DETERMINATION OF CENTER OF BALANCE AND CENTER OF GRAVITY

Section I. Center of Balance (Vehicles and General Cargo)

17-1. INTRODUCTION. To correctly plan an airlift and to segregate loads for specific aircraft, it is necessary to determine the weight and CB of cargo units. Section I discusses the procedures used to determine the weight and CB of vehicles and general cargo. Section II discusses determining an aircraft's CG. The accuracy of weight and balance computation is as important to flight safety as proper maintenance.

17-2. VEHICLE MEASUREMENTS. Vehicle measurements are found on the manufacturer's data plate on M-series vehicles. Where measurements are not available, vehicles are measured at specific points (Figure 17-1). However, data plate weights are not used for airlift purposes.

NOTE: The individual axle weight must be marked above each axle.

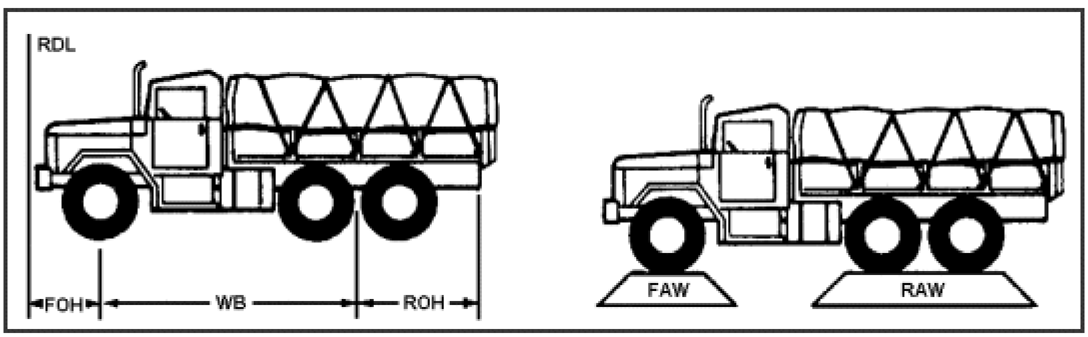


Figure 17-1. Vehicle measurement points

a. If scales are not available to the unit commander, the method of determining weights will be resolved at the joint planning conference.

b. Figure 17-1 shows the vehicle measurement points that must be used to calculate the CB of a vehicle. The acronyms and terms used in Figure 17-1 and elsewhere to compute CB are as follows:

- FOH - (front overhang) distance in inches from front bumper to center of front axle.
- WB - (wheel base) distance in inches from center of front axle to center of rear axle or center of tandem axles.
- ROH - (rear overhang) distance from rear axle or center of tandem axles to rear bumper.
- FAW - front axle weight in pounds.
- RAW - rear axle weight in pounds.

- **GW - gross weight in pounds.**
- **RDL - (reference datum line) a predetermined point from which all measurements are taken.**
- **MOMENT - the product obtained by multiplying the weight by the distance in inches from the RDL.**

17-3. WEIGHT AND CENTER OF BALANCE. The CB of cargo items must be determined before the weight and balance of a loaded aircraft can be computed.

a. The shipping agency must mark each item of cargo with the correct gross weight and a CB point. Mark all items measuring 20 feet or longer and those having a balance point other than at its center. In addition, mark vehicles having a load-carrying capability to show an empty or loaded CB, as appropriate. Also, if trucks and towed equipment are to be transported coupled, a combined CB will be computed and marked on the appropriate vehicle.

b. Determine the weight and CB of a vehicle after all secondary cargo is secured, ready for airlift. The total weight of the secondary cargo must be included in the total vehicle weight. Nothing can be added to or removed from a vehicle that has been weighed and marked unless it is reweighed.

(1) Compute the CB location of vehicles using this formula: Multiply weight by distance (in inches) of each axle from the reference line, then divide the total results by the vehicle gross weight. The resulting figure is the number of inches to be measured aft from the reference line to the CB of the vehicle.

Formula: (W1 x D1) + (W2 x D2
= C
Gross Weight

W1 = front axle weight
W2 = rear axle weight
D1 = distance from RDL to front axle
D2 = distance from RDL to rear axle

(2) The vehicle CB is computed to the nearest whole inch. Any answer that has a fraction of .5 or higher is increased to the next higher number, if .4 or less the number is dropped.

(3) After computing the vehicle CB, mark both sides of the vehicle with masking tape to form the letter "T." Use a grease pencil or magic marker to write the gross weight in the crossbar of the "T." Write "CB" in the vertical bar to mark the exact CB position (see Figure 17-2). Mark axle weights above each axle.

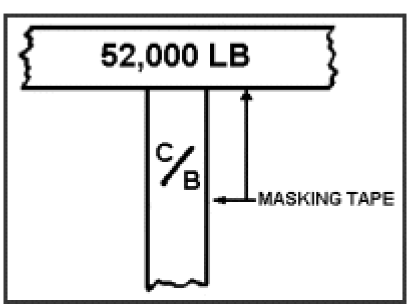
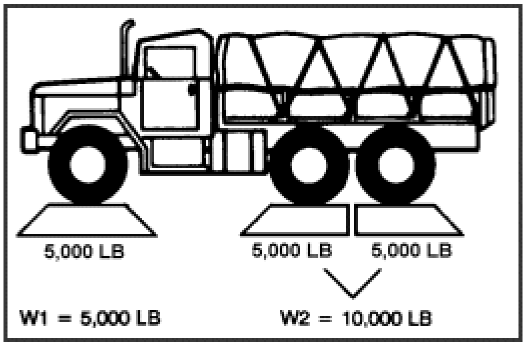


Figure 17-2. Center of balance marker

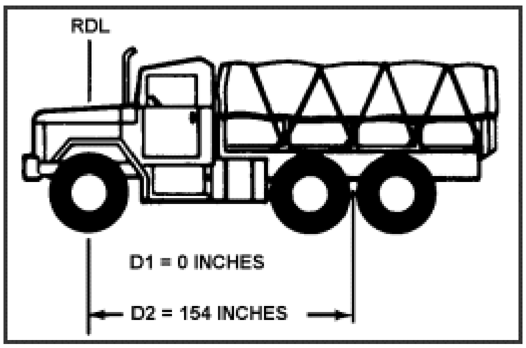
(4) The following illustrations show examples of methods used to determine the weight and CB location of typical cargo units. These cargo units include general cargo, large or skid-mounted cargo, track-type vehicles, and single- and multiple-axle vehicles.

EXAMPLE 1 – Vehicles.

STEP 1. **Determine front and rear axle weights.**



STEP 2. **Determine distance from the front and rear axles to the RDL.**



STEP 3. **Enter the information obtained in steps 1 and 2 into the formula.**

(W1 x D1) + (W2 x D2) = CB
Gross Weight

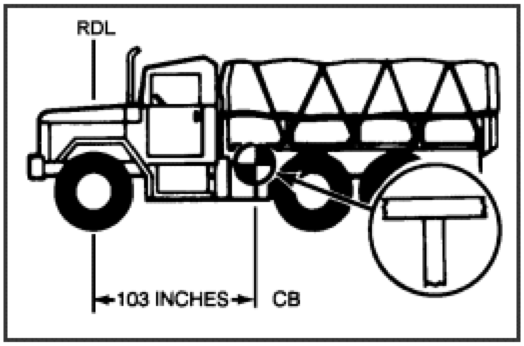
(CB = distance in inches to be measured aft from the RDL which gives the center of balance.)

(5,000 x 60) + (10,000 x 180) =
5,000

300,000 + 1,800,000 =
15,000

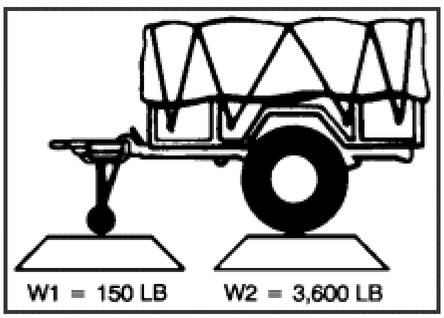
STEP 4. **Divide the total moment by the gross weight. This final result (140 inches) is the CB of the vehicle measured from the front end (reference data line).**

2,100,000 = 140 inches from the RDL gives the CB
15,000

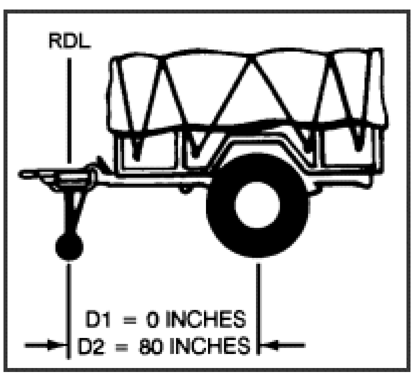


EXAMPLE 2 – Trailers. The same idea is used in determining the CB for a trailer as was used for the truck in Example 1. The main difference is that the tongue is weighed as the front axle, and the actual axle is weighed as the rear axle.

STEP 1. **Weigh tongue and axle.**



STEP 2. **Measure the distance from the end of the tongue to the center of the axle.**



STEP 3. **Enter the weights.**

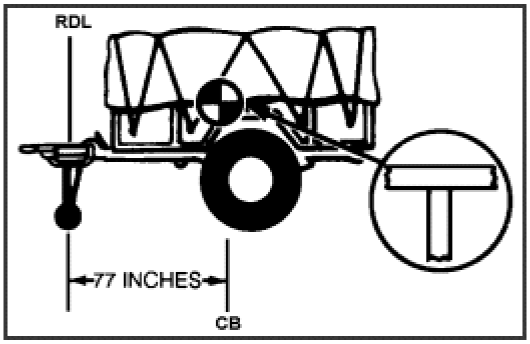
$$\frac{(W1 \times D1) + (W2 \times D2)}{\text{Gross Weight}} = CB$$

$$\frac{(150 \times 1) + (3{,}600 \times 80)}{3{,}750} =$$

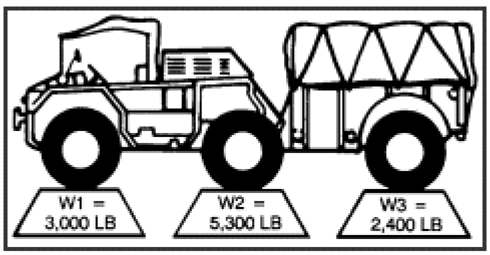
$$\frac{(150 + 288{,}000)}{3{,}750} =$$

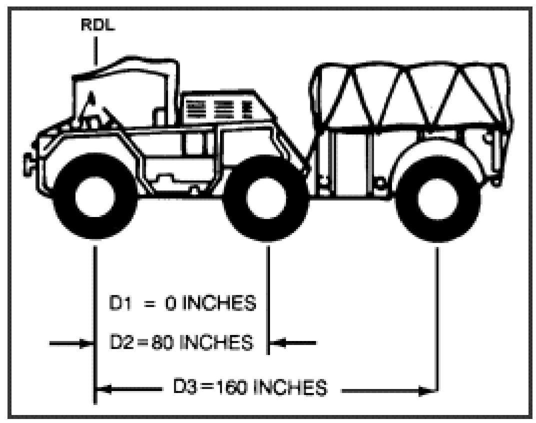
$$\frac{288{,}150}{3{,}750} = 76.84$$

STEP 4. **Now measure 77 inches from the tongue aft to obtain the CB on the trailer.**



EXAMPLE 3 – Multi-axle vehicles. To determine the CB for a multi-axle vehicle such as the one shown here, weigh each axle as in step 1 in the first example, then measure the distance from the RDL to each axle as was done in step 2 before.





$$\frac{(W1 \times D1) + (W2 \times D2) + (W3 \times D3)}{\text{Gross Weight}} = CB$$

(CB = distance in inches to be measured aft from the RDL which gives the center of balance.)

STEP 3. **Now as before, enter the information obtained in steps 1 and 2 into the formula.**

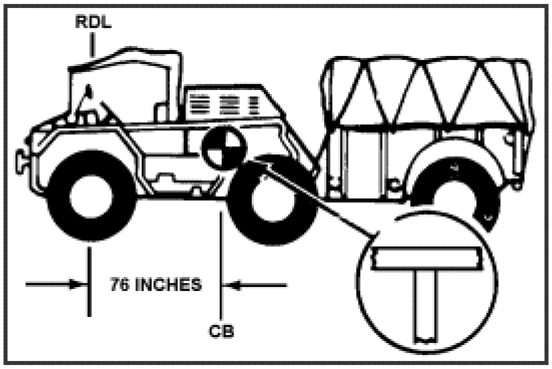
$$\frac{(3{,}000 \times 24) + (5{,}300 \times 104) + (2{,}400 \times 184)}{10{,}700} =$$

(moment)

$$\frac{72{,}000 + 551{,}200 + 441{,}600}{10{,}700} = \frac{1{,}064{,}800}{10{,}700}$$

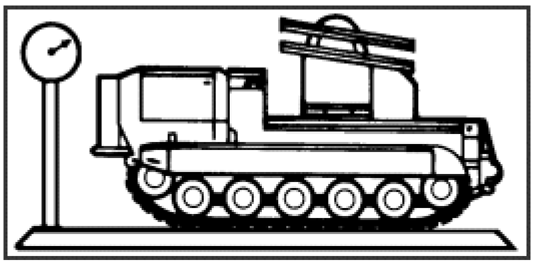
STEP 4. **Divide the total moment by the total weight.**

$$\frac{1{,}064{,}800}{10{,}700} = 99.4$$ **inches from the RDL gives the location of the CB**

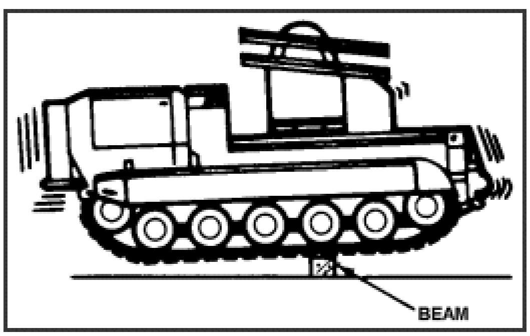


EXAMPLE 4 – Tracked vehicles.

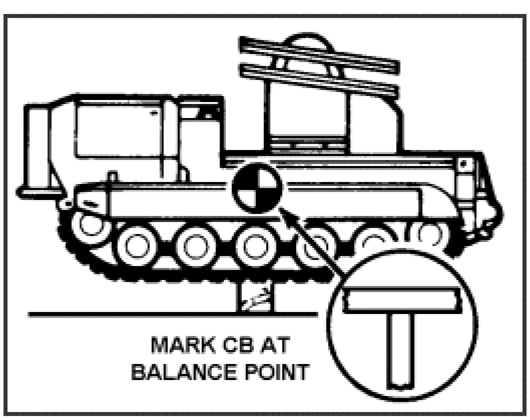
STEP 1. **To determine weight, drive the vehicle onto a platform scale (for example, truck scale, coal yard scale) large enough to accommodate the entire vehicle. Record weight.**



STEP 2. **To determine CB, drive the vehicle onto a wooden beam or pole until it tilts forward. Mark the side of the vehicle at the point of tilt.**

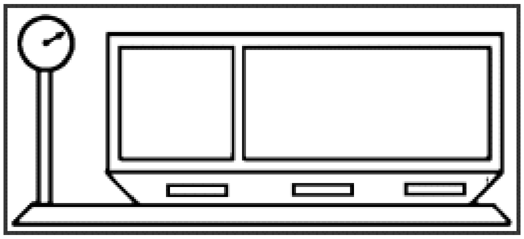


STEP 3. **With appropriate materials, mark the CB and gross weight of the vehicle.**

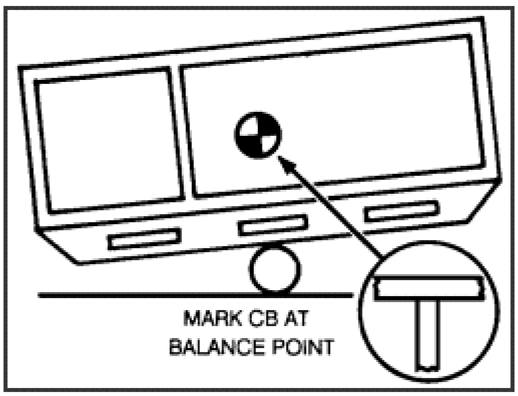


EXAMPLE 5 –- Skid-mounted cargo.

STEP 1. **If the skid-mounted cargo will fit on the scale, weigh the whole load to use as the weight figure.**



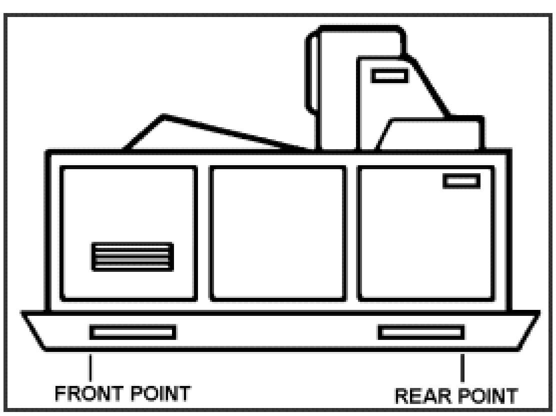
STEP 2. **Determine the CB by placing that load onto a pipe and centering the cargo until it balances, then marking the CB.**



EXAMPLE 6 – Skid-mounted cargo. If the skid-mounted cargo is too large to fit on the scale at one time it will have to be weighed and measured as in examples 1 and 2, using the same formula.

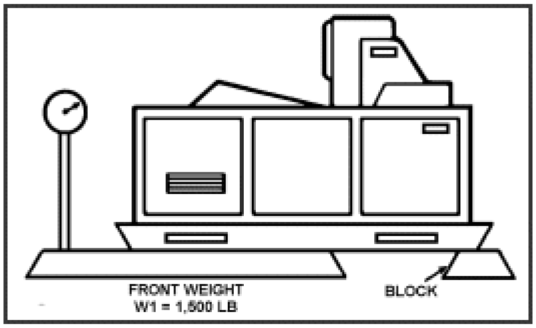
$$\frac{(W1 \times D1) + (W2 \times D2)}{\text{Gross Weight}} = CB$$

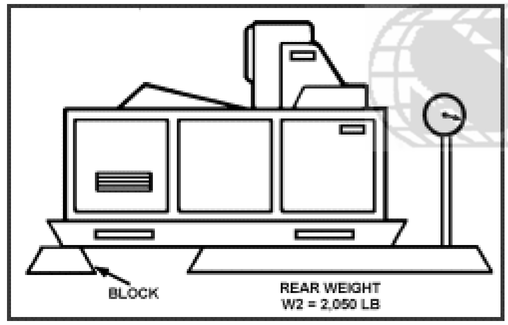
NOTE: The points to use as the axles should be support braces between the skids, as shown here.



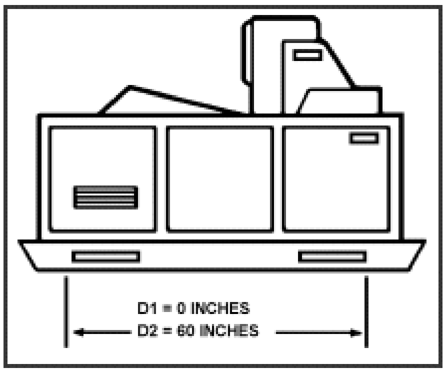
Now go through steps 1 through 3 as before in examples 1 and 2.

STEP 1. **Support the overhang at the same height as the scale with a block of wood.**





STEP 2. **Measure the distance from the RDL to the front and rear points of support (same as axles).**

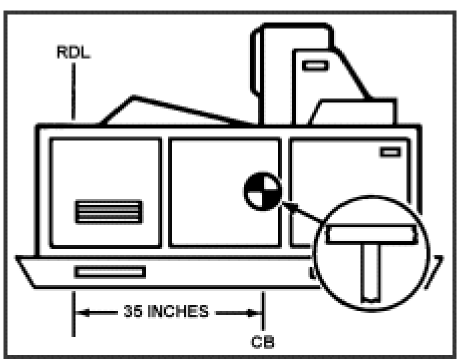


STEP 3. **Again enter the information obtained in steps 1 and 2 into the formula.**

$$\frac{(S1 \times D1) + (S2 \times D2)}{\text{Gross Weight}} =$$

$$\frac{(1{,}500 \times 40) + (2{,}050 \times 110)}{3{,}550} =$$

$$\frac{75{,}000 + 225{,}500}{3{,}550} = \frac{300{,}500}{3{,}550} = \text{84.6 or 85 inches aft from the RDL}$$



Section II. Aircraft Center of Gravity (Weight and Balance)

17-4. CENTER OF GRAVITY. The maximum weight that can be carried on any specific mission is limited by the maximum allowable gross weight and is dependent upon the aircraft's basic weight, number of crew, and the amount of fuel and oil aboard the aircraft. The flight performance of the aircraft depends on the CG location. If the CG is too far out of position, the aircraft will not fly. As fuel, oil, cargo, and other weights are added, removed burned off, or relocated within the aircraft, the

aircraft CG changes. The aircraft is designed to permit such changes provided the CG location remains within certain specified limits.

17-5. WEIGHT AND BALANCE. To understand aircraft methods of weight and balance, personnel must know how and where to find the RDL and aircraft station as indicated below.

- **The RDL is at or near the aircraft nose and is the point of an aircraft from which all longitudinal measurements are made. The RDL always is fuselage station O.**
- **Aircraft stations, sometimes called fuselage stations, are measurements in inches aft of the RDL and are usually identified by a number on the wall of the aircraft. For example, station 520 in the aircraft is a point 520 inches aft of the RDL. These measurements or distances are used for determining the location of cargo in the aircraft and for computation of the aircraft CG. See Figure 17-3 for a diagram showing aircraft station/arm measurements.**

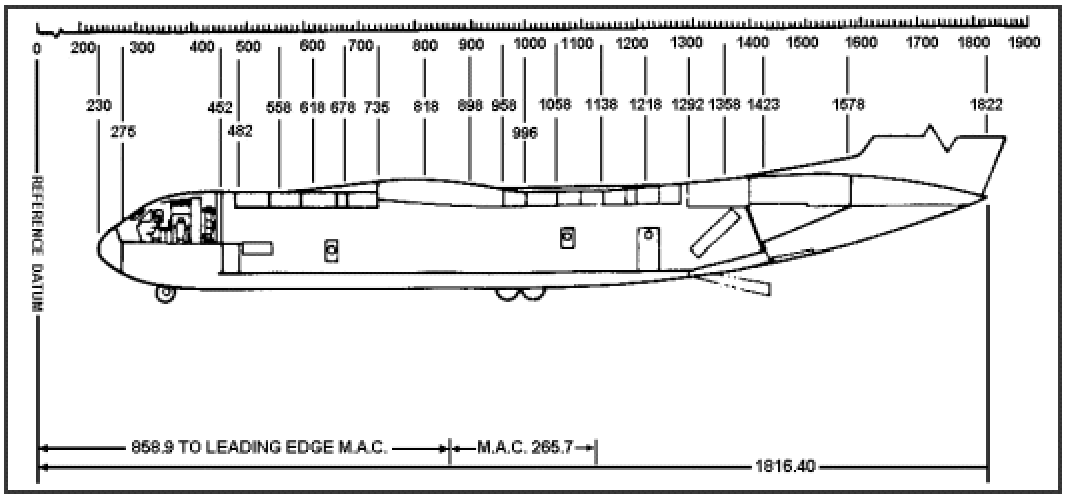


Figure 17-3. Airplane diagram (station/arm)

- **Arm is the horizontal distance in inches from the RDL to the center of gravity of an object.**
- **Moment is the product of the weight of an item multiplied by its arm. Moment may be expressed in pound-inches; for example, 2 pounds (weight) x 10 inches (arm) = 20 pound-inches (moment). For instance, in Figure 17-4 you see a board perfectly balanced with a 20-pound weight on one end and a 40-pound weight on the other. To understand how this is possible, you must learn the meaning of an inch-pound or moment. A moment is the product obtained when the distance (arm) is multiplied by the weight. For the board to balance, the weights placed on each side of the fulcrum must create an equal number of moments. If the 20-pound weight is paced 60 inches from the fulcrum on one end of the board, it creates 1,200 moments; consequently, the 40-pound weight is placed only 30 inches from the fulcrum on the other end to create the same number of moments and balance the board.**

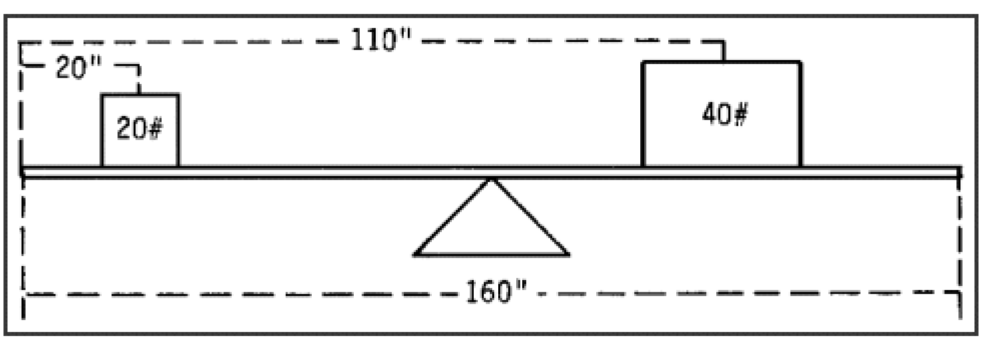


Figure 17-4. Achieving moment of balance

a. The only way to assure an aircraft is safely balanced is to know how to find the CG of the aircraft and load.

b. Figure 17-5 helps illustrate the procedure used in computing aircraft and load CG. The reference line (same as aircraft RDL) is at the end of the board. For instance—

The CB of the 20-pound box is located 20 inches from the end of the board. The 40-pound box is located 110 inches from the end of the board.

The following formula is used:

$$\frac{(W1 \times D1) + (W2 \times D2)}{\text{Gross Weight}} = CG$$

$$W \times D = M$$

$$20 \times 20 = 400$$

<u>40</u> x <u>110</u> = <u>4,400</u>
60 x 4,800

4,800 $\div 60 = 80$ **CG = 80 inches**

Therefore, CG is located 80 inches from the end of board (at the fulcrum).

c. An empty aircraft always is in balance, regardless of the amount of fuel aboard. Only when a load is added does the weight and balance become a concern. Each aircraft has a specified forward and aft limitation that must be maintained to ensure the aircraft is safely balanced for flight. These limits vary according to the gross weight of the aircraft. The only way to ensure an aircraft is safety balanced is to know how to find the CG of a load and to determine that it will fall in the proper location on the aircraft.

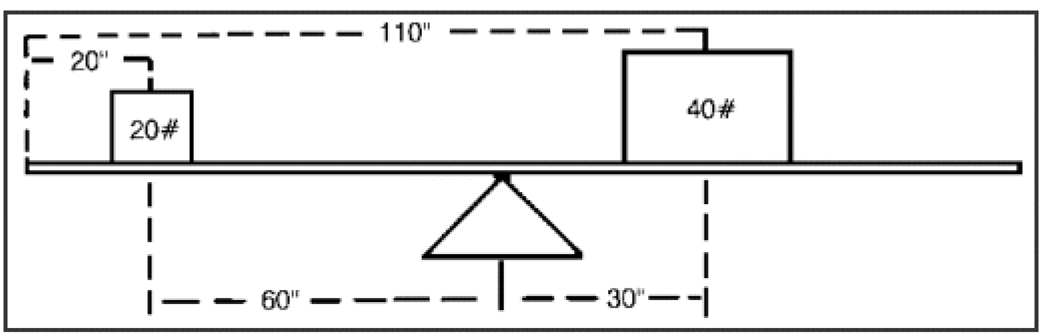


Figure 17-5. Computing aircraft and load CG