Chapter 4

General Aviation Aircraft Operational Weight and Balance Computations

Weight and balance data allows the pilot to determine the loaded weight of the aircraft and determine whether or not the loaded CG is within the allowable range for the weight. *See* Figure 4-1 for an example of the data necessary for these calculations.

Airplane basic empty weight	1,874.0 lbs, EWCG +36.1
CG range	(+40.9) to (+46.0) at 3,100 lbs (+33.0) to (+46.0) at 2,250 lbs or less Straight line variation between points given
Empty weight CG range	None
Maximum weight	3,100 lbs takeoff/flight 2,950 lbs landing
No. of seats	4 (2 front at –37.0) (2 rear at +74.0)
Maximum baggage	160 lbs Area A (100 lbs at –97.0) Area B (60 lbs at +116.0)
Fuel capacity	92 gal (88 gal usable); two 46 gal integral tanks in wings at +46.6 See NOTE 1 for data on unusable fuel.
Oil capacity	12 qt (–15)

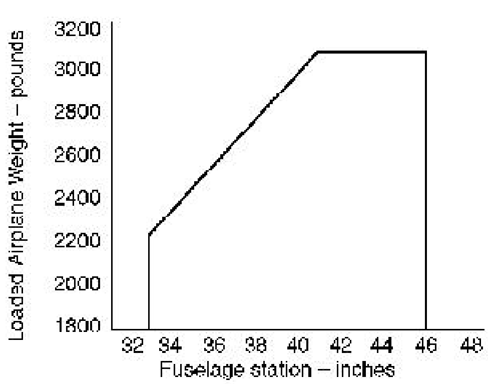


Figure 4-1. *Weight and balance data needed to determine proper loading of a 14 CFR, Part 23 airplane.*

Determining the Loaded Weight and CG

An important part of preflight planning is to determine that the aircraft is loaded so its weight and CG location are within the allowable limits. [Figure 4-2] There are two ways of doing this: by the computational method using weights, arms, and moments; and by the **loading graph** method, using weight and **moment indexes**.

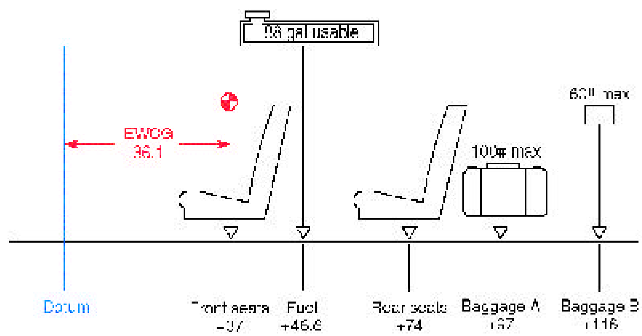


Figure 4-2. *Airplane loading diagram.*

Computational Method

The computational method uses weights, arms, and moments and relates the total weight and CG location to a CG limits chart similar to those included in the TCDS and the POH/AFM.

A worksheet such as the one in Figure 4-3 provides space for all of the pertinent weight and balance data. Data is included for the airplane weight, CG, and moment along with the arms of the seats, fuel, and baggage areas.

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.*

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 passengers .... 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.

Loading Graph Method

Everything possible is done to make flying safe, and one expedient method is the use of charts and graphs from the POH/AFM to simplify and speed up the preflight weight and balance computations. Some use a loading graph and moment indexes rather than the arms and moments. These charts eliminate the need for calculating the moments and thus make computations quicker and easier. [Figure 4-5]

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.*

Loading Graph Method

Loading graphs simplify weight and balance computations because they eliminate the need for multiplication when computing a loaded CG.

Loading graph: A graph of load weight and load moment indexes. Diagonal lines for each item relate the weight to the moment index without having to use mathematics.

Moment index: A moment that has been divided by a reduction factor to obtain a smaller number to make computations easier and reduce the likelihood of mathematical errors.

CG limits envelope: An enclosed area on a graph of the airplane loaded weight and the CG location. If lines drawn from the weight and CG cross within this envelope, the airplane is properly loaded.

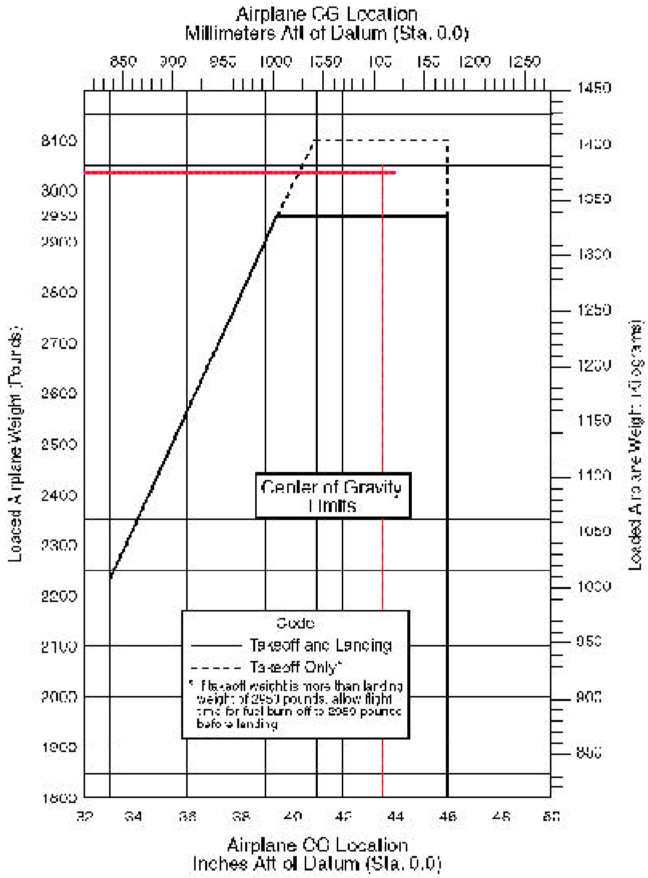


Figure 4-5. *Center of gravity limits chart from a typical POH.*

Moment Indexes

Moments determined by multiplying the weight of each component by its arm result in large numbers that are awkward to handle and can become a source of mathematical error. To eliminate these large numbers, moment indexes are used. The moment is divided by a **reduction factor** such as 100 or 1,000 to get the moment index. The loading graph provides the moment index for each component, so you can avoid mathematical calculation. The CG envelope uses moment indexes rather than arms and moments.

Loading Graph

Figure 4-6 (*see* Page 4-4) is a typical loading graph taken from the POH of a modern four-place GA airplane. To compute the weight and balance, using the loading graph in Figure 4-6, make a **loading schedule** chart like the one in Figure 4-7.

In Figure 4-6, follow the horizontal line for 300 pounds load weight to the right until it intersects the diagonal line for pilot and front passenger. From this point, drop a line vertically to the load moment index along the bottom to determine the load moment for the front seat occupants. This is 11.1 lb-in/1,000. Record it in the loading schedule chart.

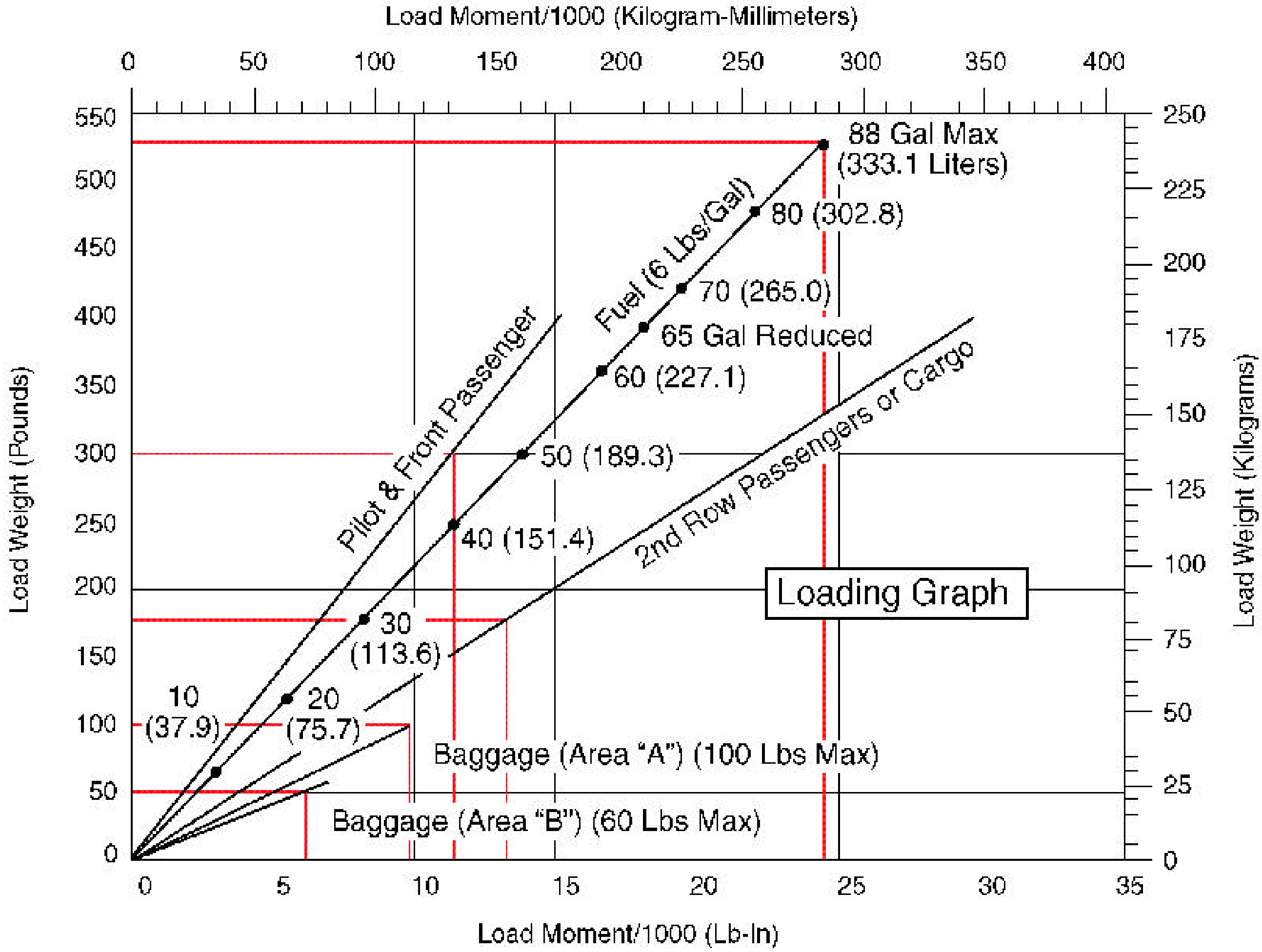
Determine the load moment for the 175 pounds of rear seat occupants along the diagonal for 2nd row passengers or cargo. This is 12.9; record it in the loading schedule chart.

Item	Weight	Moment/1000
Airplane (BEW)	1,874	67.7
Front seat	300	11.1
Rear seat	175	12.9
Fuel	528	24.6
Baggage A	100	9.7
Baggage B	50	5.8
Total	3,027	131.8

Figure 4-7. *Loading schedule chart.*

Reduction factor: The number, usually 100 or 1,000, that is used to divide the moment to get the moment index.

Loading schedule: A chart filled in by the pilot during preflight planning that lists the weight and moment indexes of all occupants, fuel, and baggage.



Note: **Line representing adjustable seats shows pilot and front seat passenger center of gravity on adjustable seats positioned for an average occupant. Refer to the Loading Arrangements diagram for forward and aft limits of occupant CG range.**

Figure 4-6. *Loading graph.*

Determine the load moment for the fuel and the baggage in areas A and B in the same way and enter them all in the loading schedule chart. The maximum fuel is marked on the diagonal line for fuel in terms of gallons and liters. The maximum is 88 gallons of **usable fuel**. The total capacity is 92 gallons, but 4 gallons are unusable and have already been included in the empty weight of the aircraft. The weight of 88 gallons of gasoline is 528 pounds and its moment index is 24.6. The 100 pounds of baggage in area A has a moment index of 9.7 and the 50 pounds in area B has an index of 5.8. Enter all of these weights and moment indexes in the loading schedule chart and add all of the weights and moment indexes to determine the totals. Transfer these values to the **CG moment envelope** in Figure 4-8.

The loading schedule shows that the total weight of the loaded aircraft is 3,027 pounds, and the loaded airplane moment/ 1,000 is 131.8.

Draw a line vertically upward from 131.8 on the horizontal index at the bottom of the chart, and a horizontal line from 3,027 pounds in the left-hand vertical index. These lines intersect within the dashed area which shows that the aircraft is loaded properly for takeoff but it is too heavy for landing.

If the aircraft had to return for landing, it would have to fly long enough to burn off 77 pounds (slightly less than 13 gallons) of fuel to reduce its weight to the amount allowed for landing.

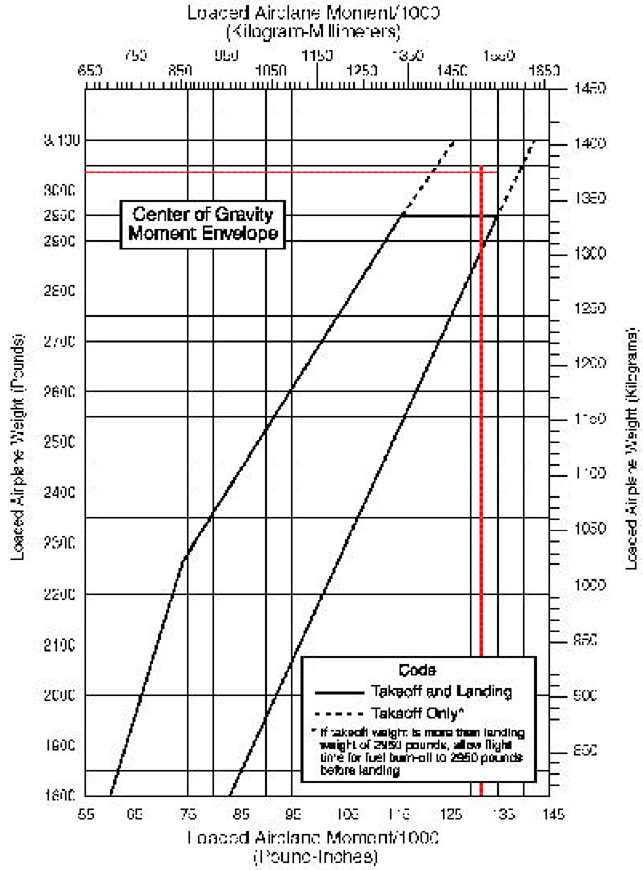


Figure 4-8. *CG moment envelope.*

Usable fuel (GAMA): Fuel available for flight planning.

CG moment envelope: An enclosed area on a graph of the airplane loaded weight and loaded moment. If lines drawn from the weight and loaded moment cross within this envelope, the airplane is properly loaded.

Multiengine Airplane Weight and Balance Computations

Weight and balance computations for general aviation multiengine airplanes are similar to those discussed for single-engine airplanes. Computations for large airline and cargo airplanes are discussed in Chapter 6. *See* Figure 4-9 for an example of weight and balance data for a typical twin-engine general aviation airplane.

Datum—Forward face of fuselage bulkhead ahead of rudder pedals
Seats
2 at 37.0
2 at 75.0
1 at 113.0—Weight limit 200 lbs
Fuel
213.4 gal (2 wing tanks, 105.0 gal each 103.0 gal usable at +61.0)
Undrainable fuel—1.6 lbs at +62
Oil
24 quarts (12 quarts in each engine)— –3.3
Baggage
Forward 100# limit— –15
Aft 200# limit—+113
CG Range
(+38) to (+43.1) at 5,200 lbs
(+43.6) at 4,800 lbs
(+32) to (+43.6) at 4,300 lbs or less
Straight line variation between points given
Engines (2) 240 horsepower horizontally opposed engines
Fuel burn—24 gph for 65% cruise at 175 knot
29 gph for 75% cruise at 180 knot

Figure 4-9. *Typical weight and balance data for a twin-engine general aviation airplane.*

The airplane in this example was weighed to determine its basic empty weight and EWCG. The weighing conditions and results are:

Fuel drained —
Oil full —
Right wheel scales — 1,084 lbs, tare 8 lbs
Left wheel scales — 1,148 lbs, tare 8 lbs
Nose wheel scales — 1,202 lbs, tare 14 lbs

Determining the Loaded CG

Beginning with the basic empty weight and EWCG and using a chart such as the one in Figure 4-11, the loaded weight and CG of the aircraft can be determined. [Figure 4-10]

The aircraft is loaded as shown here:

Fuel (140 gal) .... 840 lbs
Front seat .... 320 lbs
Row 2 seats .... 310 lbs
Fwd. baggage .... 100 lbs
Aft baggage .... 90 lbs

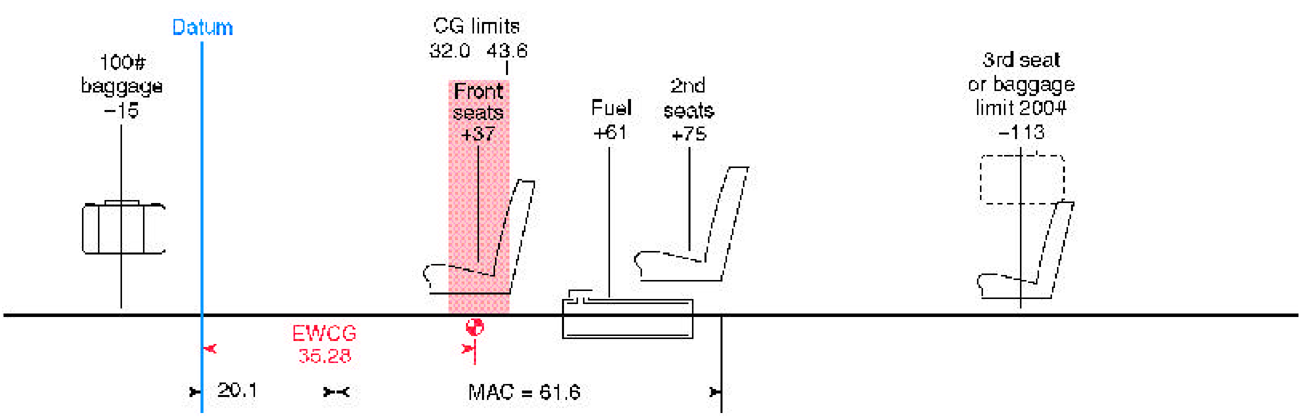


Figure 4-10. *Twin-engine airplane weight and balance diagram.*

The Chart Method Using Weight, Arm, and Moments

Make a chart showing the weights, arms, and moments of the airplane and its load.

Item	Weight pounds (5,200 max.)	Arm (inches)	Moment (lb-in)	CG
Aircraft	3,404	35.28	120,093	
Fuel (140 gal)	840	61.0	51,240	
Front seat	320	37.0	11,840	
Row 2 seats	310	75.0	23,250	
Fwd. baggage	100	–15	–1,500	
Aft baggage	90	113	10,170	
Total	5,064		215,093	42.47

Figure 4-11. *Determining the loaded center of gravity of the airplane in Figure 4-10.*

The loaded weight for this flight is 5,064 pounds, and the CG is located at 42.47 inches aft of the datum.

To determine that the weight and CG are within the allowable range, refer to the CG range chart of Figure 4-12. Draw a line vertically upward from 42.47 inches from the datum and one horizontally from 5,064 pounds. These lines cross inside the envelope, showing that the airplane is properly loaded.

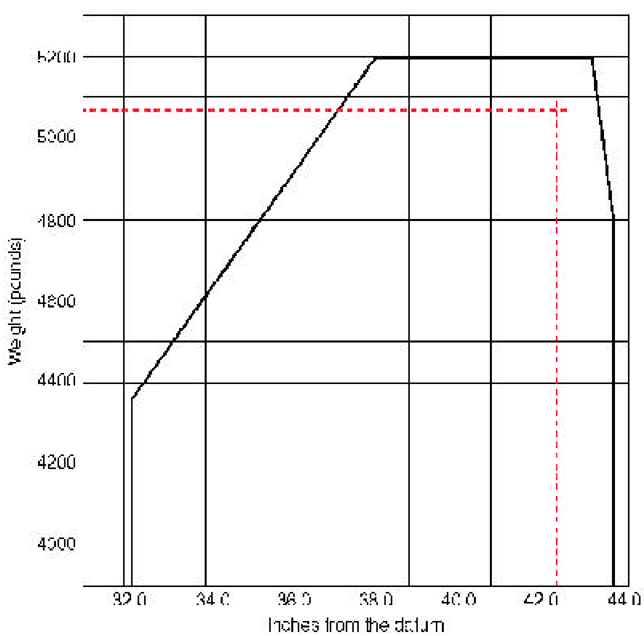


Figure 4-12. *Center of gravity range chart.*

Determining the CG in Percent of MAC

Refer again to Figures 4-10 and 4-11.

The loaded CG is 42.47 inches aft of the datum.
The MAC is 61.6 inches long.
The LEMAC is located at station 20.1.
The CG is 42.47 – 20.1 = 22.37 inches aft of LEMAC.
Use this formula:

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

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

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

The loaded CG is located at 36.3% of the mean aerodynamic chord.

The Chart Method Using Weight and Moment Indexes

As mentioned in the previous chapter, anything that can be done to make careful preflight planning easier makes flying safer. Many manufacturers furnish charts in the POH/AFM that use weight and moment indexes rather than weight, arm, and moments. They further help reduce errors by including tables of moment indexes for the various weights.

Consider the loading for this particular flight:

Cruise fuel flow = 16 gallons per hour
Estimated time en route = 2 hours 10 minutes
Reserve fuel = 45 minutes = 12 gallons
Total required fuel = 47 gallons

The pilot completes a chart like the one in Figure 4-13 using moment indexes from the tables in Figures 4-14 through 4-16.

Weight and Balance Loading Form

Model ______________________________ Date ______________________________

Serial Number ______________________ Reg. Number ________________________

Item	Pounds (3,900 max.)	Index Moment/100
Airplane basic empty weight	2,625	2,864
Front seat occupants	320	336
Row 2 seats	290	412
Baggage (200# max.)	90	150
Sub Total Zero fuel condition (3,500 max.)	3,325	3,762
Fuel loading – gallons 80	480	562
Sub Total Ramp condition	3,805	4,324
*Less fuel for start, taxi, and takeoff	-24	-14
Sub Total Takeoff condition	3,781	4,310
Less fuel to destination – gallons 35	-210	-246
Landing condition	3,571	4,064

* Fuel for start, taxi, and takeoff is normally 24 pounds at a moment index of 14.

Figure 4-13. *Typical weight and balance loading form.*

The moments/100 in the index column are found in the charts in Figures 4-14 through 4-16. If the exact weight is not in the chart, **interpolate** between the weights that are included. When a weight is greater than any of those shown in the charts, add the moment indexes for a combination of weights to get that which is desired. For example, to get the moments/100 for the 320 pounds in the front seat, add the moment indexes for 100 pounds (105) to that for 220 pounds (231). This gives the moment index of 336 for 320 pounds in the front seat.

Use the **moment limits vs. weight envelope** in Figure 4-17 on Page 4-10 to determine if the weight and balance conditions will be within allowable limits for both takeoff and landing at the destination.

Interpolate: To determine a value in a series between two known values.

Moment limits vs. weight envelope: An enclosed area on a graph of three parameters. The diagonal line representing the moment/100 crosses the horizontal line representing the weight at the vertical line representing the CG location in inches aft of the datum. When the lines cross inside the envelope, the aircraft is loaded within its weight and CG limits.

Takeoff — 3,781 lbs and 4,310 moment/100
Landing — 3,571 lbs and 4,064 moment/100

Locate the moment/100 diagonal line for 4,310 and follow it down until it crosses the horizontal line for 3,781 pounds. These lines cross inside the envelope at the vertical line for a CG location of 114 inches aft of the datum.

The maximum allowable takeoff weight is 3,900 pounds, and this airplane weighs 3,781 pounds. The CG limits for 3,781 pounds are 109.8 to 117.5. The CG of 114 inches falls within these allowable limits.

Occupants Moments/100		
Weight	Front seats Arm +105	Row 2 seats Arm +142
100	105	142
110	116	156
120	126	170
130	137	185
140	147	199
150	158	213
160	168	227
170	179	241
180	189	256
190	200	270
200	210	284
210	221	298
220	231	312
230	242	327
240	252	341
250	263	355

Figure 4-14. *Weight and moment index for occupants.*

Baggage Moments/100	
Weight	Arm 167
10	17
20	33
30	50
40	67
50	84
60	100
70	117
80	134
90	150
100	167
110	184
120	200
130	217
140	234
150	251
160	267
170	284
180	301
190	317
200	334

Figure 4-15. *Weight and moment index for baggage.*

Usable Fuel – Arm +117		
Gallons	Pounds	Moment/100
10	60	70
20	120	140
30	180	211
40	240	281
50	300	351
60	360	421
70	420	491
80	480	562
90	540	632
100	600	702

Figure 4-16. *Weight and moment index for fuel.*

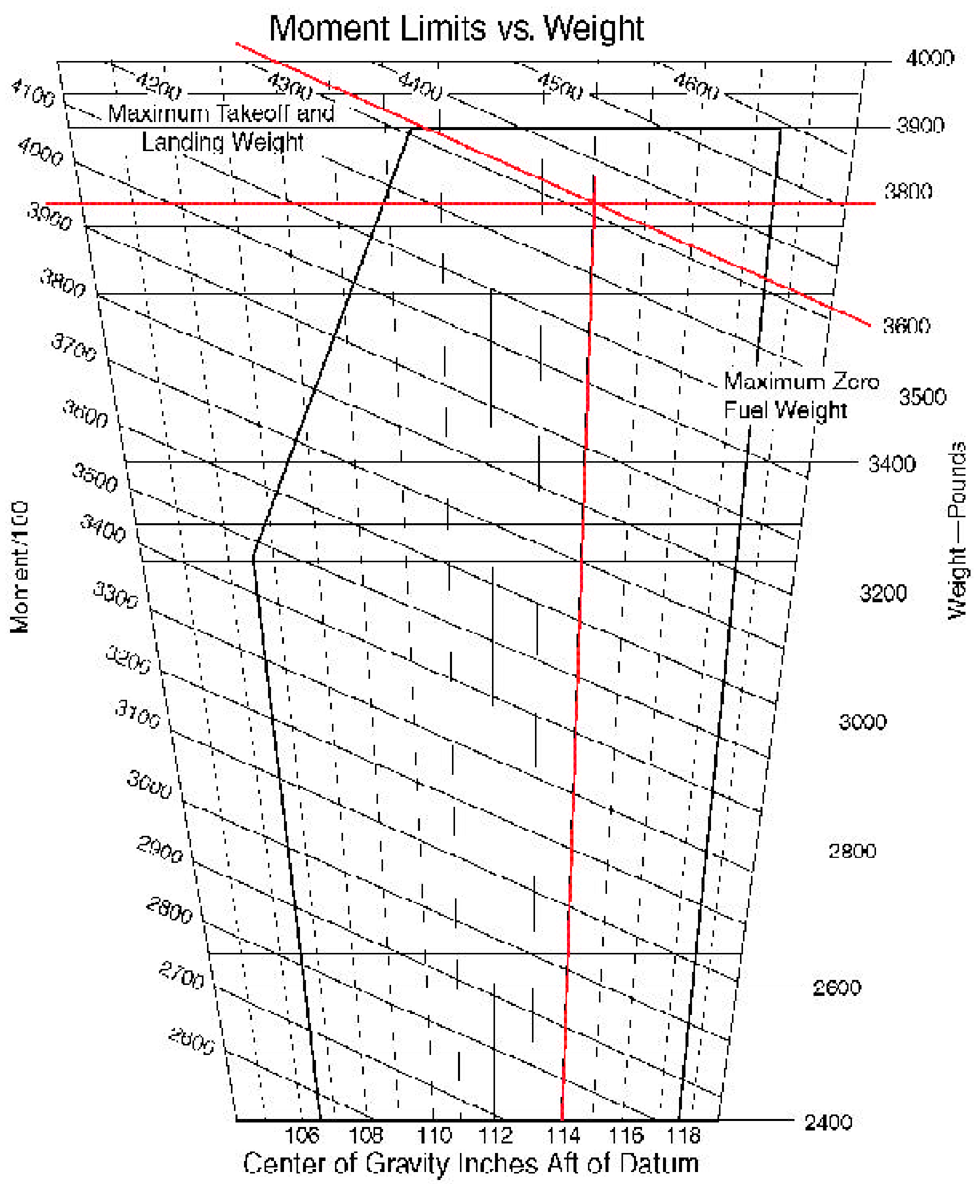
Interpolation

Determine the weight and moment index of 55 gallons of fuel

Gallons	Pounds	Moment/100
50	300	351
60	360	421

55 is 50% of the way between 50 and 60. The weight and moment index of 55 gallons is 50% of the difference between the weights and moment indexes for 50 gallons and 60 gallons.

Weight	Moment index
360 – 300 = 60.	421 – 351 = 70.
50% of 60 = 30.	50% of 70 = 35.
300 + 30 = 330.	351 + 35 = 386.



Envelope Based on the Following Weight and Center of Gravity Limit Data (Landing Gear Down)

Weight Condition	FWD CG Limit	Aft CG Limit
3,900 Pounds (Max Takeoff/Landing)	110.6	117.5
3,250 Pounds or Less	106.6	117.5

Figure 4-17. *Moment limits vs. weight envelope.*