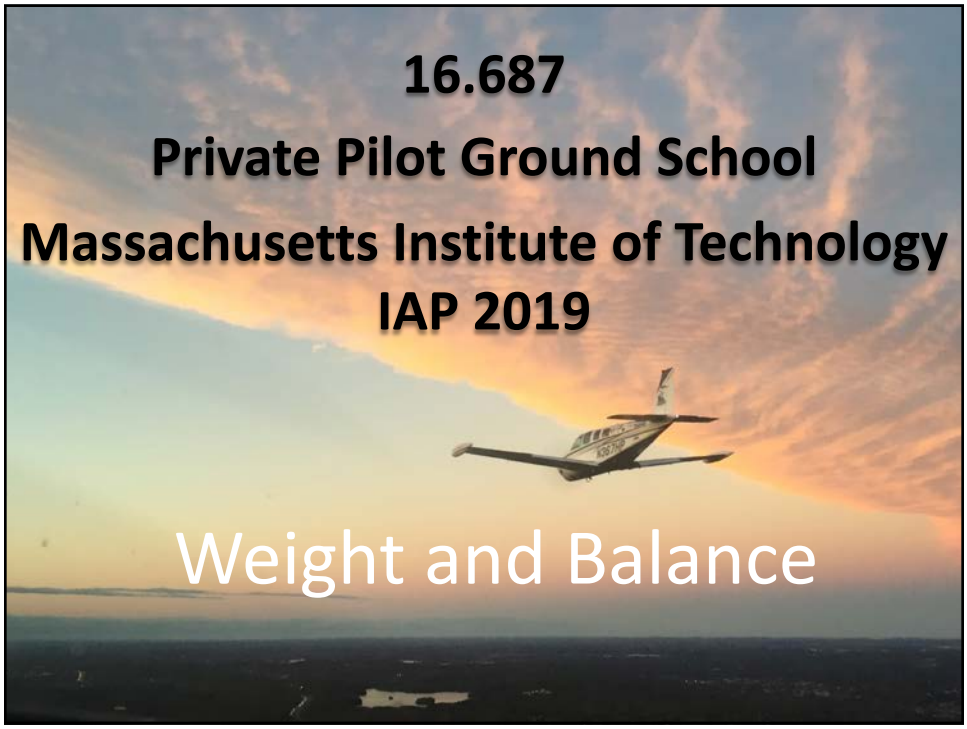

Importance of Weight and Balance

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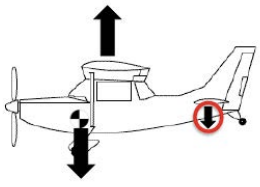
- Controllability
  - Longitudinal Stability requires center of gravity to be within limits
  - Elevator may not have enough authority for abnormal loadings
- Structural
  - Max gross weight is typically limited by airframe stress in turbulence
- Performance with higher weights
  - Stall speed increases
  - Takeoff distances increase
  - Climb rate reduced
  - Cruise speeds decrease
  - Fuel Economy is reduced
  - Landing distance increase
  - Over-gross: test pilot territory! (but military does it and round-the-world pilots)



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Weight Terms

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- **Empty Aircraft**
  - **Standard Empty Weight** – weight of a standard airplane including unusable fuel, full operating fluids and full oil
  - **Basic Empty Weight** – Standard Empty Weight plus optional equipment
    - Starting Point of Weight and Balance
- **Fuel**
  - **Usable Fuel** – fuel which can be used for flight planning
  - **Unusable Fuel** – fuel which cannot be use in flight due to fuel tank design
  - **6 lbs per gallon for gasoline (6.7 for Jet A)**

Weight Terms

16.687

- Weight
  - Force that acts straight down to the center of the Earth
  - Decreases with fuel burn
- Loaded Aircraft
  - Maximum Ramp Weight
    - Maximum allowable mass for ground operations
    - Assures ground maneuverability
    - Includes fuel for taxi, run-up and start
  - Maximum Takeoff Weight
    - Maximum allowable mass for initiation of takeoff roll
  - Maximum Landing Weight
    - Maximum allowable mass at touchdown
    - Generally limitation of landing gear and associated structure
  - Baggage Compartment Limits
    - Structural limitation to prevent bracket/bulkhead/floor failure

Weight Terms

16.687

- **Useful Load – total usable fuel, passengers, and cargo**
  - Maximum Ramp Weight – Basic Empty Weight = Useful Load
- **Payload – passengers and cargo**
  - What essentially could be generating revenue
- **Zero Fuel Weight – Weight of aircraft without fuel**
  - Typically a limitation for jets

Basic Empty Weight
+ Payload
= Zero Fuel Weight
+ Usable Fuel
= Ramp Weight
- Fuel used for start, taxi and run-up
= Takeoff Weight
- Fuel used for flight
= Landing Weight

Balance Terms

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- **Arm**
  - Distance from the datum measured along the longitudinal axis
    - If located in front of datum, negative
    - If located in back of datum, positive
- **Moment**
  - Weight multiplied by its arm
  - Tendency of a mass to cause a rotation about the Center of Gravity
- **Reference Datum ("pivot point")**
  - Reference base for location of components
  - Imaginary vertical plane
  - Location specified from manufacturer
  - Lies on longitudinal axis
  - Warrior – 78.4 inches from wing leading edge
- **Center of Gravity (CG)**
  - Point of a mass through which gravity acts
  - Point where aircraft would balance if suspended
  - Point where all three axis intersect
  - **Divide total moment of aircraft by weight of aircraft**

Basic W&B Math

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- **Moment = Weight X Arm**
- **Location of the Center of Gravity**

$$\text{Location}_{CG} = \frac{\text{Sum of All Moments}}{\text{Gross Weight}}$$

- **For the next few examples…**
  - The seesaw is synonymous with the aircraft
  - The people are synonymous with the weight of fuel, equipment, passengers, etc…
  - The fulcrum can be thought of as lift, supporting the entire mass
  - The datum can be considered the nose of the aircraft

See-Saw Example

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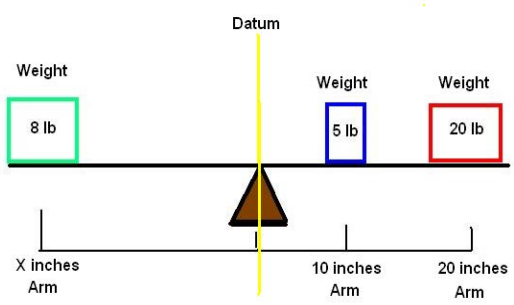
- Where should we put the Green weight to balance the See-Saw
- Moment on Right
  - 5*10+20*20=450
  - Moment = 450
- Moment on Left
  - Moment must = 450
  - 8*X=450
  - X = 56.25 inches



Finding Center of Gravity

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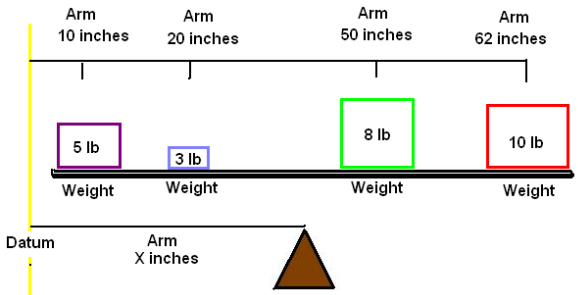
Item	Weight	Arm	Moment
Units	lbs	inches	lb-inches
Purple	5	10	50
Lavender	3	20	60
Green	8	50	400
Red	10	62	620
The Board	15	35	525
Total	41		1655
Center of Gravity		1655/41 =40.37	inches

Where do we put the triangle to balance the SeeSaw



The board itself weighs 15 lbs
The boards center of gravity is located at 35 inches

Once we know where the CG is, we can support the entire board there and it will balance

Basic W&B Relationships

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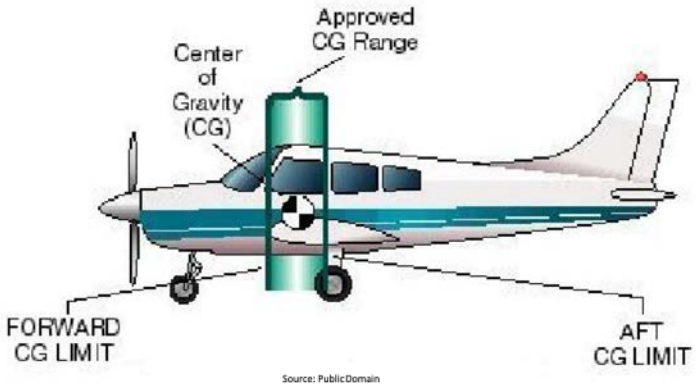
- Center of Gravity Limits



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Results of Aircraft Overloading

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- Stall Speed ➔ Increases
- Takeoff and Landing Distance ➔Increases
- Climb Rate ➔Reduced
- Cruise Speed ➔Reduced
- Fuel Consumption ➔Greater
- Range and Endurance ➔Reduced
- Stability ➔Increased

- **Overweight aircraft no longer certified as structurally sound throughout its flight envelope. You become a test pilot!**

Results of a Forward CG

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- Static Longitudinal Stability becomes excessive
  - Rotation and Flare are more difficult
- Takeoff Roll ➔Increased
- Cruise Speed ➔Decreased
  - A greater tail down force must be produced. For a given angle of attack, this requires elevator deflection and increases drag.
- Climb Rate ➔Reduced
- Range and Endurance ➔Reduced
- Stall Speed ➔Increased

Effects of an Aft CG

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- Longitudinally Stability ➔Reduced
- Takeoff Roll ➔Reduced
  - Tendency to Over-Rotate
- Landing Roll ➔Reduced
  - Tendency to Over-Flare
- Cruise Speeds ➔Increased
  - Less tail down force, is less drag
- Climb Rates ➔Increased
- Fuel Consumption ➔Decreased
- Range and Endurance ➔Increased
- Stall Speeds ➔Reduced
  - Recovery hindered due to reduced longitudinal stability

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LOADING ARRANGEMENTS

* Pilot or passenger center of gravity on adjustable seats positioned for average occupant. Numbers in parentheses indicate forward and aft limits of occupant center of gravity range.

**Baggage area center of gravity.

NOTES:
1. The usable fuel C.G. arm is located at station 43.0.
2. The aft baggage wall (approximate station 166) can be used as a convenient interior reference point for determining the location of baggage area fuselage station.

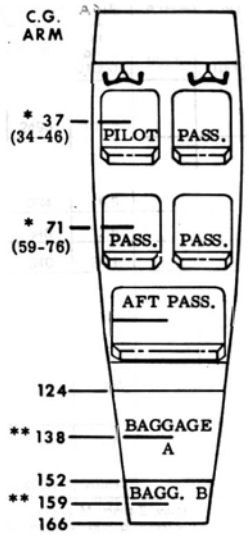

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Figure 6-3. Loading Arrangements

Calculating Weight and Balance

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- For each flight, the PIC is required to calculate weight and balance of the aircraft
- The Pilot Operating Handbooks of aircraft contains the information required to calculate weight and balance
- http://trumpetb.net/alph/wb172N.html
  - Note: uses 7 lb/gal instead of 6 lb/gal
- In the Warrior POH, section 6 contains…
  - Weight and Balance Calculation procedure for the aircraft
  - Basic Empty Weight and Moment of the aircraft
  - Changes to the Weight and Balance

Computation Method

16.687

- This method uses the basic weight and balance formula to determine center of gravity
  - Can be used for most aircraft
  - Extremely accurate, fewer arithmetic errors
- Example: Piper Warrior (PA-28-161)
- Procedure
  1. Determine the Basic Empty Weight of the aircraft
  2. Find the moment of each weight to be carried
  3. Add all moments and all weights
  4. Divide the total moment by the total weight. This number is your Center of Gravity
  5. Compare this number to the CG limits for the aircraft

Weight and Balance
Piper Warrior

16.687

For our first problem, we use a weight and balance form for a Piper Warrior

Piper Warrior

16.687

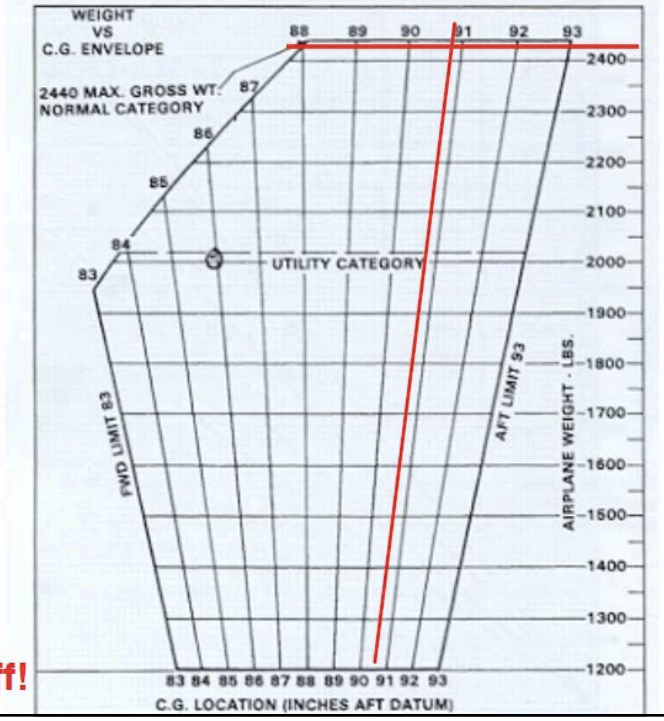
	Weight (lbs.)	Arm (in.)	Moment (lbs.-in.)
Basic Empty Weight	1,500		128,850
Pilot, Front Passengers	340	80.5	27,370
Rear Passengers	340	118.1	40,154
Baggage (200 lb. Max)			
Zero Fuel Condition	2,180		196,374

Next, check ramp condition

Piper Warrior

16.687

	Weight (lbs.)	Arm (in.)	Moment (lbs.-in.)
Basic Empty Weight	1,500		128,850
Pilot, Front Passengers	340	80.5	27,370
Rear Passengers	340	118.1	40,154
Baggage (200 lb. Max)			
Zero Fuel Condition	2,180		196,374
Fuel (48 gallons max)	267	95	25,365
Ramp Condition	2,447		221,739
Taxi, start, runup fuel	- 7	95	- 665
Takeoff condition	2,440	90.6	221,074



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Go for Take-Off!

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Check Landing Condition

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	Weight (lbs.)	Arm (in.)	Moment (lbs.-in.)
Takeoff condition	2,440	90.6	221,074
Cruise fuel (30 gallons)	-180	95.0	-17,100
Landing condition	2,260	90.25	203,974

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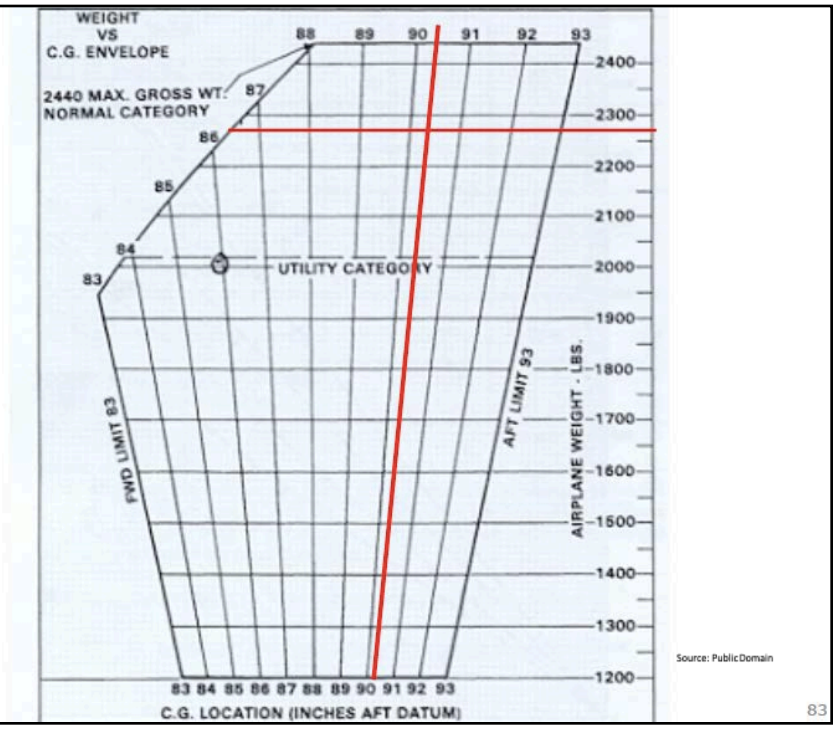

Use App

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- Data: http://eastcoastaeroclub.com/weight-and-balance.pdf
- N707WT Cirrus SR20:
  - Empty weight 2124.02
  - CG 140.49 in
  - Moment 298,414
- Pilot: 200; Copilot: 80; Rear seat: 190; Baggage: 50
- Fuel: 50 gallons at start; 15 to burn

Web and Spreadsheets

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- West Valley Flying Club: example SR20
- Journeys Aviation (Colorado)
- A spreadsheet for an SR20
- Fltplan.com offers a tool

Chart Method

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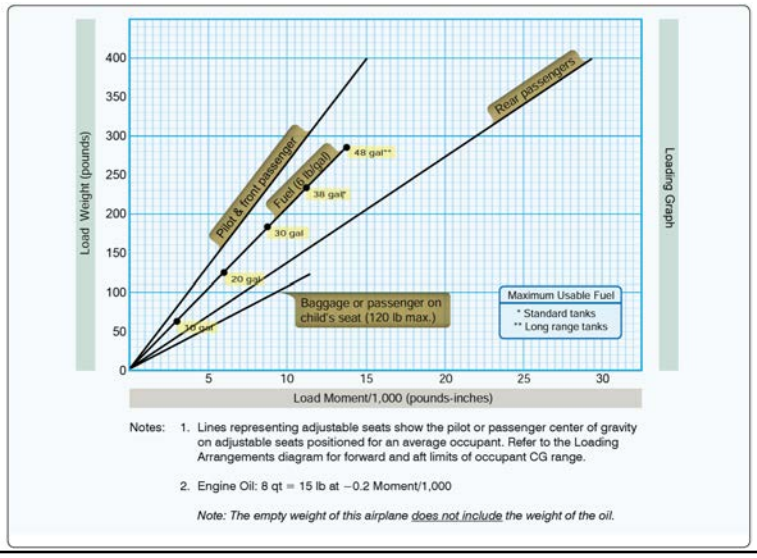

Notes:
1. Lines representing adjustable seats show the pilot or passenger center of gravity on adjustable seats positioned for an average occupant. Refer to the Loading Arrangements diagram for forward and aft limits of occupant CG range.
2. Engine Oil: 8 qt = 15 lb at −0.2 Moment/1,000

Note: The empty weight of this airplane does not include the weight of the oil.

Source: Public Domain

25

Table Method

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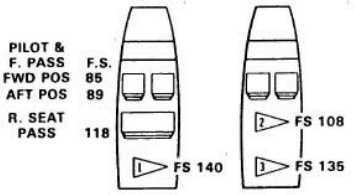
- Procedure
  1. Find the tabular data provided in Section 6 of the POH. (These may or may not be provided)
  2. Correlate the weight to the appropriate tables to determine the moment. (interpolate if necessary)
  3. Add the moments determined from the tables and correlate them to the CG Limit chart.

The empty weight and moment of the airplane at the time of delivery are shown on the airplane Empty Weight and Balance form. Useful load items which may be loaded into the airplane are shown on the Useful Load Weight and Moment tables. The minimum and maximum moments are indicated on the Moment Limits vs Weight table. These moments correspond to the forward and aft center of gravity flight limits for a particular weight. All moments are divided by 100 to simplify computations.

SEATING, BAGGAGE AND EQUIPMENT ARRANGEMENTS



1. MAXIMUM WEIGHT 270 POUNDS INCLUDING EQUIPMENT AND BAGGAGE.
2. MAXIMUM WEIGHT 200 POUNDS FORWARD OF REAR SPAR INCLUDING EQUIPMENT AND CARGO WITH REAR SEAT REMOVED.
3. MAXIMUM WEIGHT 270 POUNDS AFT OF REAR SPAR INCLUDING EQUIPMENT AND CARGO WITH REAR SEAT REMOVED.

ALL BAGGAGE/CARGO MUST BE SECURED

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
3000 lb. (take-off or landing)	82.1	86.7
2600 lb. or less	77.0	86.7

Weight	Minimum Moment / 100	Maximum Moment / 100
2100	1617	1821
2110	1625	1829
2120	1632	1838
2130	1640	1847
2140	1648	1855
2150	1656	1864
2160	1663	1873
2170	1671	1881
2180	1679	1890
2190	1686	1899
2200	1694	1907
2210	1702	1916
2220	1709	1925
2230	1717	1933
2240	1725	1942
2250	1733	1951
2260	1740	1959
2270	1748	1968
2280	1756	1977
2290	1763	1985

USEFUL LOAD WEIGHTS AND MOMENTS

OCCUPANTS

	Front Seats		Rear Seat
	Fwd Position	Aft Position	
	ARM 85	ARM 89	ARM 118
WEIGHT	MOM/100	MOM/100	MOM/100
120	102	107	142
130	110	116	153
140	119	125	165
150	128	134	177
160	136	142	189
170	144	151	201
180	153	160	212
190	162	169	224
200	170	178	236

NOTE: OCCUPANT POSITIONS FOR ADJUSTABLE SEATS ARE SHOWN AT THEIR EXTREME POSITIONS. INTERMEDIATE POSITIONS WILL REQUIRE INTERPOLATION OF THE MOMENT/100 VALUES.

BAGGAGE
ARM 140

Weight	Moment / 100	Weight	Moment / 100
10	14	70	98
20	28	80	112
30	42	90	126
40	56	100	140
50	70	110	154
60	84	120	168

BAGGAGE (Continued)
ARM 140

Weight	Moment / 100	Weight	Moment / 100
130	182	210	294
140	196	220	308
150	210	230	322
160	224	240	336
170	238	250	350
180	252	260	364
190	266	270	378
200	280		

CARGO (With Rear Seat Removed)

AHEAD OF SPAR ARM 108		AFT OF SPAR ARM 135	
Weight	Moment / 100	Weight	Moment / 100
20	22	20	27
40	43	40	54
60	65	60	81
80	86	80	108
100	108	100	135
120	130	120	162
140	151	140	189
160	173	160	216
180	194	180	243
200	216	200	270
		220	297
		240	324
		260	351
		270	364

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Questions?

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Back-up

Weight & Balance – Cessna P210

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Cessna P210

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- Basic Empty Weight: 2,632 lbs. (Moment 109,000)
- Front Seat (170 lbs.)
- Center Seat (160 and 150 lbs)
- Aft Seat (200 and 170 lbs)
- Baggage Area A (150 lbs)
- Baggage Area B (0)

Zero Fuel Condition

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Item	Weight	Arm	Moment
BEW	2632		109000
Front Seat	170	37	6290
Center Seat	310	71	22010
Aft Seat	370	102	37740
Baggage A	150	138	20700
Zero-Fuel	**3632**	**53.89**	**195740**

Ramp Condition

16.687

- Add 64 gallons of fuel

Item	Weight	Arm	Moment
Zero-Fuel	3632	53.89	195740
Fuel	384	43	16512
Ramp Weight	**4016**	**52.85**	**212252**

Takeoff Condition

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- Run-up: minus 16 lbs of fuel

Item	Weight	Arm	Moment
Ramp Weight	4016	52.85	212252
Run-up	-16	43	-688
Takeoff	**4000**	**52.89**	**211564**

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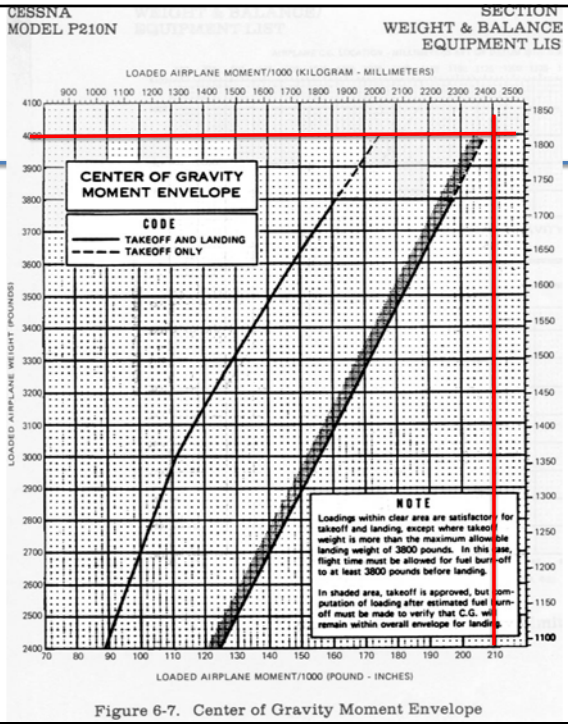

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Figure 6-7. Center of Gravity Moment Envelope

AERO AST

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SECTION 6
WEIGHT & BALANCE/
EQUIPMENT LIST

CESSNA
MODEL P210N

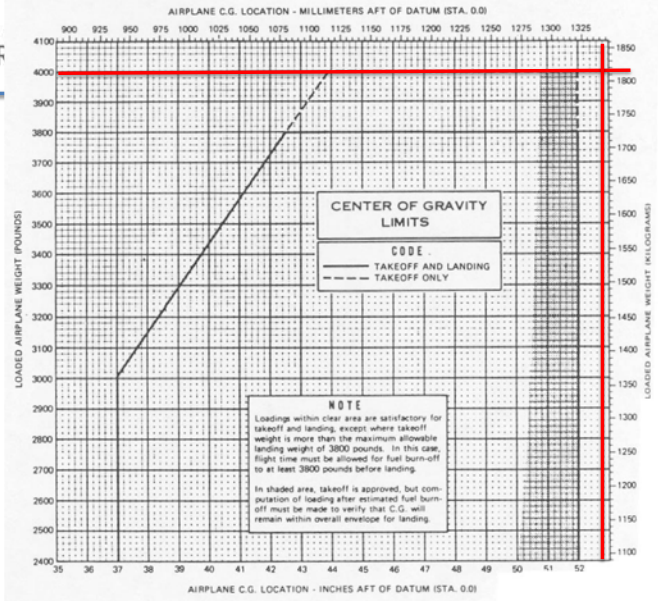

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Figure 6-8. Center of Gravity Limits

AERO MIT AST RO

Shift a Passenger

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- Move the 200 lb passenger from the aft seat to the front seat
- Equation:

$$\frac{\text{WEIGHT MOVED}}{\text{WEIGHT OF AIRPLANE}} = \frac{\text{DISTANCE CG MOVES}}{\text{DISTANCE BETWEEN ARMS}}$$

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SECTION 6
WEIGHT & BALANCE/
EQUIPMENT LIST

CESSNA
MODEL P210N

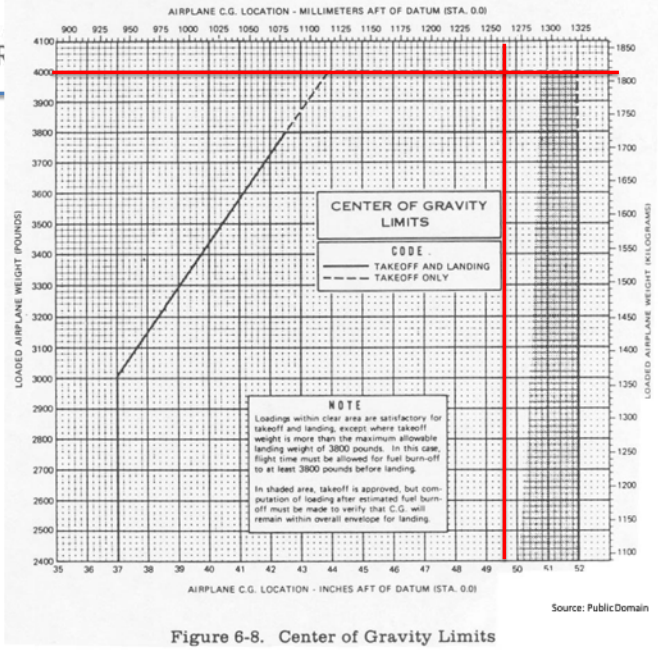

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Figure 6-8. Center of Gravity Limits

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Fuel Burn

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- 2.5 hour flight at 20 gallons per hour

Item	Weight	Arm	Moment
Takeoff	4000	49.64	198560
Fuel Burn	(2.5 x 20 x 6) -300	43	-12900
Landing	**3700**	**50.18**	**185660**

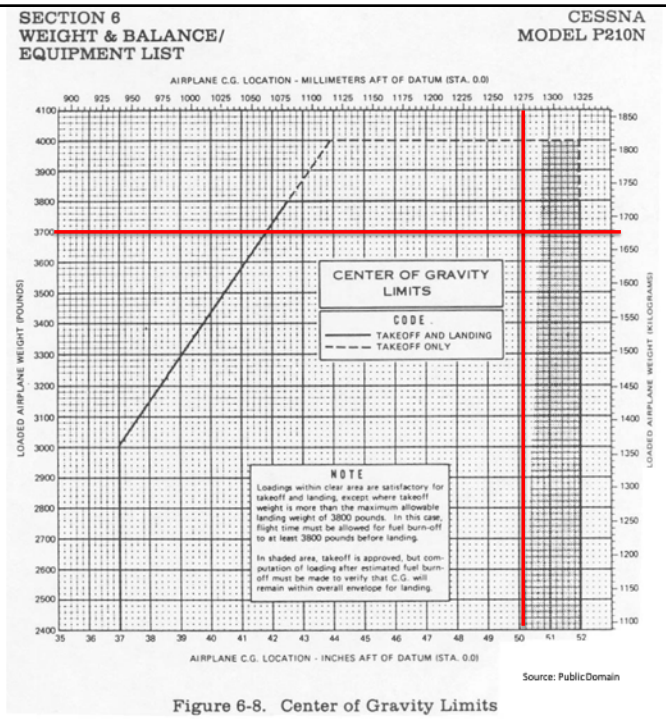

Figure 6-8. Center of Gravity Limits

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