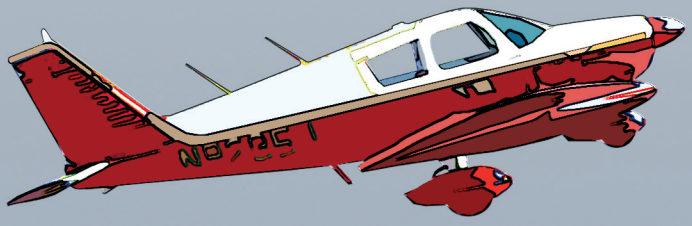
Federal Aviation Administration

Aircraft Weight and Balance Handbook

FAA-H-8083-1A



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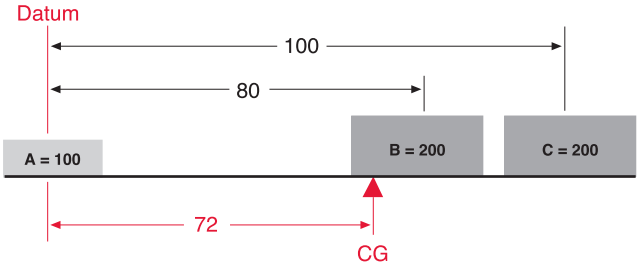

Figure 2-10. *Moving the CG of a board by shifting the weights. This is the original configuration.*

Item	Weight	Arm	Moment	CG
Weight A	100	0	0	
Weight B	200	80	16,000	
Weight C	200	100	20,000	
	500		36,000	72

Figure 2-11. *Shifting the CG of a board by moving one of the weights. This is the original condition of the board.*

To shift weight B so the board will balance about its center, 50 inches from the CG of weight A, first determine the arm of weight B that will produce a moment that causes the total moment of all three weights around this desired balance point to be zero. The combined moment of weights A and C around this new balance point, is 5,000 in-lb, so the moment of weight B will have to be -5,000 lb-in in order for the board to balance. [Figure 2-12]

Item	Weight	Arm	Moment
Weight A	100	–50	–5,000
Weight B			
Weight C	200	+50	+10,000
			+5,000

Figure 2-12. *Determining the combined moment of weights A and C.*

Determine the arm of weight B by dividing its moment, -5,000 lb-in, by its weight of 200 pounds. Its arm is -25 inches.

$$\text{Arm B} = \frac{\text{Moment}}{\text{Weight}}$$

$$= \frac{-5{,}000}{200}$$

$$= -25$$

To balance the board at its center, weight B will have to be placed so its CG is 25 inches to the left of the center of the board, as in Figure 2-13.

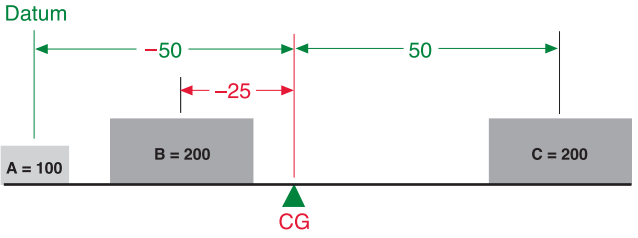

Figure 2-13. *Placement of weight B to cause the board to balance about its center.*

Basic Weight and Balance Equation

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

This equation can be rearranged to find the distance a weight must be shifted to give a desired change in the CG location:

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

This equation can also be rearranged to find the amount of weight to shift to move the CG to a desired location:

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

It can also be rearranged to find the amount the CG is moved when a given amount of weight is shifted:

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

Finally, this equation can be rearranged to find the total weight that would allow shifting a given amount of weight to move the CG a given distance:

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

Solution by Formula

This same problem can also be solved by using this basic equation:

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

Rearrange this formula to determine the distance weight B must be shifted:

Item	Weight (3,100 max.)	Arm (inches)	Moment (lb-in)	CG (in/datum)
Airplane (BEW)	1,874	36.1	67,651.4	
Front seats		37		
Rear seats		74		
Fuel (88 gal usable)		46.6		
Baggage A (100 max.)		97		
Baggage B (60 max.)		116		

Figure 4-3. *Blank weight and balance worksheet.*

Item	Weight (3,100 max.)	Arm (inches)	Moment (lb-in)	CG (in/datum)
Airplane (BEW)	**1,874**	**36.1**	**67,651.4**	
Front seats	300	**37**	11,100	
Rear seats	175	**74**	12,950	
Fuel (88 gal usable)	528	**46.6**	24,604.8	
Baggage A (100 max.)	100	**97**	9,700	
Baggage B (60 max.)	50	**116**	5,800	
	3,027		131,806.2	+ 43.54

Figure 4-4. *Completed weight and balance worksheet.*

When planning the flight, fill in the blanks in the worksheet with the specific data for the flight. [Figure 4-4]

Pilot.....120 lbs
Front seat passenger.....180 lbs
Rear seat passenger.....175 lbs
Fuel 88 gal .....528 lbs
Baggage A .....100 lbs
Baggage B.....50 lbs

Determine the moment of each item by multiplying its weight by its arm. Then determine the total weight and the sum of the moments. Divide the total moment by the total weight to determine the CG in inches from the datum. The total weight is 3,027 pounds and the CG is 43.54 inches aft of the datum.

To determine that the airplane is properly loaded for this flight, use the CG limits envelope in Figure 4-5 (which is typical of those found in the POH/AFM). Draw a line vertically upward from the CG of 43.54 inches, and one horizontally to the right from the loaded weight of 3,027 pounds. These lines cross inside the envelope, which shows the airplane is properly loaded for takeoff, but 77 pounds overweight for landing.

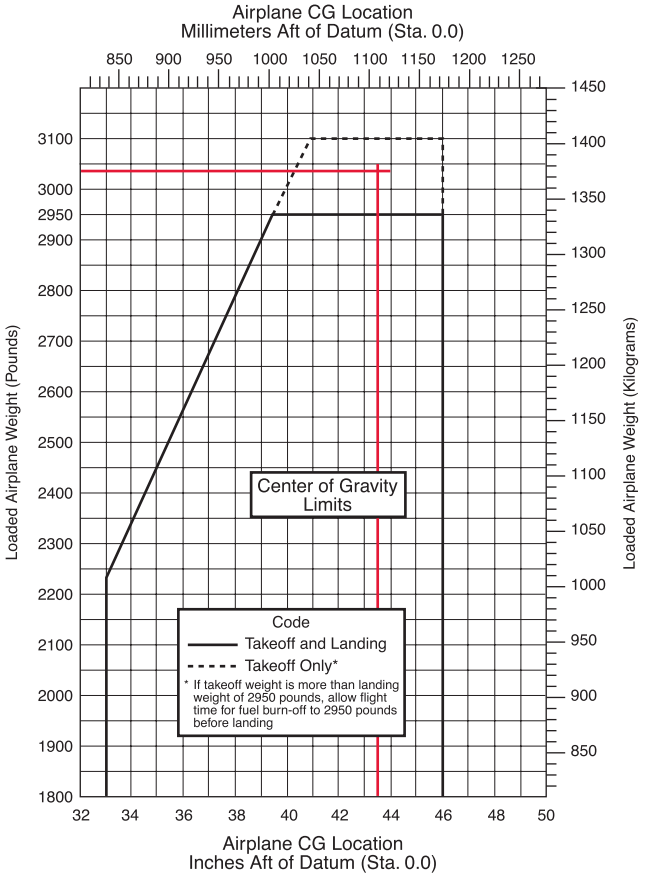

Figure 4-5. *Center of gravity limits chart from a typical POH.*

Computations Using Weight and Moment Indexes

If the weight and balance data uses moment indexes rather than arms and moments, this same alteration can be computed using a chart like the one shown on Figure 5-4.

Subtract the weight and moment indexes of all the removed equipment from the empty weight and moment index of the airplane. Add the weight and moment indexes of all equipment installed and determine the total weight and the total moment index. To determine the position of the new CG in inches aft of the datum, multiply the total moment index by 100 to get the moment, and divide this by the total weight to get the new CG.

Empty-Weight CG Range

The fuel tanks, seats, and baggage compartments of some aircraft are so located that changes in the fuel or occupant load have a very limited effect on the balance of the aircraft. Aircraft of such a configuration show an EWCG range in the TCDS. [Figure 5-5] If the EWCG is located within this range, it is impossible to legally load the aircraft so that its loaded CG will fall outside of its allowable range.

Empty-Weight CG Range	+12.5 to +16.2

Figure 5-5. *Typical notation in a TCDS when an aircraft has an empty-weight CG range.*

If the TCDS list an empty-weight CG range, and after the alteration is completed the EWCG falls within this range, then there is no need to compute a fore and aft check for adverse loading.

But if the TCDS lists the EWCG range as “None” (and most of them do), a check must be made to determine whether or not it is possible by any combination of legal loading to cause the aircraft CG to move outside of either its forward or aft limits.

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 (lbs)	Moment Indexes (lb-in/100)	New CG (inches from datum)
Airplane	1,876.0	+677.2	
Radio removed	–12.2	–1.93	
Power supply removed	–9.2	–8.74	
ELT removed	–3.2	–4.32	
Radio installed	+8.4	+1.23	
ELT installed	+1.7	+2.29	
Passenger seat installed	+21.0	+20.37	
Total	1,882.5	+686.1	+36.4

Figure 5-4. *Weight and moment index changes caused by a typical alteration.*

Determining the Loaded CG of the Airplane in Percent MAC

The basic operating weight (BOW) and the operating index are entered into a loading schedule like the one in Figure 7-1 and the variables for the specific flight are entered as are appropriate to determine the loaded weight and CG.

Use the data in this example:

Basic operating Weight ..... 105,500 lbs.
Basic operating index (total moment/1,000) ... 98,837.0
MAC ..... 180.9 in
LEMAC 860.5

Item		Weight	Moment/1000
BOW		105,500	92,837
PAX forward	18	3,060	1,781
PAX aft	95	16,150	16,602
Fwd cargo		1,500	1,020
Aft cargo		2,500	2,915
Fuel tank 1		10,500	10,451
Fuel tank 3		10,500	10,451
Fuel tank 2		28,000	25,589
		177,710	161,646

Figure 7-1. *Loading tables.*

Use Figure 7-2 to determine the moment indexes for the passengers (PAX), cargo, and fuel.

The airplane is loaded in this way:

Passengers (nominal weight 170 pounds each)
Forward compartment 18
Aft compartment 95

Cargo
Forward hold ..... 1,500 lbs
Aft hold ..... 2,500 lbs

Fuel
Tank 1 & 3 ..... 10,500 lbs each
Tank 2 ..... 28,000 lbs

Determine the location of the CG in inches aft of the datum by using this formula:

$$\text{CG in. aft of datum} = \left(\frac{\text{Total moment index}}{\text{Total weight}}\right) \times 1{,}000$$
$$= \left(\frac{161{,}646}{177{,}710}\right) \times 1{,}000$$
$$= 909.6 \text{ inches}$$

Determine the distance from the CG to the LEMAC by subtracting the distance between the datum and LEMAC from the distance between the datum and the CG:

$$\text{Distance CG to LEMAC} = \text{Datum to CG} - \text{datum to LEMAC}$$
$$= 909.6 - 860.5$$
$$= 49.1 \text{ inches}$$

The location of the CG in percent of MAC must be known in order to set the stabilizer trim takeoff. Use this formula:

$$\text{CG \% MAC} = \left(\frac{\text{Distance CG to LEMAC}}{\text{MAC}}\right) \times 100$$
$$= \left(\frac{49.1}{180.9}\right) \times 100$$
$$= 27.1\%$$

On Board Aircraft Weighing System

Some large transport airplanes have an on board aircraft weighing system (OBAWS) that, when the aircraft is on the ground, gives the flightcrew a continuous indication of the aircraft total weight and the location of the CG in % MAC.

The system consists of strain-sensing transducers in each main wheel and nose wheel axle, a weight and balance computer, and indicators that show the gross weight, the CG location in percent of MAC, and an indicator of the ground attitude of the aircraft.

The strain sensors measure the amount each axle deflects and sends this data into the computer, where signals from all of the transducers and the ground attitude sensor are integrated. The results are displayed on the indicators for the flightcrew.

Item	Weight	Arm	Moment/100	CG
Airplane basic EW	9,226		25,823	
Crew	340	129	439	
Passengers				
Row 1	300	200	600	
Row 2	250	230	575	
Row 3	190	260	494	
Row 4	170	290	493	
Row 5	190	320	608	
Row 6	340	350	1,190	
Row 7	190	380	722	
Row 8		410		
Row 9		440		
Baggage				
Nose		65.5		
Fwd Cabin	100	163.6	164	
Aft (Fwd Section)	200	483.5	967	
Aft (Aft Section)	600	533.0	3,198	
Fuel Jet A @ +25°C				
Gallons 390	2,633		7,866	
	14,729		43,139	292.9

Figure 7-7. *Determining the loaded weight and CG of a Beech 1900 in the passenger configuration.*

USEFUL LOAD WEIGHTS AND MOMENTS OCCUPANTS

WEIGHT	CREW	CABIN SEATS								
	F.S. 129	F.S. 200	F.S. 230	F.S. 260	F.S. 290	F.S. 320	F.S. 350	F.S. 380	F.S. 410	F.S. 440
	MOMENT/100									
80	103	160	184	208	232	256	280	304	328	352
90	116	180	207	234	261	288	315	342	369	396
100	129	200	230	260	290	320	350	380	410	440
110	142	220	253	286	319	352	385	418	451	484
120	155	240	276	312	348	384	420	456	492	528
130	168	260	299	338	377	416	455	494	533	572
140	181	280	322	364	406	448	490	532	574	616
150	194	300	345	390	435	480	525	570	615	660
160	206	320	368	416	464	512	560	608	656	704
170	219	340	391	442	493	544	595	646	697	748
180	232	360	414	468	522	576	630	684	738	792
190	245	380	437	494	551	608	665	722	779	836
200	258	400	460	520	680	640	700	760	820	880
210	271	420	483	546	609	672	735	798	861	924
220	284	440	506	572	638	704	770	836	902	968
230	297	460	529	598	667	736	805	874	943	1012
240	310	480	552	624	696	768	840	912	984	1056
250	323	500	575	650	725	800	875	950	1025	1100

Note: Weights reflected in above table represent weight per seat.

Figure 7-8. *Weights and moments - occupants.*

USEFUL LOAD WEIGHTS AND MOMENTS BAGGAGE

WEIGHT	NOSE BAGGAGE COMPARTMENT F.S. 65.5	FORWARD CABIN BAGGAGE COMPARTMENT F.S. 163.6	AFT BAGGAGE/ CARGO COMPARTMENT (FORWARD SECTION) F.S. 483.5	AFT BAGGAGE/ CARGO COMPARTMENT (AFT SECTION) F.S. 533.0
	MOMENT/100			
10	7	16	48	53
20	13	33	97	107
30	20	49	145	160
40	26	65	193	213
50	33	82	242	266
60	39	98	290	320
70	46	115	338	373
80	52	131	387	426
90	59	147	435	480
100	66	164	484	533
150	98	245	725	800
200		327	967	1066
250		409	1209	1332
300			1450	1599
350			1692	1866
400			1934	2132
450			2176	2398
500			2418	2665
550			2659	2932
600			2901	3198
630			3046	3358
650			3143	
700			3384	
750			3626	
800			3868	
850			4110	
880			4255	

Figure 7-9. *Weights and moments - baggage.*

Nose Wheel Airplane with Datum Behind the Main Wheels

The datum (D) is 75 inches behind the main-wheel weighing points, the weight of the nose wheel (F) is 340 pounds, and the distance between main wheels and nose wheel (L) is 78 inches. The total weight (W) of the airplane is 2,006 pounds. Refer to Figure 3-6 on page 3-5. Use this formula:

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

1. Determine the CG in inches from the main wheels:

   (340)(x)(78)(÷)(2006)(=) 13.2

2. Determine the CG in inches from the datum:

   (75)(+)(13.2)(=) 88.2

   The minus sign before the parenthesis in the formula means the answer is negative. The CG is 88.2 inches ahead of the datum (-88.2).

Tail Wheel Airplane with Datum Ahead of the Main Wheels

The datum (D) is 7.5 inches ahead of the main-wheel weighing points, the weight of the tail wheel (R) is 67 pounds, and the distance between main wheels and tail wheel (L) is 222 inches. The total weight (W) of the airplane is 1,218 pounds. Refer to Figure 3-7 on page 3-6.

Use this formula:

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

1. Determine the CG in inches from the main wheels.

   (67)(x)(222)(÷)(1218)(=) 12.2

2. Determine the CG in inches from the datum:

   (7.5)(+)(12.2)(=) 19.7

   The CG is 19.7 inches behind the datum.

Tail Wheel Airplane with Datum Behind the Main Wheels.

The datum (D) is 80 inches behind the main-wheel weighing points, the weight of the tail wheel (R) is 67 pounds, and the distance between main wheels and tail wheel (L) is 222 inches. The total weight (W) of the airplane is 1,218 pounds. Refer to Figure 3-8 on page 3-6.

Use this formula:

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

1. Determine the CG in inches from the main wheels:

   (67)(x)(222)(÷)(1218)(=) 12.2

2. Determine the CG in inches from the datum:

   (80)(+/-)(+)(12.2)(=) -67.8

   The CG is 67.8 inches ahead of the datum.

Determining CG, Given Weights and Arms

Some weight and balance problems involve weights and arms to determine the moments. Divide the total moment by the total weight to determine the CG. Figure 8-5 contains the specifications for determining the CG using weights and arms.

Determine the CG by using the data in Figure 8-5 and following these steps:

1. Determine the total weight and record this number:

   (830)(+)(836)(+)(340)(=)(2006)

2. Determine the moment of each weighing point and record them:

   (830)(x)(128)(=)106240
   (836)(x)(128)(=) 107008
   (340)(x)(50)(=) 17000

Weighing Point	Weight (lbs)	Arm (in)	Moment (lb-in)	CG
Right side	830	128	106,240	
Left side	836	128	107,008	
Nose	340	50	17,000	
Total	2,006		230,248	114.8

Figure 8-5. *Specifications for determining the CG of an airplane using weight and arm.*