Aircraft Weight & Balance

Why is it important?

A small mistake in CG can lead to much bigger problem. Picture courtesy of CASA

WEIGHT

PERFORMANCE EFFECTS

The pilot should always be aware of the consequences of overloading. An overloaded aircraft may not be able to leave the ground, or if it does become airborne, it may exhibit unexpected and unusually poor flight characteristics. If not properly loaded, the initial indication of poor performance usually takes place during takeoff.

Excessive weight reduces the flight performance in almost every respect. For example, the most important performance deficiencies of an overloaded aircraft are:

- Higher takeoff speed
- Longer takeoff run
- Reduced rate and angle of climb
- Lower maximum altitude
- Shorter range
- Reduced cruising speed
- Reduced maneuverability
- Higher stalling speed
- Higher approach and landing speed
- Longer landing roll
- Excessive weight on the nose wheel or tail wheel

WEIGHT CHANGES

The operating weight of an aircraft can be changed by simply altering the fuel load. Gasoline has considerable weight—6 pounds per gallon. Thirty gallons of fuel may weigh more than one passenger. If a pilot lowers airplane weight by reducing fuel, the resulting decrease in the range of the airplane must be taken into consideration during flight planning.

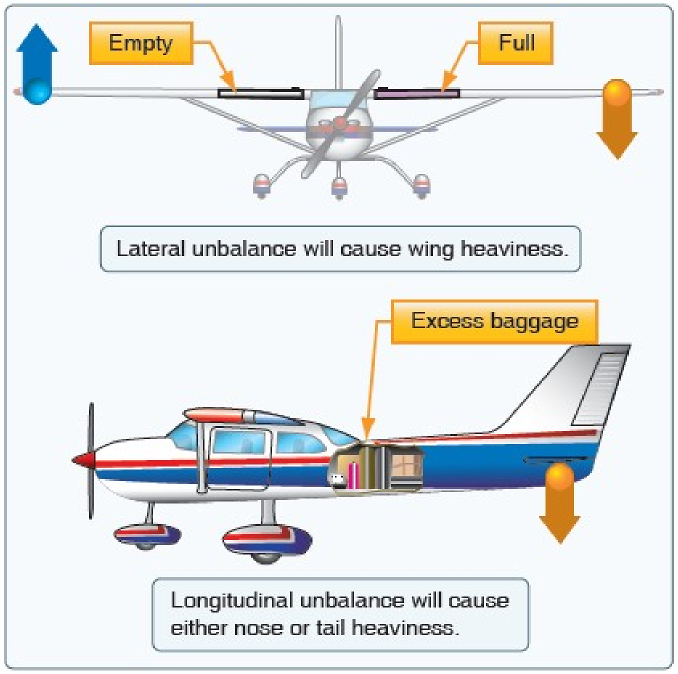
Other Causes for Weight Changes

- Reduction of Fuel of an aircraft in flight which will also change the center of gravity (Balance)
- Changes in fixed equipment added to, removed or replaced in the aircraft. W&B must be recalculated and updated in the aircraft maintenance log.

Balance, Stability, and Center of Gravity

Balance refers to the location of the ***center of gravity (CG)*** of an aircraft, and is important to stability and safety in flight. The CG is a point at which the aircraft would balance if it were suspended at that point.

The primary concern in balancing an aircraft is the fore and aft location of the CG along the longitudinal axis. The CG is not necessarily a fixed point; its location depends on the distribution of weight in the aircraft. As variable load items are shifted or expended, there is a resultant shift in CG location. The distance between the forward and back limits for the position of the center for gravity or CG range is certified for an aircraft by the manufacturer. The pilot should realize that if the CG is displaced too far forward on the longitudinal axis, a nose-heavy condition will result. Conversely, if the CG is displaced too far aft on the longitudinal axis, a tail heavy condition results. It is possible that the pilot could not control the aircraft if the CG location produced an unstable condition.



Effects of Adverse Balance

Adverse balance conditions affect flight characteristics in much the same manner as those mentioned for an excess weight condition. *It is **vital** to comply with weight and balance limits established for all aircraft.* Operating above the maximum weight limitation compromises the structural integrity of the aircraft and can adversely affect performance. Stability and control are also affected by improper balance.

Stability

Loading in a nose-heavy condition causes problems in controlling and raising the nose, especially during takeoff and landing. Loading in a tail heavy condition has a serious effect upon longitudinal stability, and reduces the capability to recover from stalls and spins. Tail heavy loading also produces very light control forces, another undesirable characteristic. This makes it easy for the pilot to inadvertently overstress an aircraft.

Stability and Center of Gravity

Limits for the location of the CG are established by the manufacturer. These are the fore and aft limits beyond which the CG should not be located for flight. These limits are published for each aircraft in the Type Certificate Data Sheet (TCDS), or aircraft specification and the AFM or pilot's operating handbook (POH). If the CG is not within the allowable limits after loading, it will be necessary to relocate some items before flight is attempted.

The forward CG limit is often established at a location that is determined by the landing characteristics of an aircraft. During landing, one of the most critical phases of flight, exceeding the forward CG limit may result in excessive loads on the nosewheel, a tendency to nose over on tailwheel type airplanes, decreased performance, higher stalling speeds, and higher control forces.

Effects of Adverse Balance

Control

In extreme cases, a CG location that is beyond the forward limit may result in nose heaviness, making it difficult or impossible to flare for landing.

In addition to decreased static and dynamic longitudinal stability, other undesirable effects caused by a CG location aft of the allowable range may include extreme control difficulty, violent stall characteristics, and very light control forces which make it easy to overstress an aircraft inadvertently.

A restricted forward CG limit is also specified to assure that sufficient elevator/control deflection is available at minimum airspeed. When structural limitations do not limit the forward CG position, it is located at the position where full-up elevator/control deflection is required to obtain a high AOA for landing.

The aft CG limit is the most rearward position at which the CG can be located for the most critical maneuver or operation. As the CG moves aft, a less stable condition occurs, which decreases the ability of the aircraft to right itself after maneuvering or turbulence.

Management of Weight and Balance

Control

Weight and balance control should be a matter of concern to all pilots. The pilot controls loading and fuel management (the two variable factors that can change both total weight and CG location) of a particular aircraft.

Before any flight, the pilot should determine the weight and balance condition of the aircraft. Simple and orderly procedures based on sound principles have been devised by the manufacturer for the determination of loading conditions. The pilot uses these procedures and exercises good judgment when determining weight and balance. In many modern aircraft, it is not possible to fill all seats, baggage compartments, and fuel tanks, and still remain within the approved weight and balance limits. If the maximum passenger load is carried, the pilot must often reduce the fuel load or reduce the amount of baggage.

Terms and Definitions

The pilot should be familiar with the appropriate terms regarding weight and balance. The following list of terms and their definitions is standardized, and knowledge of these terms aids the pilot to better understand weight and balance calculations of any aircraft. Terms defined by the General Aviation Manufacturers Association (GAMA) as industry standard are marked in the titles with GAMA.

Terms and Definitions

- **Arm** (moment arm)—the horizontal distance in inches from the reference datum line to the CG of an item. The algebraic sign is plus (+) if measured aft of the datum and minus (–) if measured forward of the datum.
- **Basic empty weight**—the standard empty weight plus the weight of optional and special equipment that have been installed.
- **Center of gravity** (CG)—the point about which an aircraft would balance if it were possible to suspend it at that point. It is the mass center of the aircraft or the theoretical point at which the entire weight of the aircraft is assumed to be concentrated. It may be expressed in inches from the reference datum or in percent of MAC. The CG is a three-dimensional point with longitudinal, lateral, and vertical positioning in the aircraft.
- **CG limits**—the specified forward and aft points within which the CG must be located during flight. These limits are indicated on pertinent aircraft specifications.
- **CG range**—the distance between the forward and aft CG limits indicated on pertinent aircraft specifications.
- **Datum** (reference datum)—an imaginary vertical plane or line from which all measurements of arm are taken. The datum is established by the manufacturer. Once the datum has been selected, all moment arms and the location of CG range are measured from this point.
- **Delta**—a Greek letter expressed by the symbol **r** to indicate a change of values. As an example, rCG indicates a change (or movement) of the CG.
- **Floor load limit**—the maximum weight the floor can sustain per square inch/foot as provided by the manufacturer.

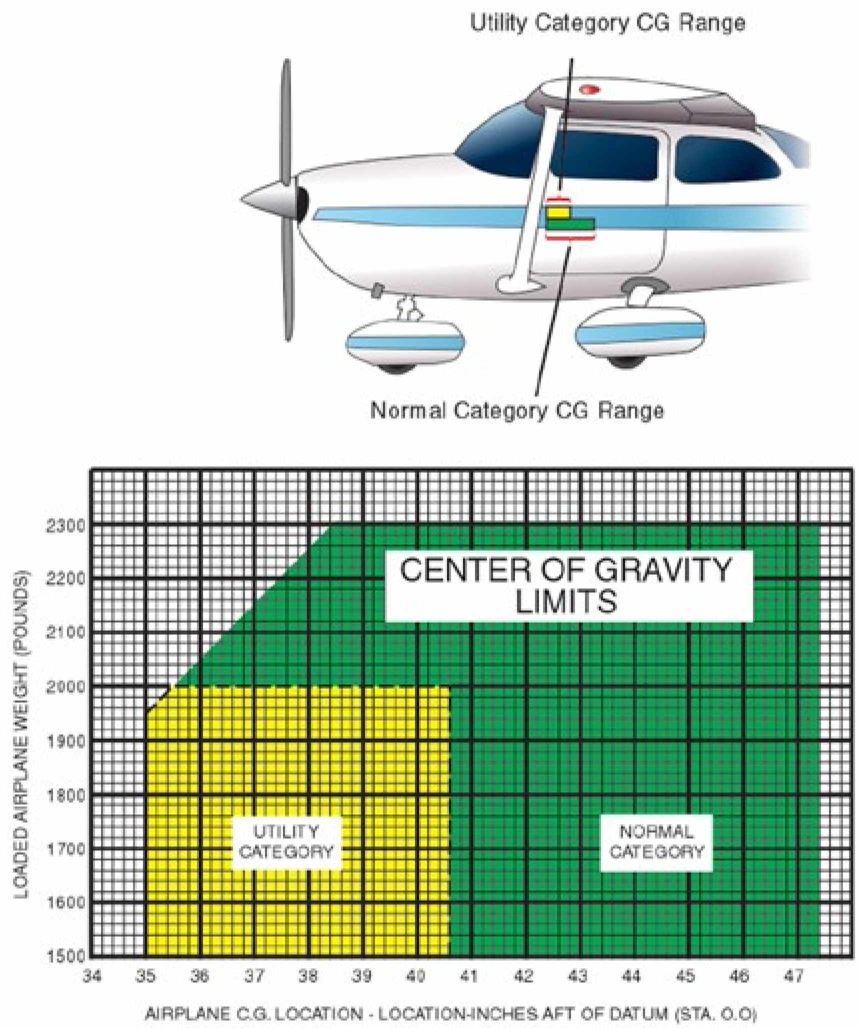
- **Fuel load** —the expendable part of the load of the aircraft. It includes only usable fuel, not fuel required to fill the lines or that which remains trapped in the tank sumps.
- **Licensed empty weight**—the empty weight that consists of the airframe, engine(s), unusable fuel, and undrainable oil plus standard and optional equipment as specified in the equipment list. Some manufacturers used this term prior to GAMA standardization.
- **Maximum landing weight**—the greatest weight that an aircraft is normally allowed to have at landing.
- **Maximum ramp weight**—the total weight of a loaded aircraft including all fuel. It is greater than the takeoff weight due to the fuel that will be burned during the taxi and run-up operations. Ramp weight may also be referred to as taxi weight.
- **Maximum takeoff weight**—the maximum allowable weight for takeoff.
- **Maximum weight**—the maximum authorized weight of the aircraft and all of its equipment as specified in the TCDS for the aircraft.
- **Maximum zero fuel weight** (GAMA)—the maximum weight, exclusive of usable fuel.
- **Mean aerodynamic chord** (MAC) —the average distance from the leading edge to the trailing edge of the wing.
- **Moment**—the product of the weight of an item multiplied by its arm. Moments are expressed in pound-inches (in-lb). Total moment is the weight of the airplane multiplied by the distance between the datum and the CG.
- **Moment index** (or index)—a moment divided by a constant such as 100, 1,000, or 10,000. The purpose of using a moment index is to simplify weight and balance computations of aircraft where heavy items and long arms result in large, unmanageable numbers.

- **Payload** (GAMA)—the weight of occupants, cargo, and baggage.
- **Standard empty weight** (GAMA)—aircraft weight that consists of the airframe, engines, and all items of operating equipment that have fixed locations and are permanently installed in the aircraft, including fixed ballast, hydraulic fluid, unusable fuel, and full engine oil.

- **Standard weights**—established weights for numerous items involved in weight and balance computations. These weights should not be used if actual weights are available. Some of the standard weights are:

Gasoline.. 6.0 lbs/US gal
Jet A, Jet A-1....................................... 6.8 lbs/US gal
Jet B..6.5 lbs/US gal
Oil...7.5 lbs/US gal
Water..,, 8.35 lbs/US gal

- **Station**—a location in the aircraft that is identified by a number designating its distance in inches from the datum. The datum is, therefore, identified as station zero. An item located at station +50 would have an arm of 50 inches.
- **Useful load**—the weight of the pilot, copilot, passengers, baggage, usable fuel, and drainable oil. It is the basic empty weight subtracted from the maximum allowable gross weight. This term applies to general aviation (GA) aircraft only.



MANEUVER LIMITS

NORMAL CATEGORY

This airplane is certificated in both the normal and utility category. The normal category is applicable to aircraft intended for non-aerobatic operations. These include any maneuvers incidental to normal flying, stalls (except whip stalls), lazy eights, chandelles, and turns in which the angle of bank is not more than 60°. Aerobatic maneuvers, including spins, are not approved.

UTILITY CATEGORY

This airplane is not designed for purely aerobatic flight. However, in the acquisition of various certificates such as commercial pilot, instrument pilot and flight instructor, certain maneuvers are required by the FAA. All of these maneuvers are permitted in this airplane when operated in the utility category.

Manufacturers Load Limit Categories

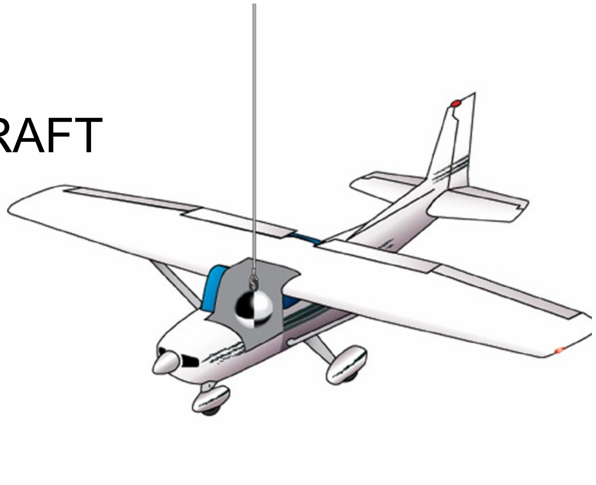
Normal +3.8G, -1.52G
Utility +4.4G, -1.76G
Acrobat +6.0G, -3.00G

Principles of Weight and Balance Computations

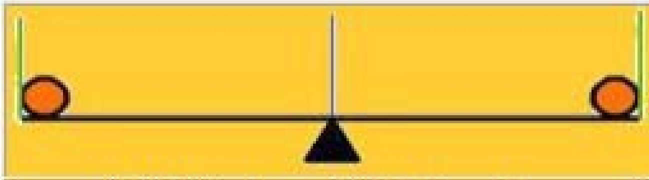
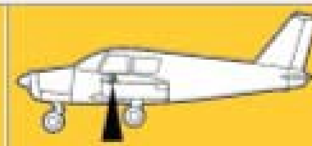
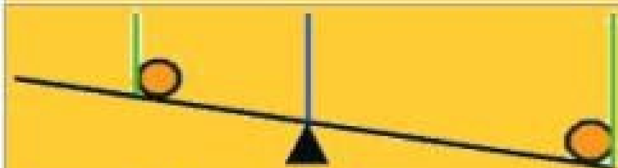
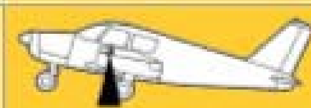
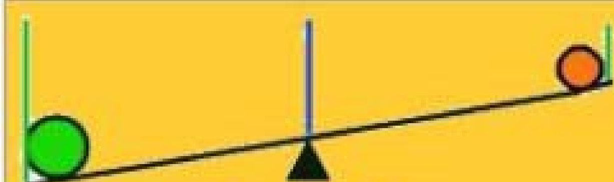
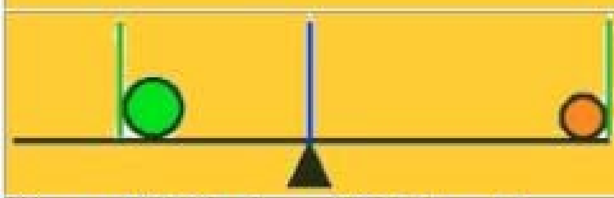
It is imperative that all pilots understand the basic principles of weight and balance determination. The following methods of computation can be applied to any object or vehicle for which weight and balance information is essential.

By determining the weight of the empty aircraft and adding the weight of everything loaded on the aircraft, a total weight can be determined—a simple concept. A greater problem, particularly if the basic principles of weight and balance are not understood, is distributing this weight in such a manner that the entire mass of the loaded aircraft is balanced around a point (CG) that must be located within specified limits. It is the imaginary point at which all the weight is concentrated. To provide the necessary balance between longitudinal stability and elevator control, the CG is usually located slightly forward of the center of lift. This loading condition causes a nose-down tendency in flight, which is desirable during flight at a high AOA and slow speeds.

(CG) - IMAGINARY POINT OF BALANCE FOR THE AIRCRAFT

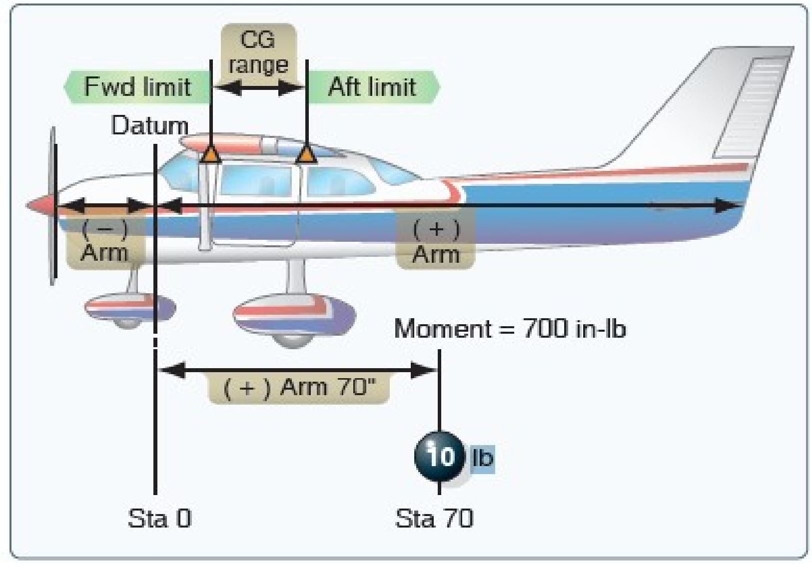


Balance

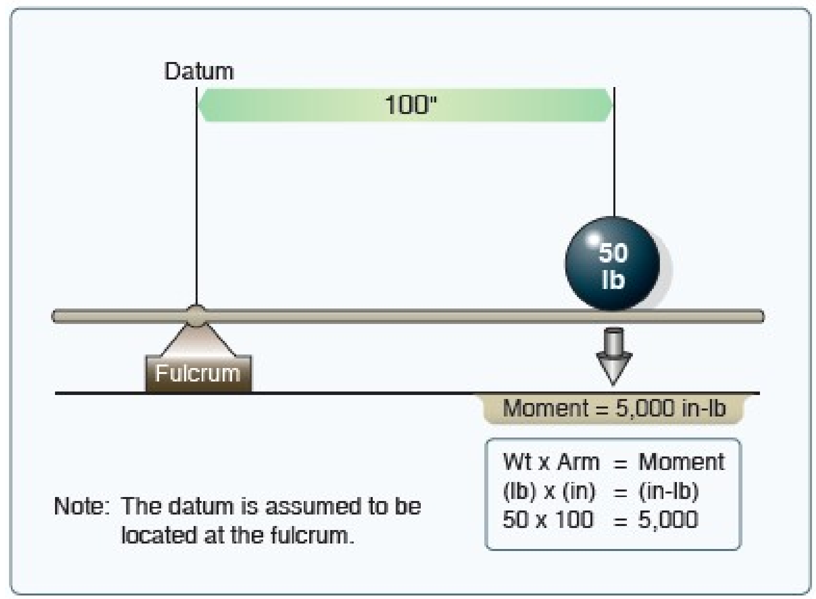
		 The airplane is balanced when weight and distance is equal from the center of gravity balance point.
5 pounds X 10 inches = 50 inch/pounds	5 pounds X 10 inches = 50 inch/pounds	
		 If one of the weights is shifted, an imbalance will also exist.
5 pounds X 5 inches = 25 inch/pounds	5 pounds X 10 inches = 50 inch/pounds	
		 If one of the weights is increased, an imbalance occurs.
10 pounds X 10 inches = 100 inch/pounds	5 pounds X 10 inches = 50 inch/pounds	
		 Shifting the weight will return the plane to a balanced condition.
10 pounds X 5 inches = 50 inch/pounds	5 pounds X 10 inches = 50 inch/pounds	

Principles of Weight and Balance Computations

The *safe zone* within which the balance point (CG) must fall is called the ***CG range***. The extremities of the range are called the forward CG limits and aft CG limits. These limits are usually specified in inches, along the longitudinal axis of the airplane, measured from a reference point called a datum reference. The datum is an arbitrary point, established by aircraft designers that may vary in location between different aircraft.



The distance from the datum to any component part or any object loaded on the aircraft is called the arm. When the object or component is located aft of the datum, it is measured in positive inches; if located forward of the datum, it is measured as negative inches or minus inches. The location of the object or part is often referred to as the station. If the weight of any object or component is multiplied by the distance from the datum (arm), the product is the moment. The moment is the measurement of the gravitational force that causes a tendency of the weight to rotate about a point or axis and is expressed in inch-pounds (in-lb).

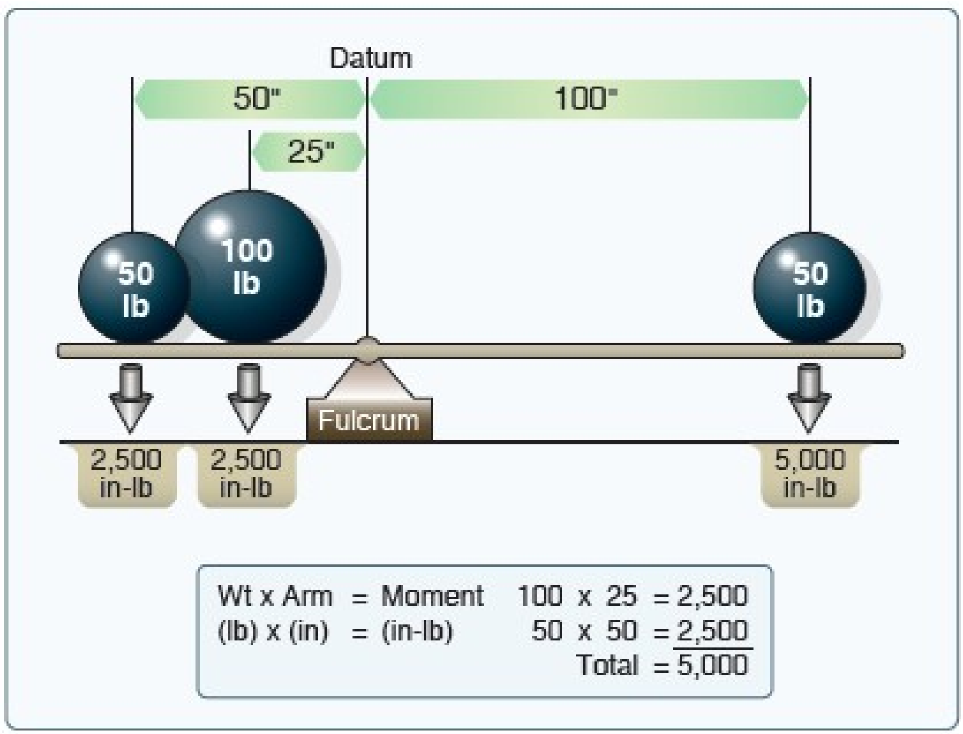


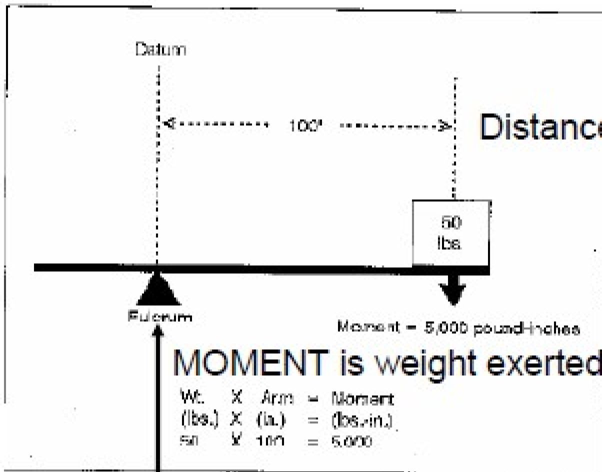
To illustrate, assume a weight of 50 pounds is placed on the board at a station or point 100 inches from the datum. The downward force of the weight can be determined by multiplying 50 pounds by 100 inches, which produces a moment of 5,000 in-lb.

Principles of Weight and Balance Computations

To establish a balance, a total of 5,000 in-lb must be applied to the other end of the board. Any combination of weight and distance which, when multiplied, produces a 5,000 in-lb moment will balance the board.

For example, if a 100-pound weight is placed at a point (station) 25 inches from the datum, and another 50-pound weight is placed at a point (station) 50 inches from the datum, the sum of the product of the two weights and their distances total a moment of 5,000 in-lb, which will balance the board. 50 lb 100" Moment = 5,000 in-lb Fulcrum Datum Wt x Arm = Moment (lb) x (in) = (in-lb) 50 x 100 = 5,000 Note: The datum is assumed to be located at the fulcrum.





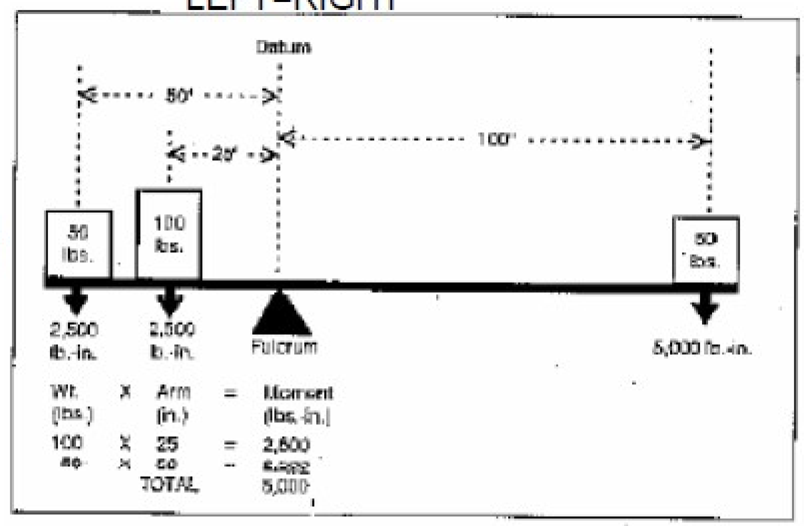
Distance weight is from datum is called ARM

MOMENT is weight exerted at end of the arm

Reference Datum is our fulcrum

LEFT=RIGHT

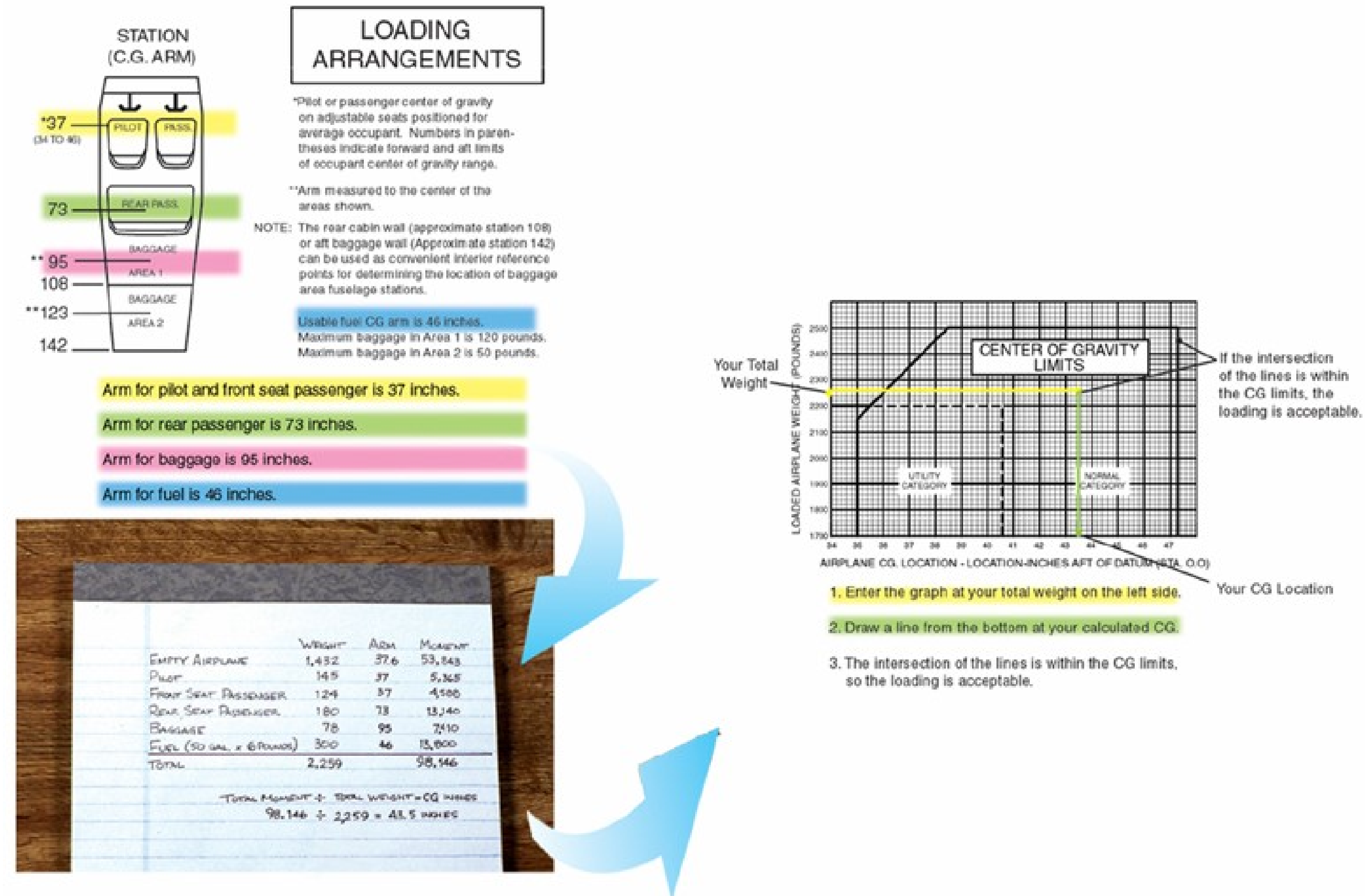
BALANCING ACT



Determining Loaded Weight and CG

There are various methods for determining the loaded weight and CG of an aircraft. There is the computational method as well as methods that utilize graphs and tables provided by the aircraft manufacturer.

COMPUTATIONAL METHOD: Get Weight, Get Arm, Multiply Wt*Arm, Add, Divide, and



COMPUTATIONAL METHOD

The following is an example of the computational method involving the application of basic math functions.

Aircraft Allowances:
Maximum gross weight.......................3,400 pounc
CG range...78–86 inch
Given:
Weight of front seat occupants............340 pound
Weight of rear seat occupants.............350 pounc
Fuel...75 gallo
Weight of baggage in area 1...................80 poun

Item	Weight	Arm	Moment
Aircraft Empty Weight	2,100	78.3	164,430
Front Seat Occupants	340	85.0	28,900
Rear Seat Occupants	350	121.0	42,350
Fuel	450	75.0	33,750
Baggage Area 1	80	150.0	12,000
Total	3,320		281,430
			281,430 ÷ 3,320 = 84.8

1. List the weight of the aircraft, occupants, fuel, and baggage. Remember that aviation gas (AVGAS) weighs 6 pounds per gallon and is used in this example.
2. Enter the moment for each item listed. Remember "weight x arm = moment."
3. Find the total weight and total moment.
4. To determine the CG, divide the total moment by the total weight.

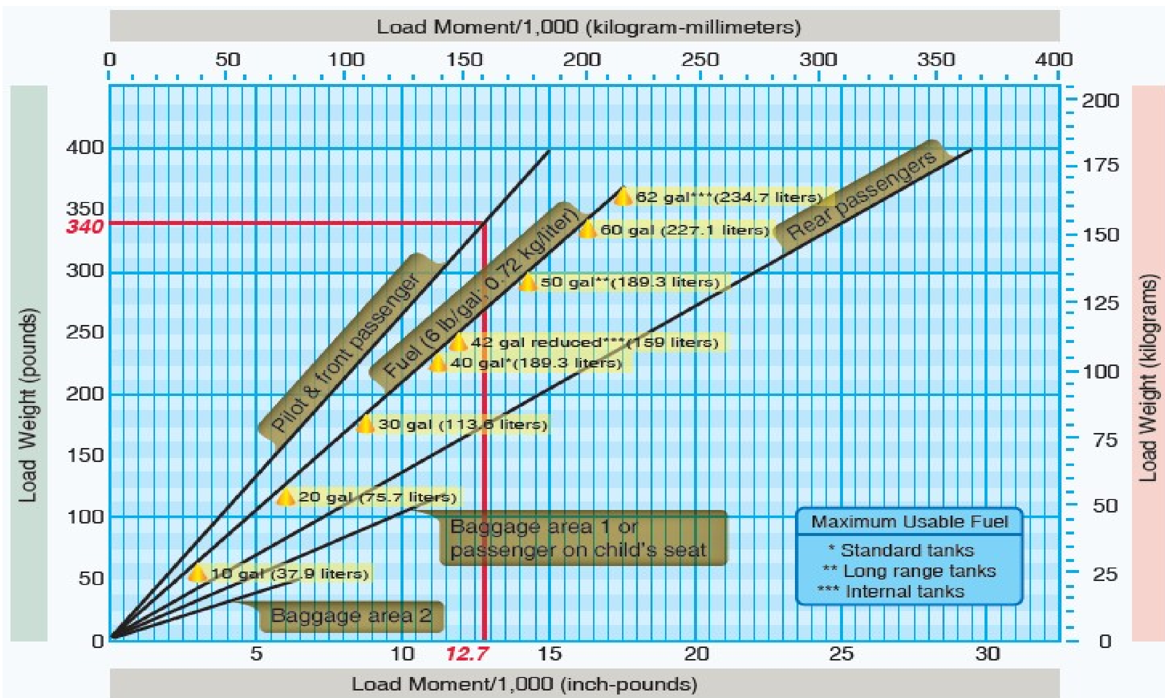
NOTE: The weight and balance records for a particular aircraft provide the empty weight and moment, as well as the information on the arm distance.

The total loaded weight of 3,320 pounds does not exceed the maximum gross weight of 3,400 pounds, and the CG of84.8 is within the 78–86 inch range; therefore, the aircraft is loaded within limits.

Graph Method

The same steps should be followed in the graph method as were used in the computational method except the graphs provided will calculate the moments and allow the pilot to determine if the aircraft is loaded within limits. To determine the moment using the loading graph, find the weight and draw a line straight across until it intercepts the item for which the moment is to be calculated. Then draw a line straight down to determine the moment. (The red line on the loading graph represents the moment for the pilot and front passenger.

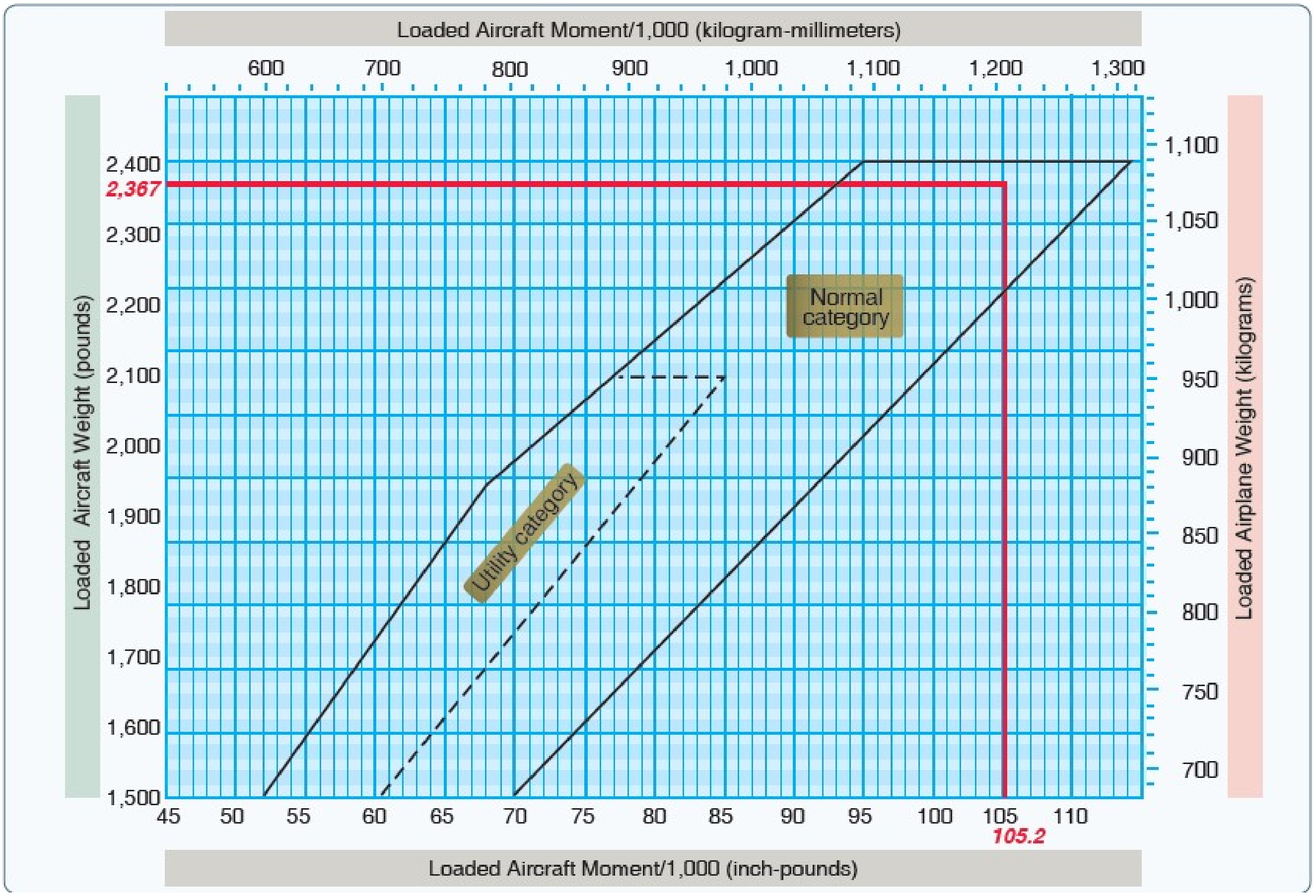
Sample Loading Problem	Weight (lb)	Moment (in-lb/1,000)
1. Basic empty weight (Use data pertaining to aircraft as it is presently equipped) includes unusable fuel and full oil	1,467	57.3
2. Usable fuel (At 6 lb/gal)		
■ Standard tanks (40 gal maximum)	240	11.5
■ Long range tanks (50 gal maximum)		
■ Integral tanks (62 gal maximum)		
■ Integral reduced fuel (42 gal)		
3. Pilot and front passenger (Station 34 to 46)	340	12.7
4. Rear passengers	300	21.8
5. Baggage area 1 or passenger on child's seat (Station 82 to 108, 120 lb maximum)	20	1.9
6. Baggage area 2 (Station 108 to 142, 50 lb maximum)		
7. Weight and moment	2,367	105.2



Graph Method

Add up all the total weights and moments. The total loaded weight of 3,320 pounds does not exceed the maximum gross weight of 3,400 lbs.

Once this has been done for each item, total the weight and moments and draw a line for both weight and moment graph. If the lines intersect within the aircraft is loaded within limits. In this example we are within the “Normal Category” and safe to proceed.



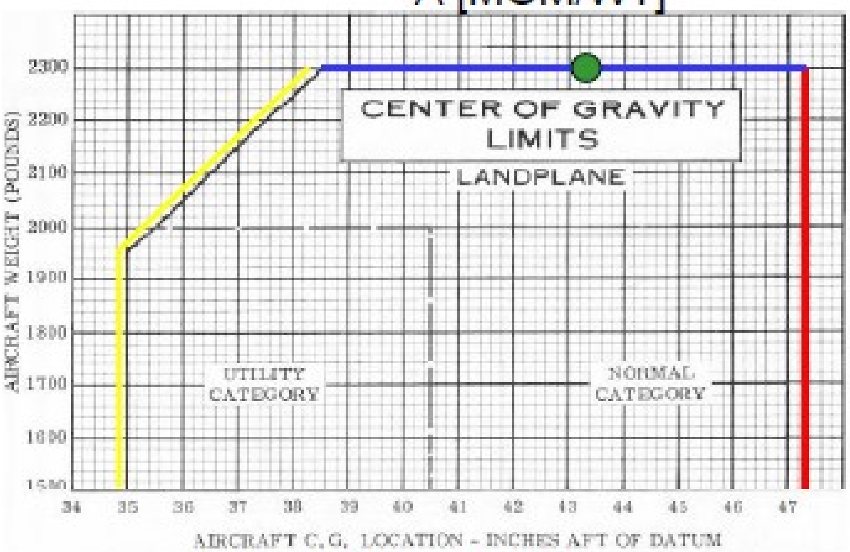
TWO types of charts require different plotting with same data

A. Center of Gravity Limits is intersect of total weight to CG
B. Center of Gravity Moment Envelop is intersect of total weight to Moments Calculation

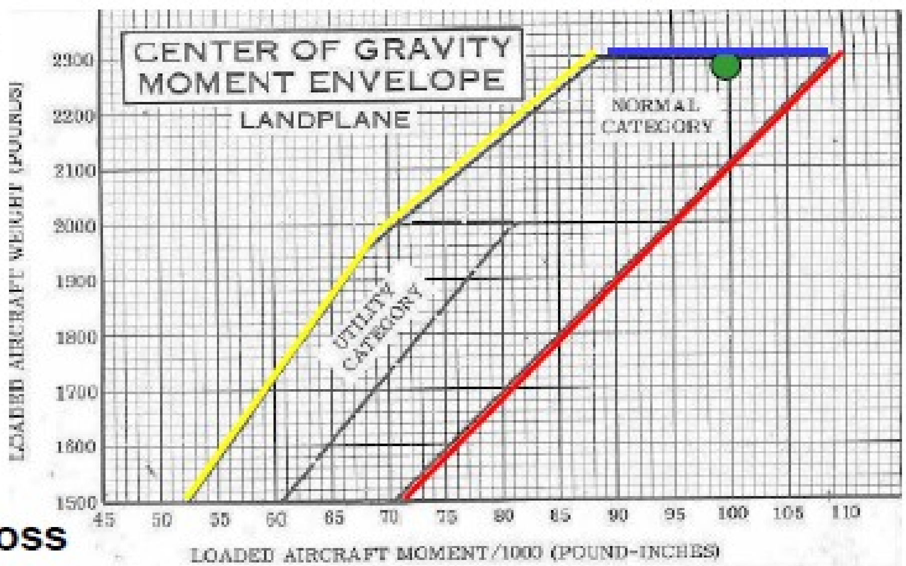
ITEM	WEIGHT		ARM	=	MOMENT
EMPTY WEIGHT	1455.6	x	38.5	=	56040.60
Fuel (40 G. Max)	240	x	45.3	=	
Pilot/Front Seat	340	x	37	=	
Rear Seat	170	x	72.8	=	
Baggage Area 1	94	x	94.9	=	
Baggage Area 2	0	x	123	=	

ITEM	WEIGHT		ARM	=	MOMENT
EMPTY WEIGHT	1455.6	x	38.5	=	56040.60
Fuel (40 G. Max)	240	x	45.3	=	10872.00
Pilot/Front Seat	340	x	37	=	12580.00
Rear Seat	170	x	72.8	=	12376.00
Baggage Area 1	94	x	94.9	=	8902.60
Baggage Area 2	0	x	123	=	0.00
Total	2299.6				100789.2
CG WT/MOM=43.83 (A)				MOM /1000=	(B) 100.78

A [MOM/WT]



B [MOM/1000]



Forward CG Limit

Aft CG Limit

Exceeds Gross

TABLE METHOD

Simplified: Look up weight and total moment, removes need to multiply by arm.

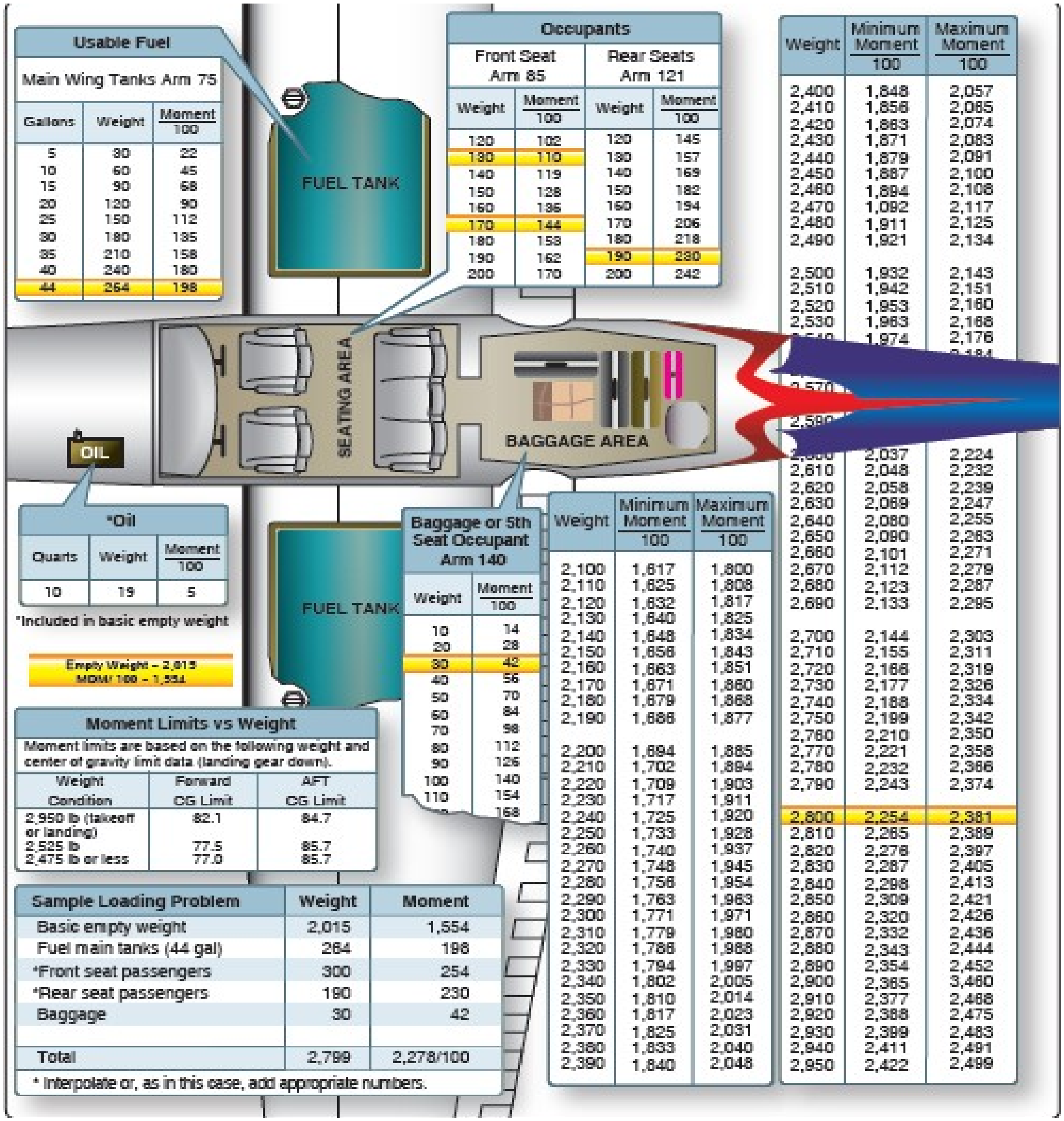
Table Method

The information and limitations are contained in tables provided by the manufacturer.

YOU determine Total Moments

In this problem, the total weight of 2,799 pounds and moment of 2,278/100 are within the limits of the table.

START HERE →



Usable Fuel		
Main Wing Tanks Arm 75		
Gallons	Weight	Moment/100
5	30	22
10	60	45
15	90	68
20	120	90
25	150	112
30	180	135
35	210	158
40	240	180
44	264	198

Occupants			
Front Seat Arm 85		Rear Seats Arm 121	
Weight	Moment/100	Weight	Moment/100
120	102	120	145
130	110	130	157
140	119	140	169
150	128	150	182
160	136	160	194
170	144	170	206
180	153	180	218
190	162	190	230
200	170	200	242

*Oil		
Quarts	Weight	Moment/100
10	19	5

*Included in basic empty weight

Empty Weight – 2,015
MOM/ 100 – 1,554

Baggage or 5th Seat Occupant Arm 140	
Weight	Moment/100
10	14
20	28
30	42
40	56
50	70
60	84
70	98
80	112
90	126
100	140
110	154
[illegible]	168

Moment Limits vs Weight

Moment limits are based on the following weight and center of gravity limit data (landing gear down).

Weight Condition	Forward CG Limit	AFT CG Limit
2,950 lb (takeoff or landing)	82.1	84.7
2,525 lb	77.5	85.7
2,475 lb or less	77.0	85.7

Sample Loading Problem	Weight	Moment
Basic empty weight	2,015	1,554
Fuel main tanks (44 gal)	264	198
*Front seat passengers	300	254
*Rear seat passengers	190	230
Baggage	30	42
Total	2,799	2,278/100

* Interpolate or, as in this case, add appropriate numbers.

Weight	Minimum Moment/100	Maximum Moment/100
2,100	1,617	1,800
2,110	1,625	1,808
2,120	1,632	1,817
2,130	1,640	1,825
2,140	1,648	1,834
2,150	1,656	1,843
2,160	1,663	1,851
2,170	1,671	1,860
2,180	1,679	1,868
2,190	1,686	1,877
2,200	1,694	1,885
2,210	1,702	1,894
2,220	1,709	1,903
2,230	1,717	1,911
2,240	1,725	1,920
2,250	1,733	1,928
2,260	1,740	1,937
2,270	1,748	1,945
2,280	1,756	1,954
2,290	1,763	1,963
2,300	1,771	1,971
2,310	1,779	1,980
2,320	1,786	1,988
2,330	1,794	1,997
2,340	1,802	2,005
2,350	1,810	2,014
2,360	1,817	2,023
2,370	1,825	2,031
2,380	1,833	2,040
2,390	1,840	2,048

Weight	Minimum Moment/100	Maximum Moment/100
2,400	1,848	2,057
2,410	1,856	2,065
2,420	1,863	2,074
2,430	1,871	2,083
2,440	1,879	2,091
2,450	1,887	2,100
2,460	1,894	2,108
2,470	1,092	2,117
2,480	1,911	2,125
2,490	1,921	2,134
2,500	1,932	2,143
2,510	1,942	2,151
2,520	1,953	2,160
2,530	1,963	2,168
[illegible]	1,974	2,176
[illegible]	[illegible]	[illegible]
[illegible]	2,037	2,224
2,610	2,048	2,232
2,620	2,058	2,239
2,630	2,069	2,247
2,640	2,080	2,255
2,650	2,090	2,263
2,660	2,101	2,271
2,670	2,112	2,279
2,680	2,123	2,287
2,690	2,133	2,295
2,700	2,144	2,303
2,710	2,155	2,311
2,720	2,166	2,319
2,730	2,177	2,326
2,740	2,188	2,334
2,750	2,199	2,342
2,760	2,210	2,350
2,770	2,221	2,358
2,780	2,232	2,366
2,790	2,243	2,374
2,800	2,254	2,381
2,810	2,265	2,389
2,820	2,276	2,397
2,830	2,287	2,405
2,840	2,298	2,413
2,850	2,309	2,421
2,860	2,320	2,426
2,870	2,332	2,436
2,880	2,343	2,444
2,890	2,354	2,452
2,900	2,365	3,460
2,910	2,377	2,468
2,920	2,388	2,475
2,930	2,399	2,483
2,940	2,411	2,491
2,950	2,422	2,499

<-safe

BAGGAGE	
ARM 150	
Weight	Moment
10	15
20	30
30	45
40	60
50	75
60	90
70	105
80	120
90	135
100	150
110	165
120	180
130	195
140	210
150	225
160	240
170	255
180	270
190	285
200	300
210	315
220	330
230	345
240	360
250	375
260	390
270	405

EMPTY WEIGHT DATA		
*Oil is included in empty weight	Empty Weight (Lb.)	Empty Weight Moment (/100)
Certificated Weight	2110	1652

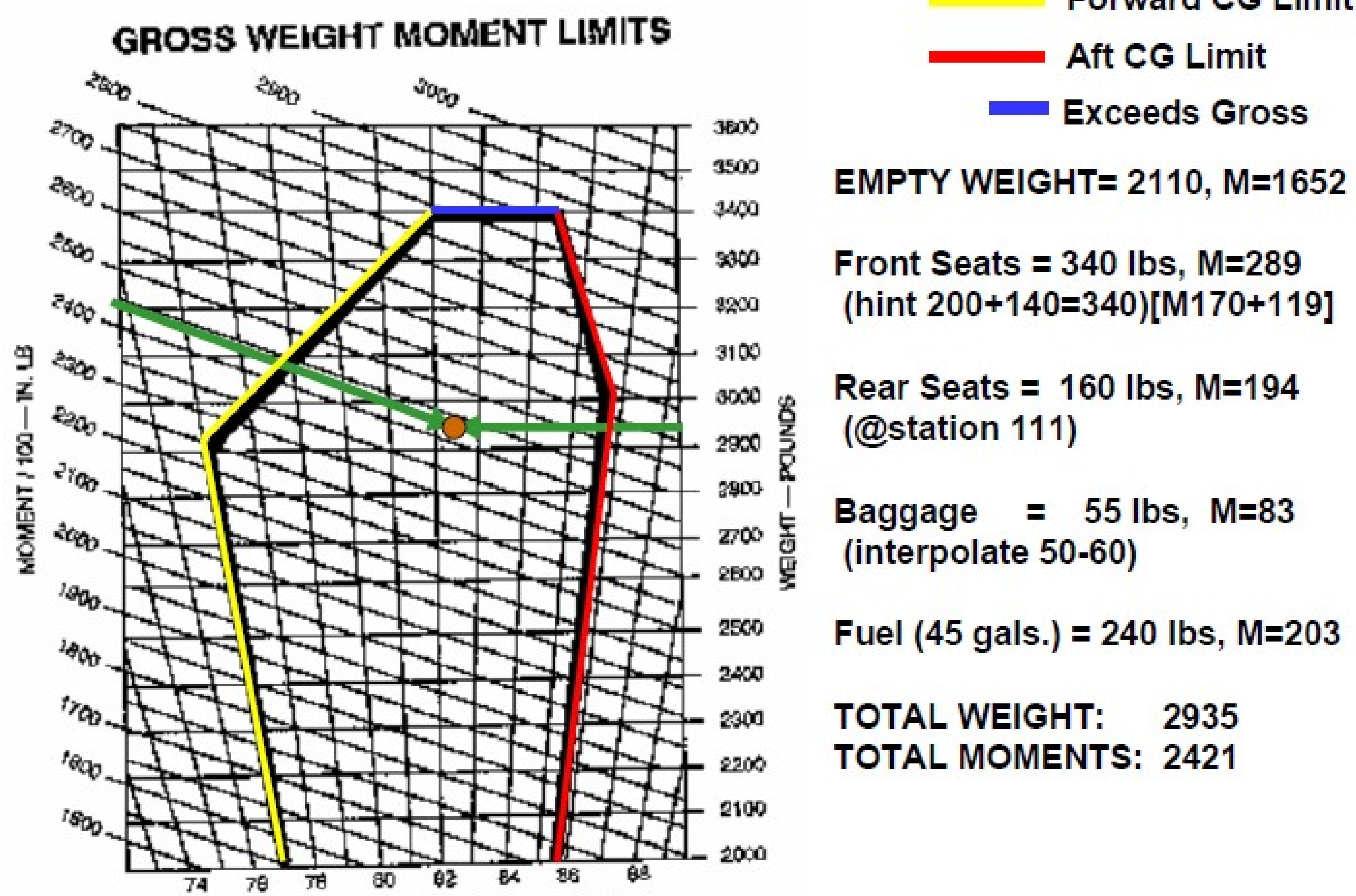
TRY THIS:

Front Seats = 340 lbs
(hint 200+140=340)
Rear Seats = 160 lbs
(@station 111)
Baggage = 55 lbs
(interpolate)
Fuel (45 gals.) =

SUM WEIGHT :
SUM MOMENTS:

OCCUPANTS				
Front Seats ARM 85		Rear Seats		
			Fwd Position ARM 111	Aft Position ARM 136
Weight	Moment	Weight	Moment	Moment
120	102	120	145	163
130	111	130	157	177
140	119	140	169	190
150	128	150	182	204
160	136	160	194	218
170	145	170	206	231
180	153	180	218	245
190	162	190	230	258
200	170	200	242	273

FUEL					
ARM 75					
Gallons	Weight	Moment	Gallons	Weight	Moment
5	30	23	45	270	203
10	60	45	49	294	221
15	90	68	65	330	248
20	120	90	60	360	270
26	150	113	65	390	293
30	180	135	70	420	315
35	210	158	75	450	338
40	240	180	80	480	360



EMPTY WEIGHT= 2110, M=1652

Front Seats = 340 lbs, M=289
(hint 200+140=340)[M170+119]

Rear Seats = 160 lbs, M=194
(@station 111)

Baggage = 55 lbs, M=83
(interpolate 50-60)

Fuel (45 gals.) = 240 lbs, M=203

TOTAL WEIGHT: 2935
TOTAL MOMENTS: 2421

Shifting, Adding, and Removing Weight

A pilot must be able to solve any problems accurately that involve the shift, addition, or removal of weight. For example, the pilot may load the aircraft within the allowable takeoff weight limit, then find that the CG limit has been exceeded. The most satisfactory solution to this problem is to shift baggage, passengers, or both. The pilot should be able to determine the minimum load shift needed to make the aircraft safe for flight. Pilots should be able to determine if shifting a load to a new location will correct an out-of-limit condition. There are some standardized calculations that can help make these determinations.

Weight Shifting

When weight is shifted from one location to another, the total weight of the aircraft is unchanged. The total moments, however, do change in relation and proportion to the direction and distance the weight is moved. When weight is moved forward, the total moments decrease; when weight is moved aft, total moments increase. The moment change is proportional to the amount of weight moved. Since many aircraft have forward and aft baggage compartments, weight may be shifted from one to the other to change the CG. If starting with a known aircraft weight, CG, and total moments, calculate the new CG (after the weight shift) by dividing the new total moments by the total aircraft weight.

Shifting, Adding, and Removing Weight

To determine the new total moments, find out how many moments are gained or lost when the weight is shifted. Assume that 100 pounds has been shifted from station 30 to station 150. This movement increases the total moments of the aircraft by 12,000 in-lb.

Moment when at station 150 = 100 lb x 150 in = 15,000 in-lb
Moment when at station 30 = 100 lb x 30 in = 3,000 in-lb
Moment change = [15,000 – 3,000] = 12,000 in-lb

By adding the moment change to the original moment (or subtracting if the weight has been moved forward instead of aft), the new total moments are obtained. Then determine the new CG by dividing the new moments by the total weight:

Total moments = 616,000 in-lb + 12,000 in-lb = 628,000 in-lb
CG=628,000 in-lb / 8,000 lb = 78.5
The shift has caused the CG to shift to station 78.5.

A simpler solution may be obtained by using a computer or calculator and a proportional formula. This can be done because the CG will shift a distance that is proportional to the distance the weight is shifted. Example next slide.

Shifting, Adding, and Removing Weight

$$\frac{\text{Weight Moved} = X}{\text{Weight of Airplane} = 2{,}500 \text{ pounds}} = \frac{\text{Distance CG Moves} = 2 \text{ inches}}{\text{Distance Between CG Arms} = 36 \text{ inches}}$$

$$\frac{X}{2{,}500} = \frac{2}{36}$$

$$X = \frac{2{,}500 \times 2}{36}$$

$$X = 138.8 \text{ pounds}$$

We are aft-CG by 2 inches. How much weight must we move from back? Difference in back/front seats is 36 inches.

Plug formula and solve. You must move138.6 lbs. from back seat to front seat.

Shifting, Adding, and Removing Weight

Example

$$\frac{\text{Weight shifted}}{\text{Total weight}} = \frac{\Delta CG\ \text{(change of CG)}}{\text{Distance weight is shifted}}$$

$$\frac{100}{8{,}000} = \frac{\Delta CG}{120}$$

$$\Delta CG = 1.5\ \text{in}$$

The change of CG is added to (or subtracted from when appropriate) the original CG to determine the new CG:
77 + 1.5 = 78.5 inches aft of datum

The shifting weight proportion formula can also be used to determine how much weight must be shifted to achieve a particular shift of the CG. The following problem illustrates a solution of this type.

Example

Given:

Aircraft total weight	7,800 lb
CG station	81.5 in
Aft CG limit	80.5 in

Determine how much cargo must be shifted from the aft cargo compartment at station 150 to the forward cargo compartment at station 30 to move the CG to exactly the aft limit.

Solution:

$$\frac{\text{Weight to be shifted}}{\text{Total weight}} = \frac{\Delta CG}{\text{Distance weight is shifted}}$$

$$\frac{\text{Weight to be shifted}}{7{,}800\ \text{lb}} = \frac{1.0\ \text{in}}{120\ \text{in}}$$

$$\text{Weight to be shifted} = 65\ \text{lb}$$

Shifting, Adding, and Removing Weight

MOST weight shift issues are covered by the formula

$$\frac{\text{Weight Moved}}{\text{Weight of Plane}} = \frac{\text{Distance CG moves}}{\text{Distance between CG Arms}}$$

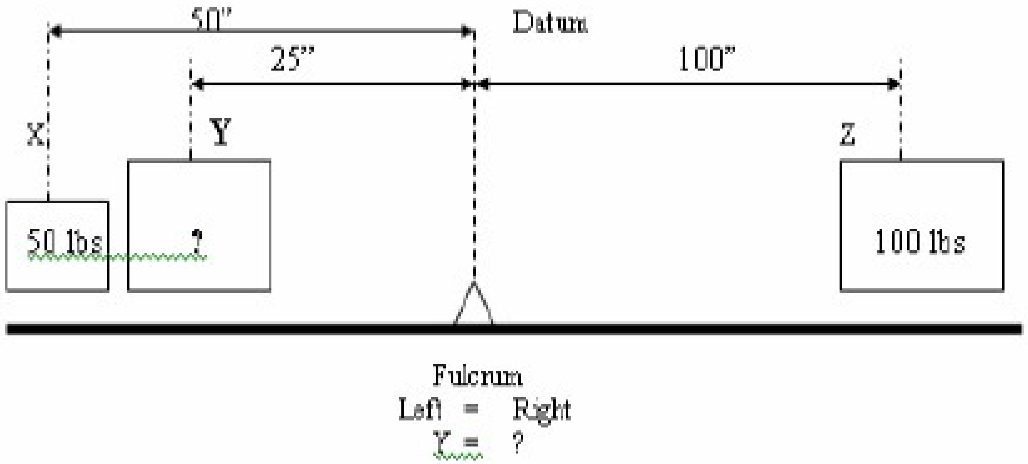
Wt. Moved * Dist. between CG Arms = Wt. of Plane * Dist. CG moves

Given 3 of the four above variables, the 4th unknown value can be determined by algebraic formulation.

Wt. Moved = (Wt. of Plane * Dist. CG moves) / Dist. Between CB Arms
Dist. Between CG Arms = (Wt. of Plane * Dist. CG moves) / Wt Moved
Dist. CG Moves = (Wt. Moved * Dist. Between CG Arms) / Wt of plane
Wt of plane = (Wt. Moved * Dist. Between CG Arms) / Dist CG Moves

FAA QUESTION….

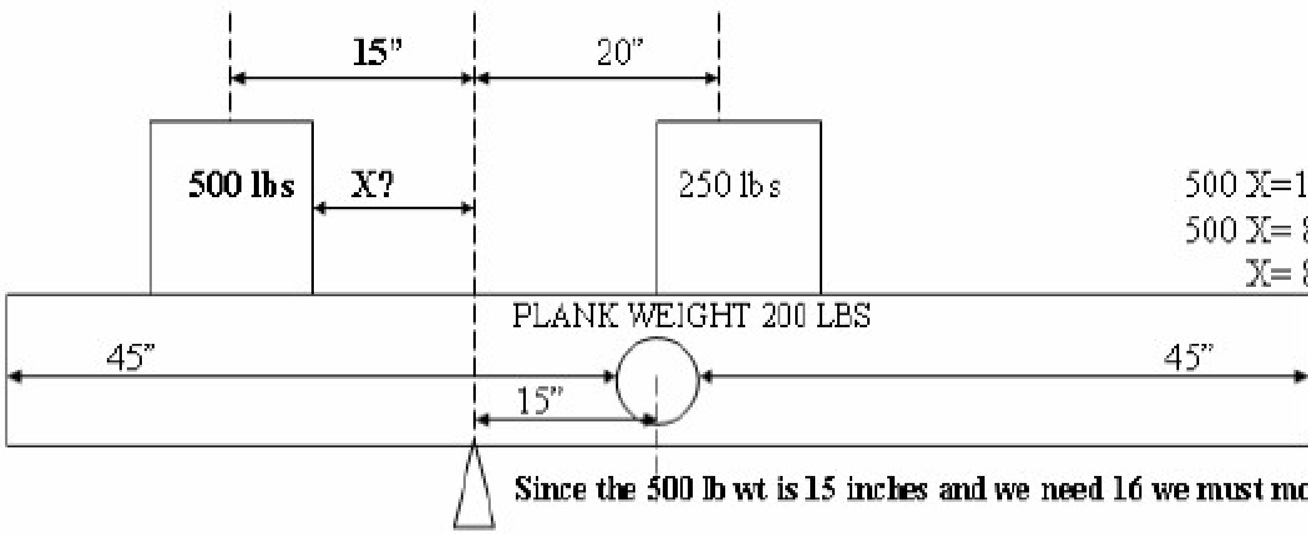
If 50 lbs of weight is located at point X and 100 lbs is located at point Z, how much weight must be located at point & to balance the plank?



SOLVE FOR Y

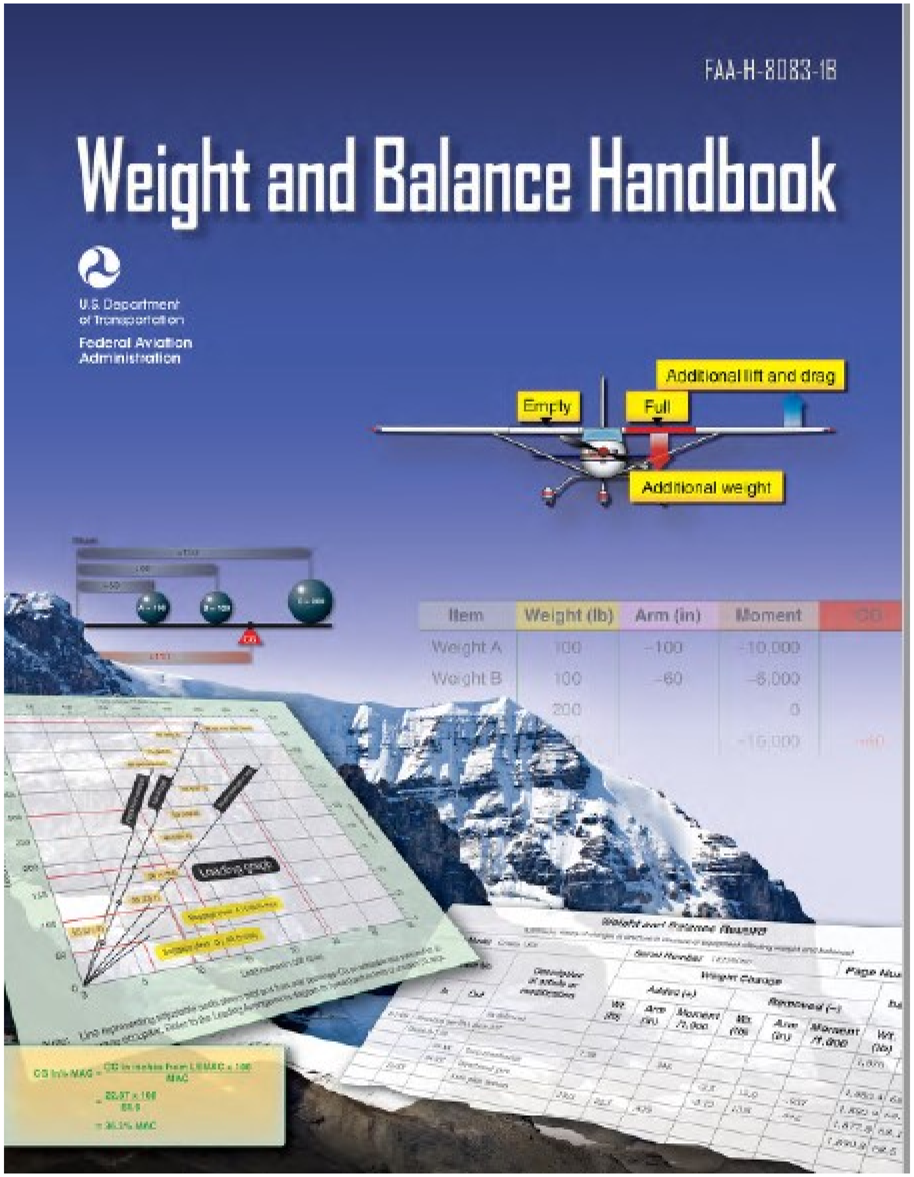
$$50*50 + 25Y = 100*100$$
$$2{,}500 + 25Y = 10{,}000$$
$$25Y = 10{,}000-2{,}500$$
$$25Y = 7{,}500$$
$$Y = 300 \text{ lbs}$$

How far should a 500 lb weight be shifted to balance a plank on the fulcrum?



$$500\,X=15*200+20*250$$
$$500\,X= 8{,}000$$
$$X= 8{,}000 / 500 = 16$$

Since the 500 lb wt is 15 inches and we need 16 we must move it 1 more inch to the left



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[REMAINING SLIDES ARE FOR COMMERCIAL STUDENTS ONLY]

Commercial Weight Shift

WEIGHT CHANGE AND WEIGHT SHIFT COMPUTATIONS

1. Authors' note: The following is an effective, intuitively appealing handout used by Dr. Melville R. Byington at Embry-Riddle Aeronautical University (used with permission).

   a. **Background** -- Center of gravity shift problems can be intimidating when an organized approach is not followed. If one goes to the usual texts for assistance, the result is often either

      1) "Just plug this/these formulas" (without adequate rationale), or
      2) Follow a set of (up to six) formulas to solve the problems, or
      3) Follow a tabular approach, which is often lengthy and tedious.

   b. **Basic theory** -- The foregoing "methods" obscure what can and should be a logical, straightforward approach. The standard question is, **"If the CG started out there, and certain changes occurred, where is it now?"** It can be answered directly using a SINGLE, UNIVERSAL, UNCOMPLICATED FORMULA.

      1) At **any** time, the CG is simply the sum of all moments (ΣM) divided by the sum of all weights (ΣW).

$$CG = \frac{\sum M}{\sum W}$$

      2) Since CG was known at some previous (#1) loading condition (with moment = M_1 and weight = W_1), it is logical that this become the point of departure. Due to weight addition, removal, or shift, the moment has changed by some amount, ΔM. The total weight has also changed if, and only if, weight has been added or removed. Therefore, the current CG is merely the current total moment divided by the current total weight. In equation format,

$$CG = \text{Current Moment/Current Weight} \text{ becomes } CG = \frac{M_1 \pm \Delta M}{W_1 \pm \Delta W}$$

Commercial Weight Shift

62. An airplane is loaded to a gross weight of 4,800 pounds, with three pieces of luggage in the rear baggage compartment. The CG is located 98 inches aft of datum, which is 1 inch aft of limits. If luggage which weighs 90 pounds is moved from the rear baggage compartment (145 inches aft of datum) to the front compartment (45 inches aft of datum), what is the new CG?

A. 96.13 inches aft of datum.

B. 95.50 inches aft of datum.

C. 99.87 inches aft of datum.

Answer (A) is correct. *(AWBH Chap 2)*

DISCUSSION: To determine the new CG, use the following formula:

$$New\ CG = \frac{M_1 \pm \Delta M}{W_1 \pm \Delta W}$$

where M_1 = original moment and W_1 = original weight.

Since there is no change in weight, $\Delta W = 0$ and weight shifted forward causes a "–" moment change.

$$New\ CG = \frac{(4,800 \times 98) - 90(145 - 45)}{4,800}$$

$$= \frac{470,400 - 9,000}{4,800}$$

$$= \frac{461,400}{4,800} = 96.13$$

Answer (B) is incorrect because the new CG is 96.13, not 95.50. Answer (C) is incorrect because the new CG is 96.13, not 99.87.

Commercial Weight Shift

63. An aircraft is loaded with a ramp weight of 3,650 pounds and having a CG of 94.0, approximately how much baggage would have to be moved from the rear baggage area at station 180 to the forward baggage area at station 40 in order to move the CG to 92.0?

A. 52.14 pounds.

B. 62.24 pounds.

C. 78.14 pounds.

Answer (A) is correct. *(AWBH Chap 2)*

DISCUSSION: To determine how much weight needs to be shifted forward (causing a "–" moment change), use the following formula:

$$\text{New CG} = \frac{M_1 \pm \Delta M}{W_1 \pm \Delta W}$$

where M_1 = original moment and W_1 = original weight, and since there is no change in weight, $\Delta W = 0$.

$$92.0 = \frac{(3{,}650 \times 94.0) - x(180 - 40)}{3{,}650}$$

$$335{,}800 = 343{,}100 - 140x$$

$$140x = 343{,}100 - 335{,}800$$

$$140x = 7{,}300$$

$$x = 52.14 \text{ lb.}$$

Answer (B) is incorrect because only 52.14 lb., not 62.24 lb., of baggage needs to be shifted. Answer (C) is incorrect because only 52.14 lb., not 78.14 lb., of baggage needs to be shifted.

Questions ?