YORKSHIRE
HELICOPTERS

Mass and Balance
Robinson R44

General Principles

Determining overall mass before you take off, as well as the position of the centre of gravity is extremely important.

Flying overweight would not only invalidate insurance but puts unnecessary strain on the aircraft structure and components such as the main rotor blades.

It may not be obvious even if you were to take off overweight, power available would not necessarily be a factor so you can't assume that just because you can take off the aircraft will be within safe limits.

Flying out of Centre of Gravity (more commonly with the C of G too far forward) can limit cyclic movement. For example, if the C of G was located too far forward, the nose of the helicopter would be lower and the cyclic must be held further aft than usual to hold a steady hover. If you were to turn downwind the cyclic must come even further back to stop any forward drift. In the event of an emergency (such as needing to flare the helicopter for an engine-off landing) the cyclic may reach the pilot's torso or rear stop before effectively slowing the aircraft down.

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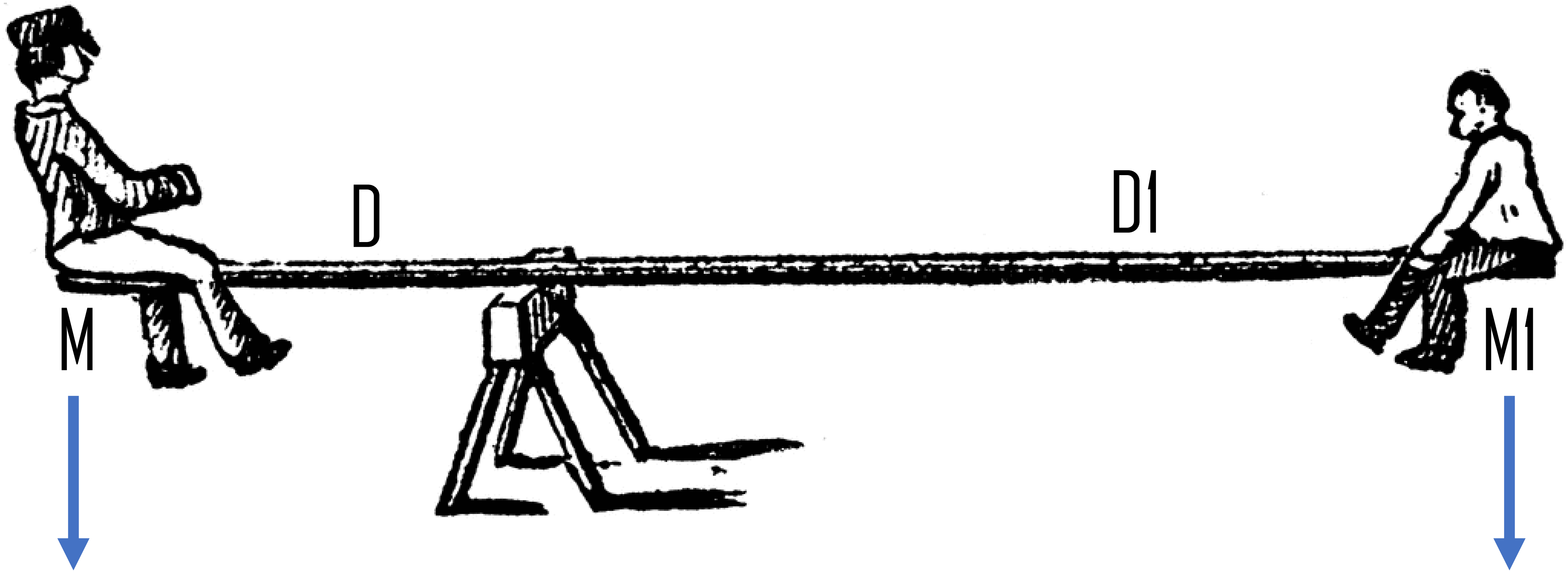
Prior to flight we calculate the mass of passengers, cargo, fuel, and anything else going into the aircraft to check it does not exceed the Maximum Take-off Mass.

In order to calculate the Centre of Gravity, we need to calculate the 'moments' for each item – this could be thought of as not just the mass but the 'effect of the mass' in that particular location. The principles of moments are used if you think about balancing out a seesaw……

The Moment = Mass x Distance (perpendicular from the turning point)

Clearly the man on the left is bigger, but the man on the right is further from the turning point and therefore produces an equal moment.

You can see that not just a mass, but the location of that mass can be important – the same applies to calculating centre of gravity of an aircraft. Thankfully, distances are generally fixed, like the pilot's seat and fuel location, so our job is to make sure we arrange the aircraft in the most sensible way and carry out a mass and balance calculation to check that the flight will be conducted legally and safely.



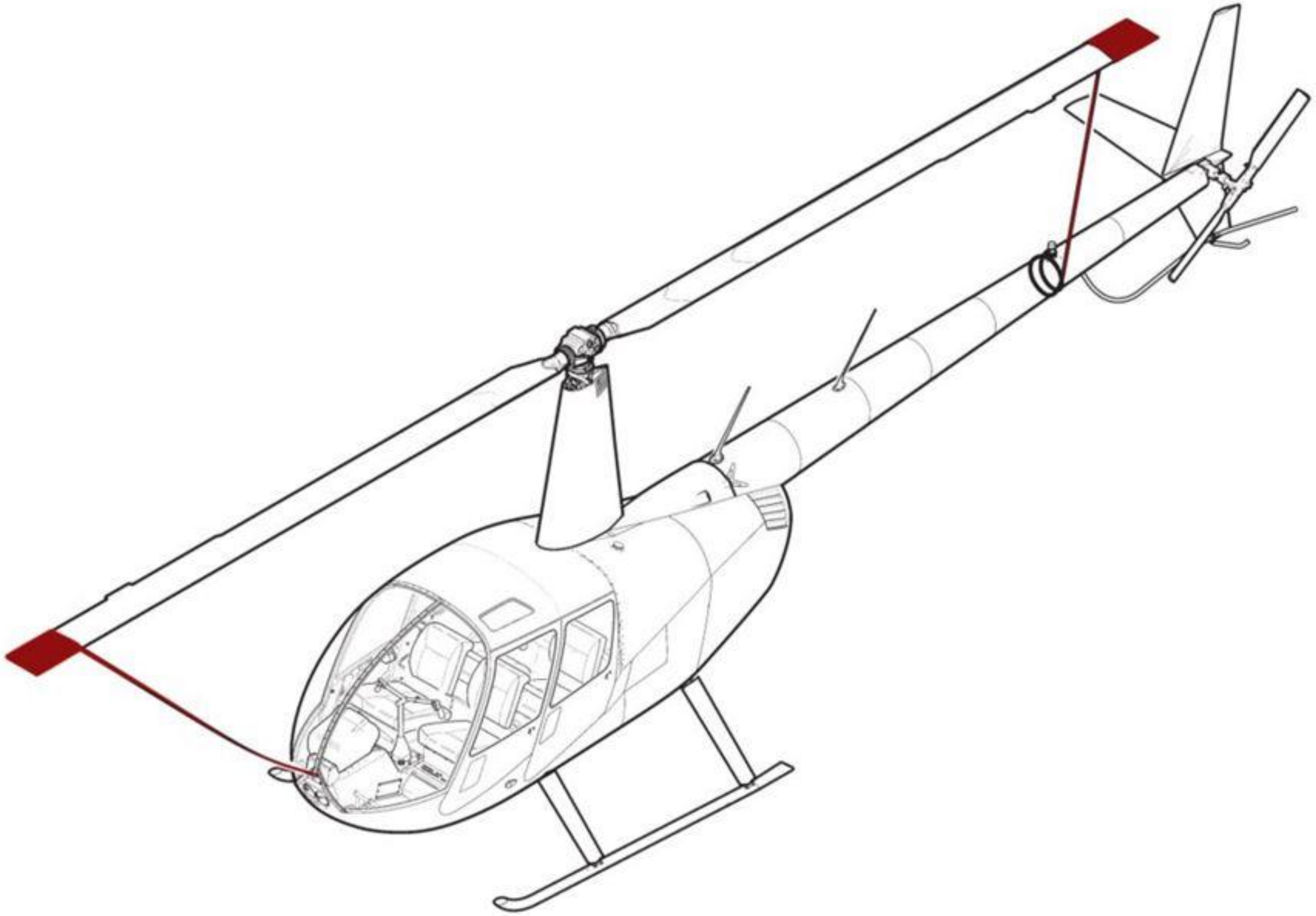
Once we have a full list of the masses (which include pilot, passengers, and cargo) that are going into the aircraft, we can calculate the moments using the fixed distances (sometimes called arms) which are often measured from the front of the aircraft. We then add up the total moment and divide it by the total mass to get the overall centre of gravity position. We then use the fore and aft limits to check where our C of G is in relation to these. This is often made easier by plotting into a graph.

We do this for our planned take-off fuel and for 'zero fuel' to check that as we burn fuel during the flight the centre of gravity remains within limits.

$$\textbf{Centre of Gravity} = \frac{\textbf{Total Moment}}{\textbf{Total Mass}}$$

Longitudinal vs Lateral Calculations

Longitudinal C of G is where the C of G sits down the longitudinal (fore & aft) axis. Lateral C of G is where the Centre of Gravity sits on the lateral axis, i.e., Left (-) and Right (+).
The helicopter is less likely to exceed its lateral limitations and often only a longitudinal calculation is required.



Check your understanding using this example question.

ITEM	MASS (lbs)	ARM (in)	MOMENT (lbs/in)
AIRCRAFT BEM	1250	75	
PILOT	170	59	
FREIGHT	150	75	
FUEL	200	80	

The Maximum Certified Weight is 1790 lbs.
The aft C of G limit is 73.5 inches.
What would be the longitudinal C of G position in relation to the aft C of G limit?

Check your understanding using this example question.

ITEM	MASS (lbs)	ARM (in)	MOMENT (lbs/in)
AIRCRAFT BEM	1250	75	93750
PILOT	170	59	10030
FREIGHT	150	75	11250
FUEL	200	80	16000
	1770		131030

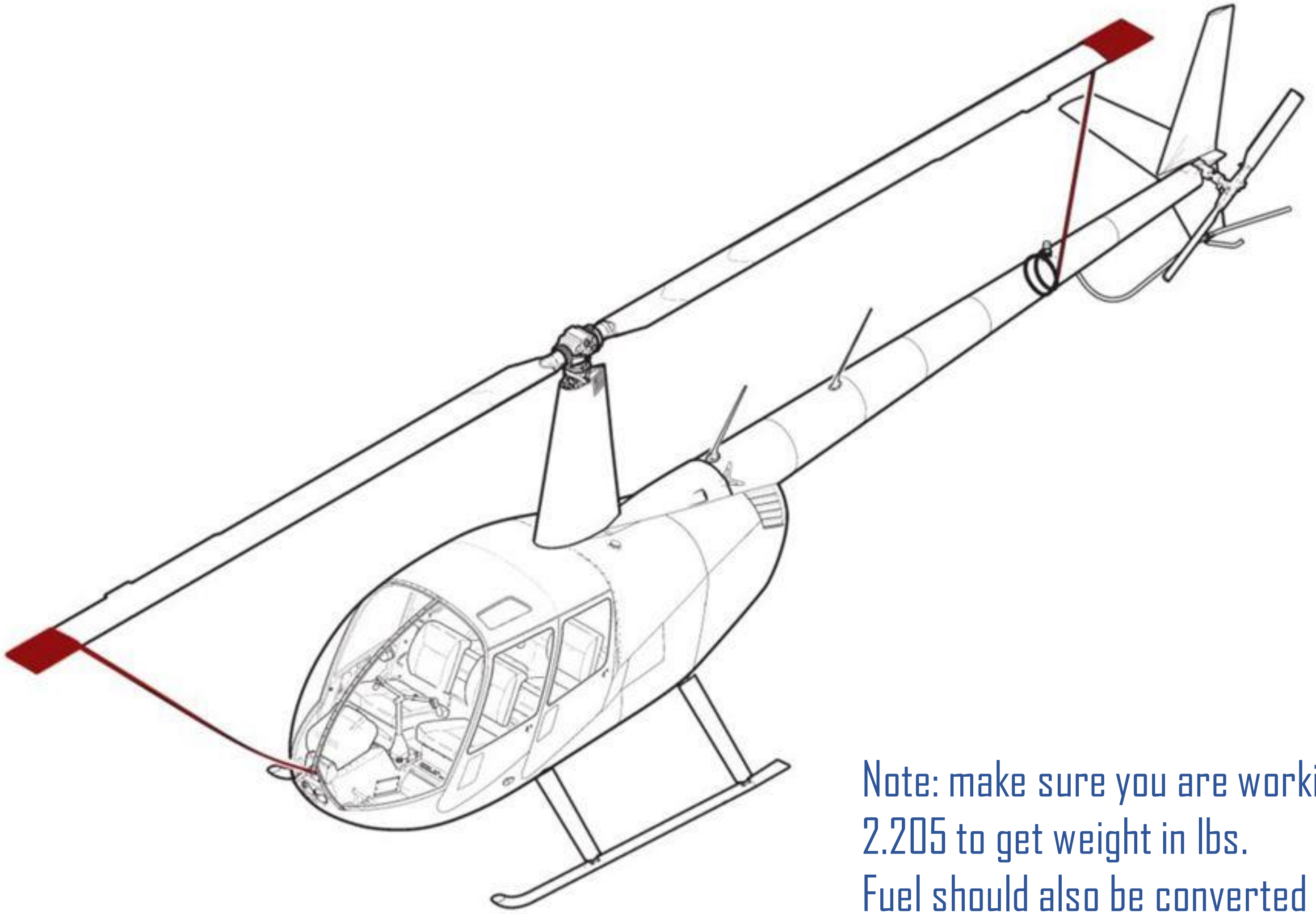
The Maximum Certified Weight is 1790 lbs.
The aft C of G limit is 73.5 inches.
What would be the longitudinal C of G position in relation to the aft C of G limit?

Total Mass is simply all the items' weights added together

Mass x Arm = Moments
We then add them all up to get the total moment

Using Total Moment divided by Total Mass we get the C of G which in this case is 74.028. In relation to the aft C of G limit, this is 0.528 further back and so in this case is out of limits with the current loading.

Mass and Balance for the Robinson R44



The maximum take-off-weight for the Raven 1 is 2400 lbs while the Raven 2 is 2500 lbs

The maximum weight per seat location (including baggage under the seat) is 300 lbs.

Maximum in each of the baggage compartments is 50 lbs.

It is wise to add 10 lbs to each of your passengers if they have only given you a verbal statement of weight.

Note: make sure you are working in pounds. Multiply stones by 14 or kilograms by 2.205 to get weight in lbs.

Fuel should also be converted to pounds using 1 USG = 6 lbs.

Definitions From the R44 POH

WEIGHT AND BALANCE DEFINITIONS

Reference Datum	A vertical plane from which horizontal distances are measured for balance purposes. The longitudinal reference datum is 100 inches forward of the main rotor shaft centerline for the R44.
Station	Fore-and-aft location along the helicopter fuselage given in terms of distance in inches from the longitudinal reference datum.
Arm	Horizontal distance from a reference datum to the center of gravity (CG) of an item.
Moment	The weight of an item multiplied by its arm.
Center of Gravity (CG)	Location on the fuselage (usually expressed in inches from the reference datum) at which the helicopter would balance. CG is calculated by dividing the total helicopter moment by total helicopter weight.
CG Limits	Extreme CG locations within which the helicopter must be operated at a given weight.
Usable Fuel	Fuel available for flight planning.
Unusable Fuel	Fuel remaining in the tank that cannot reliably provide uninterrupted fuel flow in the critical flight attitude.
Standard Empty Weight	Weight of a standard helicopter including unusable fuel, full operating fluids, and full engine oil.
Basic Empty Weight	Standard empty weight plus weight of installed optional equipment.
Payload	Weight of occupants, cargo, and baggage.
Useful Load	Difference between maximum gross weight and basic empty weight.

Item	Weight (lb)	Location		Moment	
		Long. Arm (in.)	Lat. Arm (in.) + = Right Side	Long. (in.-lb)	Lat. (in.-lb)
Basic empty weight					
Remove forward right door		49.4	24.0		
Remove forward left door		49.4	−24.0		
Remove aft right door		75.4	23.0		
Remove aft left door		75.4	−23.0		
Remove cyclic		35.8	−8.0		
Remove collective		47.0	−21.0		
Remove pedals (both)		16.8	−9.5		
Pilot (forward right seat)		49.5	12.2		
Left forward passenger		49.5	−10.4		
Aft right passenger		79.5	12.2		
Aft left passenger		79.5	−12.2		
Baggage under forward right seat		44.0	11.5		
Baggage under forward left seat		44.0	−11.5		
Baggage under aft right seat		79.5	12.2		
Baggage under aft left seat		79.5	−12.2		
Zero usable fuel weight and CG*					
Usable main fuel at 6 lb/gal.		106.0**	−13.5		
Usable aux fuel at 6 lb/gal.		102.0**	13.0		
Takeoff Gross Weight and CG*					

The weight and balance section of the POH contains a blank worksheet. It looks complicated at first but lots of the items can be missed, say if there is no baggage and you aren't likely to remove any of the doors.
You just need your specific R44 basic empty weight and its associated arm (found in the aircraft documents folder) to be able to begin.

* CG location (arm) for loaded helicopter is determined by dividing total moment by total weight.

** A longitudinal arm of 104.5 in. may be used for combined main and aux fuel. Do not use combined main and aux fuel if calculating lateral arm.

Let's go with 24 USG in the main tank and 16 USG in the auxiliary tank

Item	Weight (lb)	Location		Moment	
		Long. Arm (in.)	Lat. Arm (in.) + = Right Side	Long. (in.-lb)	Lat. (in.-lb)
Basic empty weight	1479	105	- 0.12	155295	- 177.48
Pilot (forward right seat)	180	49.5	12.2	8910	2196
Left forward passenger	196	49.5	−10.4	9702	- 2038.4
Aft right passenger	174	79.5	12.2	13833	2122.8
Aft left passenger		~~79.5~~	~~−12.2~~		
Zero usable fuel weight and CG*	**2029**	**92.5**	**1.04**	187740	2102.92
Usable main fuel at 6 lb/gal.	144	106.0**	−13.5	15264	- 1944
Usable aux fuel at 6 lb/gal.	96	102.0**	13.0	9792	1248
Takeoff Gross Weight and CG*	**2269**	**93.8**	**0.62**	212796	1406

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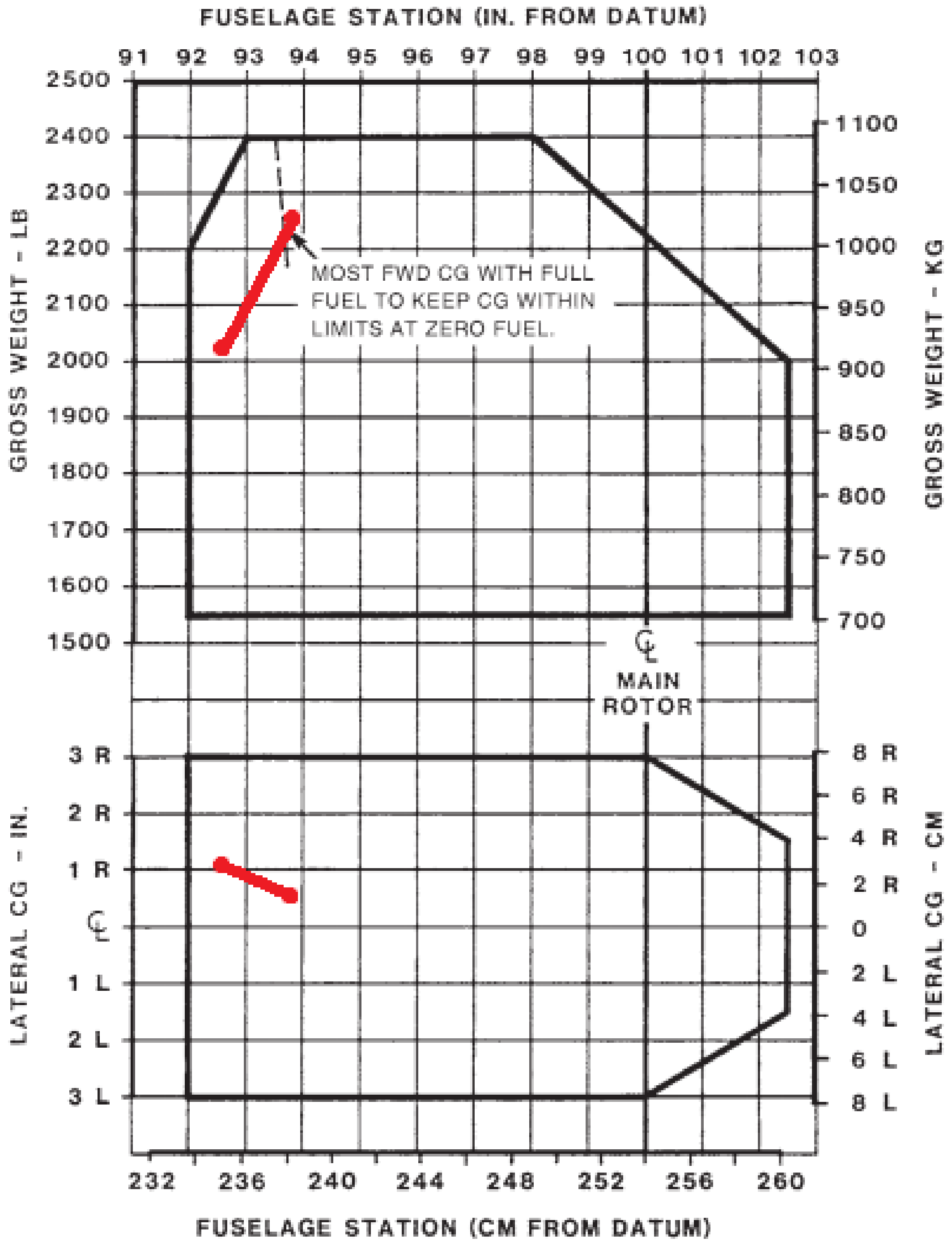
To get all our red numbers which we will plot into the graph, we have calculated the moments (both longitudinally and laterally for each item, before adding them up and dividing by the total mass, first with no fuel, then with the addition of fuel. That way we can see what happens as the fuel burns in flight
The graph is found in the 'limitations' section of the POH since it outlines the C of G limits..



The top graph is for the longitudinal C of G against weight while the bottom shows lateral C of G.
First the zero-fuel weight of 2029 lbs is plotted against 92.5 inches on the top graph. The lateral C of G is then marked directly underneath on the lower graph at a value of 1.04 inches. Because it is a positive number it is marked on the R (right) side.

We then plot our take-off weight of 2269 lbs against 93.8 inches, again on a line straight down from this position we mark on the lateral C of G of 0.62 (R).
The line represents what happens as we burn fuel; on the top graph the total weight reduces, and the C of G moves further forward. On the bottom graph the lateral C of G moves further out to the right.