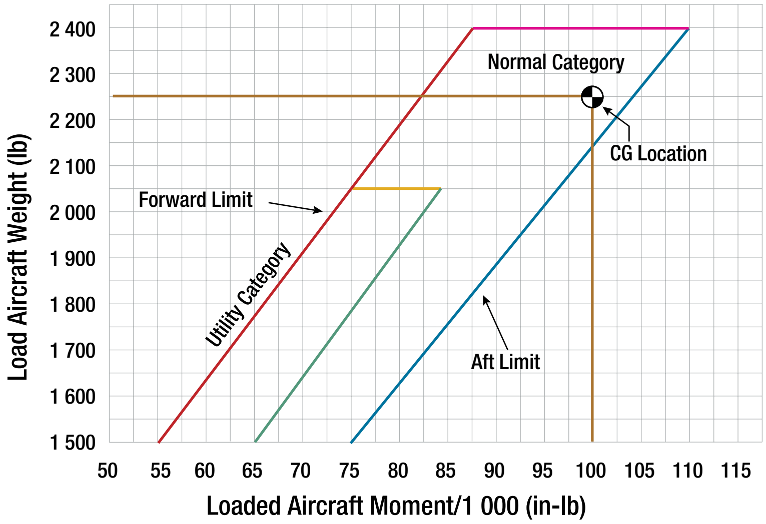


Figure 16-30. CG envelope example plot.

LARGE AIRPLANES – MEAN AERODYMANIC CHORD

On small airplanes and on all helicopters, the center of gravity location is identified as being a specific number of inches from the datum. The center of gravity range is identified the same way. On larger airplanes, from private business jets to large jumbo jets, the center of gravity and its range are typically identified in relation to the width of the wing.

The width of the wing on an airplane is known as the chord. If the leading edge and trailing edge of a wing are parallel to each other, the chord of the wing is the same along the wing's length. Business jets and commercial transport airplanes have wings that are tapered and that are swept back, so the width of their wings is different along their entire length. The width is greatest where the wing meets the fuselage and progressively decreases toward the tip. In relation to the aerodynamics of the wing, the average length of the chord on these tapered swept-back wings is known as the mean aerodynamic chord (MAC).

On these larger airplanes, the CG is identified as being at a location that is a specific percent of the mean aerodynamic chord (% MAC). For example, imagine that the MAC on a particular airplane is 100", and the CG falls 20" behind the leading edge of the MAC. That means it falls one-fifth of the way back, or at 20% of the MAC.

Figure 16-31 shows a large twin-engine commercial transport airplane. The datum is forward of the nose of the airplane, and all the arms shown in the Figure are being measured from that point. The center of gravity for the airplane is shown as an arm measured in inches. In the lower left corner of the figure, a cross section of the wing is shown, with the same center of gravity information being presented.

To convert the center of gravity location from inches to a percent of MAC, for the airplane shown in *Figure 16-31*, the steps are as follows:

1. Identify the center of gravity location, in inches from the datum.
2. Identify the leading edge of the MAC (LEMAC), in inches from the datum.
3. Subtract LEMAC from the CG location.
4. Divide the difference by the length of the MAC.
5. Convert the result in decimals to a percentage by multiplying by 100.

As a formula, the solution to solve for the percent of MAC would be:

$$\text{Percent of MAC} = \frac{\text{CG-LEMAC}}{\text{MAC}} \times 100$$

The result using the numbers shown in *Figure 16-31* would be:

$$\text{Percent of MAC} = \frac{\text{CG-LEMAC}}{\text{MAC}} \times 100$$

$$= \frac{945 - 900}{180} \times 100$$

$$= 25\%$$

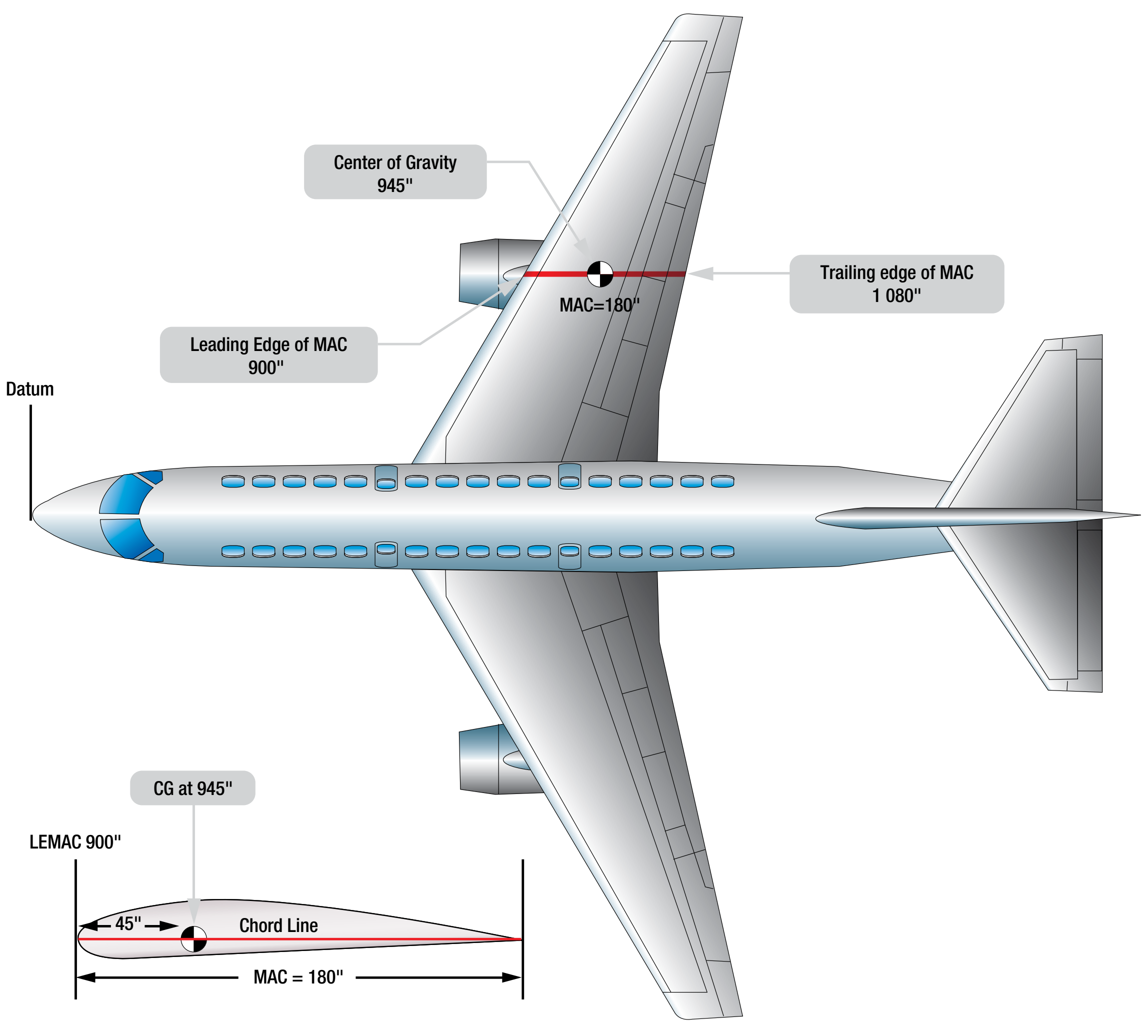


Figure 16-31. Center of gravity location on a large commercial transport.

If the center of gravity is known in percent of MAC, and there is a need to know the CG location in inches from the datum, the conversion would be done as follows:

1. Convert the percent of MAC to a decimal by dividing by 100.
2. Multiply the decimal by the length of the MAC.
3. Add this number to LEMAC.

As a formula, the solution to convert a percent of MAC to an inch value would be:

$$\text{CG in inches} = \text{MAC \%} \div 100 \times \text{MAC} + \text{LEMAC}$$

For the airplane in ***Figure 16-31***, if the CG was at 32.5% of the MAC, the solution would be:

$$\begin{aligned}\text{CG in inches} &= \text{MAC \%} \div 100 \times \text{MAC} + \text{LEMAC} \\ &= 32.5 \div 100 \times 180 + 900 \\ &= 958.5\end{aligned}$$

HELICOPTER WEIGHT AND BALANCE

All the terminology and concepts that apply to airplane weight and balance also apply generally to helicopter weight and balance. However, there are some specific differences that need to be identified.

Most helicopters have a much more restricted CG range than airplanes. In some cases, this range is less than 3". The exact location and length of the CG range is specified for each helicopter and usually extends a short distance fore and aft of the main rotor mast or centered between the main rotors of a dual rotor system. Whereas airplanes have a CG range only along the longitudinal axis, helicopters have both longitudinal and lateral CG ranges. Because the wings extend outward from the CG, airplanes tend to have a great deal of lateral stability. A helicopter, on the other hand, acts like a pendulum, with the weight of the helicopter hanging from the main rotor shaft.

Ideally, the helicopter should have such perfect balance that the fuselage remains horizontal while in a hover. If the helicopter is too nose heavy or tail heavy while it is hovering, the cyclic pitch control is used to keep the fuselage horizontal. If the CG location is too extreme, it may not be possible to keep the fuselage horizontal or maintain control of the helicopter.

WEIGHT AND BALANCE RECORDS

When a technician gets involved with the weight and balance of an aircraft, it almost always involves a calculation of the aircraft's empty weight and empty weight center of gravity. Only on rare occasions will the technician be involved in calculating extreme conditions, how much ballast is needed, or the loaded weight and balance of the aircraft. Calculating the empty weight and empty weight CG might involve putting the aircraft on scales and weighing it, or a pencil and paper exercise after installing a new piece of equipment.

Current and accurate empty weight and empty weight center of gravity are required to be known for an aircraft. This information must be included in the weight and balance report, which is a part of the aircraft permanent records. The weight and balance report must be in the aircraft when it is being flown.

There is no required format for this report, but ***Figure 16-32*** is a good example of recording the data obtained from weighing an aircraft. As it is currently laid out, the form would accommodate either a tricycle gear or tail dragger airplane. Depending on the gear type, either the nose or the tail row would be used. If an airplane is being weighed using jacks and load cells, or if a helicopter is being weighed, the item names must be changed to reflect the weight locations.

Aircraft Weight and Balance Report

Results of Aircraft Weighing

Make ______________ Model ______________

Serial # ______________ N# ______________

Datum Location ______________

Leveling Means ______________

Scale Arms: Nose ______ Tail ______ Left Main ______ Right Main ______

Scale Weights: Nose ______ Tail ______ Left Main ______ Right Main ______

Tare Weights: Nose ______ Tail ______ Left Main ______ Right Main ______

Weight and Balance Calculation

Item	Scale (lb)	Tare Wt. (lb)	Net Wt. (lb)	Arm (inches)	Moment (in-lb)
Nose					
Tail					
Left Main					
Right Main					
Subtotal					
Fuel					
Oil					
Misc.					
Total					

Aircraft Current Empty Weight: ______________

Aircraft Current Empty Weight CG: ______________

Aircraft Maximum Weight: ______________

Aircraft Useful Load: ______________

Computed By: ______________ (print name)

______________ (signature)

Certificate #: ______________ (A&P, Repair Station, etc.)

Date: ______________

Figure 16-32. Aircraft weight and balance report.

AIRCRAFT WEIGHT AND BALANCE

If an equipment change is being done on an aircraft, and the new weight and balance is calculated mathematically instead of weighing the aircraft, the same type of form shown in ***Figure 16-32*** can be used. The only change would be the use of a four column solution, instead of six columns, and there would be no tare weight or involvement with fuel and oil.