GAP
Good Aviation Practice

Weight and balance

CIVIL AVIATION AUTHORITY
OF NEW ZEALAND
Te Mana Rererangi Tūmatanui o Aotearoa

Contents

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See the CAA website for civil aviation rules, advisory circulars, airworthiness directives, forms, and more safety publications. Visit aviation.govt.nz.

Every effort is made to ensure the information in this booklet is accurate and up-to-date at the time of publishing, but numerous changes can occur with time, especially in regard to airspace and legislation. Readers are reminded to obtain appropriate up-to-date information.

Different types of aircraft have varying considerations for working out accurate weight and balance safety limits.

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Definitions

Centre of gravity (C of G)

This is the point about which an aircraft would balance if suspended. Mathematically, it can be described as the pivotal point about which the nose-heavy and tail-heavy moments are of equal magnitude.

C of G limits

These are the forward and aft points within which the C of G must fall if the aircraft is to operate normally and safely. These points are specified in the *limitations* section of the aircraft flight manual.

Datum

An imaginary vertical line, specified by the designer, from which all horizontal C of G measurements are made. In most cases, the datum is located in the vicinity of the aircraft nose, usually the firewall.

Arm

This is the horizontal distance from the datum to the C of G of the aircraft or to any item in it. A plus sign indicates measurement aft of the datum, a minus sign measurement forward of the datum. These values are found in the aircraft flight manual and may be expressed in inches, centimetres, or metres.

Moment

The weight of an item multiplied by the arm of its position.

Empty weight

The weight of an aircraft, including airframe, powerplant(s), all fixed equipment, full oil tank(s), and unusable fuel. The empty weight figure is found in the CAA2173 form, located in the aircraft flight manual, and can be expressed in pounds or kilograms. On the back of the form is listed all the equipment fitted at the time the aircraft was weighed.

Maximum all up weight (MAUW)

The maximum weight allowable for the aircraft. This value is given in the aircraft flight manual *limitations* section. Note that some aircraft have a higher permitted weight for take-off than they do for landing.

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Weight and balance

Carefully balancing the load in your aircraft is the key to keeping your centre of gravity (C of G) within a safe range.

If the C of G isn't within a safe range, you may experience dangerous safety issues such as the nose of your aircraft pitching up involuntarily, or over-rotation on take-off.

This booklet provides good practice advice on how to correctly load your aircraft, to make sure you are safe to fly.

Weight

Manufacturers conduct extensive flight tests to establish loading limits for their aircraft, because they're critical for safe flight. It's important you adhere to these limits when loading your aircraft.

Aircraft are designed to take a certain amount of G-load. Increasing the weight of the aircraft beyond the certificated limit reduces its capability to withstand G-load during both turbulence and manoeuvring. This could result in structural failure, in a worst case scenario.

An incorrectly loaded, or overloaded, aircraft may have a:

- higher take-off speed
- longer take-off ground run
- reduced rate of climb
- reduced angle of climb
- lower ceiling
- shorter range
- reduced cruise speed
- increased stall speed
- higher landing speed
- longer landing roll.

The effects above show how the total performance of the aircraft is affected.

Weight and balance are even more important for aerobatic aircraft.

Balance

It's not only the overloading of your aircraft that matters, but also the distribution of the weight. Your aircraft has C of G limits, and any loading that puts the C of G outside those limits will seriously impair your ability to control the aircraft.

The more aft the C of G, the more unstable the aircraft. Forward pressure on the elevator control and full nose-down trim may be necessary to keep the aircraft from pitching up and stalling.

The need for increased forward pressure on the elevator control, and a tendency for the aircraft to take off in a dangerously nose-high attitude, are symptoms of an aft C of G. It's often characterised by light rearward elevator control forces, making the aircraft susceptible to inadvertent overstressing by the pilot.

The further aft the C of G is, the harder it is to recover from a stall. Conversely, a forward C of G needs backward pressure on the elevator control and nose-up trim.

In addition to being very tiring, a forward C of G makes it difficult to rotate for take-off and flare for landing – assuming there was enough elevator control available to become airborne in the first place. Incorrect loading can cause the aircraft to be outside the C of G limits – even when it's within its gross weight limit.

This condition can also be brought about during flight as fuel is burnt off. The aircraft might have been within limits on take-off, but as fuel was used, the C of G moved out of limits.

The rear (or forward) limit is not valid at anything over maximum weight. This means that if you load the aeroplane over its MAUW, the C of G limits are totally invalid.

Aerobatic aircraft

Both weight and balance are even more important for aircraft engaged in manoeuvring flight, such as aerobatics or spinning. Weights above maximum aerobatic weight are likely to overstress the aircraft.

Operations outside the C of G limits can lead to loss of control. This is particularly acute for spinning. There have been fatal accidents in New Zealand caused when aircraft failed to recover from spins entered while the aircraft was outside the C of G limits.

The limits for aerobatic flight are often more restrictive than those for normal operations in the same aircraft. A number of aircraft commonly used for aerobatic and spin training can not be flown for this purpose at regular weights. In particular, when flown dual, the fuel weight that can be safely carried is often very restricted. Always check the weight and C of G limits for aircraft engaged in aerobatic flight.

Photo courtesy of Croydon Aircraft Company and Gavin Conroy

Weight and balance calculation

As pilot in command, it's your responsibility under rule 91.201 *Safety of aircraft*, to ensure before flight, that the aircraft is under or equal to maximum all up weight (MAUW). You must also ensure the C of G is within limits for the take-off and landing, and will remain so during the whole flight.

When calculating the weight and balance for an aircraft, the first place you should look is in the aircraft flight manual.

This has all the weights and measurements you'll need to start your calculations.

Below is an example weight and balance calculation for a typical four-seat light aircraft.

Typical weight and balance calculation

Item	Weight	Arm	Moment
Units	**(kg) x**	**(mm) =**	**(kg/mm)**
Empty weight of aircraft	670	2215	1484050
Fuel (79 litres x 0.72)	57	2413	137541
Front seat occupants	148	2045	302660
Rear seat occupants	145	3000	435000
Baggage compartment (max 90kg)	35	3627	126945
Total weight and moment	1055		2486196
C of G position		2357	
Limits	MAUW 1055kg	C of G 2210 to 2360mm aft of datum	

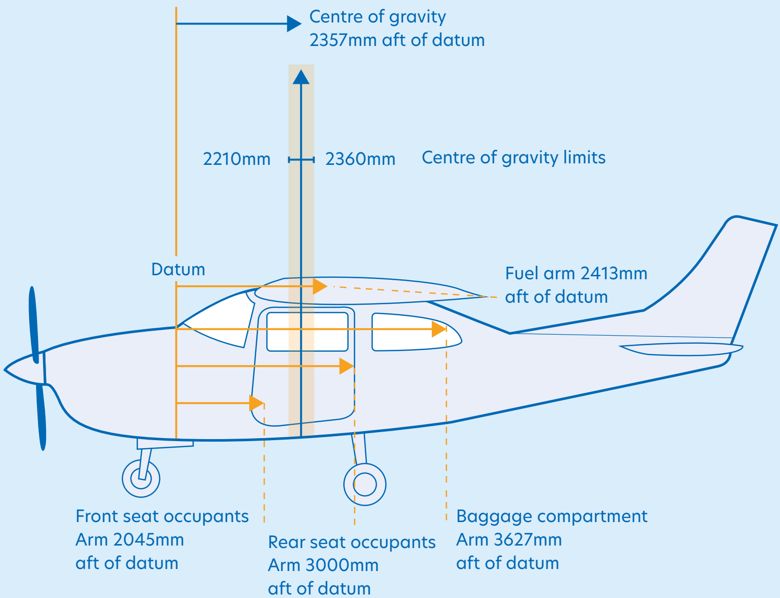
There's a sample weight and balance form on page 15 for you to copy if required.

The steps are as follows:

1. Insert weight, arm, and moment measurements for the aircraft empty weight in the appropriate columns.
2. Insert the arm measurements for fuel, front-seat occupants, rear-seat occupants, and baggage compartment.
3. Now fill in the weight column gaps:
    - Avgas weight in kilograms can be found by multiplying litres by 0.72 (for other units see the Avgas conversion factors on page 13).
    - The only way to be sure of what passengers weigh is to put them on the scales.
4. Total the weight column. If it's greater than the MAUW, then you'll need to leave something behind. Remove it from the aircraft, adjust the appropriate figure, and re-total the weight column.
5. Now multiply each weight by each arm, and insert the answer in the moment column.
6. Total the moment column.
7. Divide the total moment by the total weight, and that's your C of G position. Check that it's within limits. If not, you'll need to redistribute your load.

There are other ways of working out the weight and balance, such as graphs that are provided in the aircraft flight manual. They're good as a reference, but not as accurate as a weight and balance calculation like that shown.

Centre of gravity



This illustrates the weight and balance calculation used in the example (left).

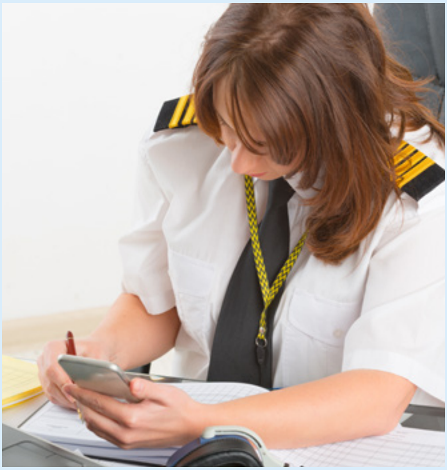
Multi-engine example

For multi-engine aircraft, and some single-engine aircraft, use the example below to work out whether your aircraft is at the right weight throughout the flight.

1. Take the empty weight of the aircraft and add the weight of occupants and baggage to be carried. This gives the zero fuel weight (ZFW) of the aircraft. Check this doesn't exceed the maximum zero fuel weight given in the aircraft flight manual.
2. Add the fuel carried to the ZFW to give the ramp weight.
3. Subtract the run-up and taxi fuel from the ramp weight to give the take-off weight. Check this doesn't exceed the maximum take-off weight.
4. Subtract the in flight fuel burn to give the landing weight. Check this doesn't exceed the maximum landing weight.

In many cases, the zero fuel weight is the limiting factor when loading multi-engine aircraft.

To calculate the C of G for multi-engine aircraft, follow the steps in the previous example.



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Ensure your calculations are appropriate for the type of aircraft you're flying.

Typical weight calculation for multi-engine aircraft

Item		Weight	Limitations
Empty weight of aircraft		1418kg	
+	Occupants	492kg	
+	Baggage	80kg	
=	**Zero fuel weight**	**1990kg**	**Max zero fuel weight = 2000kg**
+	Fuel carried	381kg	
=	**Ramp weight**	**2371kg**	
-	Run-up and taxi fuel	10kg	
=	**Take-off weight**	**2361kg**	**Max take-off weight = 2361kg**
-	Fuel burn	250kg	
=	**Landing weight**	**2111kg**	**Max landing weight = 2245kg**

Electronic flight bag (EFB) applications

Many EFB applications include a built-in weight and balance feature. You must ensure that the weight of the aircraft is properly distributed. The EFB can provide a convenient way to input and calculate the necessary data.

It's crucial that the data entered into these applications aligns with the information provided in the CAA2173 form, and the aircraft flight manual. Proper configuration of the application's basic aircraft parameters is essential for accurate weight and balance calculations.

Be aware of different weighing units on the CAA2173 form. For example, modern aircraft are now weighed in kilograms, whereas previously they were weighed in pounds.

Photo: CAA

Centre of gravity (C of G)

The EFB should allow you to calculate the C of G of the loaded aircraft. Ensure that the C of G falls within the approved range specified by the aircraft manufacturer or operator.

Payload restrictions

Some aircraft have limitations on the amount of weight they can carry, especially in terms of maximum take-off weight, maximum landing weight, or zero fuel weight. The EFB should have access to the aircraft's weight and balance limits. You must consider these restrictions when loading the aircraft.

Fuel planning

Fuel burn during the flight affects the aircraft's weight and balance. The EFB should provide tools to estimate fuel consumption based on expected flight conditions. You must ensure that the aircraft remains within its weight and balance limits considering fuel burn.

Equipment configuration

The EFB needs to account for the specific equipment installed on the aircraft. Different configurations may have weight differences that affect the weight and balance calculations. Pilots must select the correct equipment configuration parameters within the EFB, for example, with seats removed.

Updates and validation

You should regularly update the EFB's weight and balance database to have the most current information.

Packing luggage into small, soft bags can make it easier to adjust the balance in small aircraft.

Photo courtesy of Bay of Islands Aero Club

Here is an example photo of a completed EFB weight and balance profile.

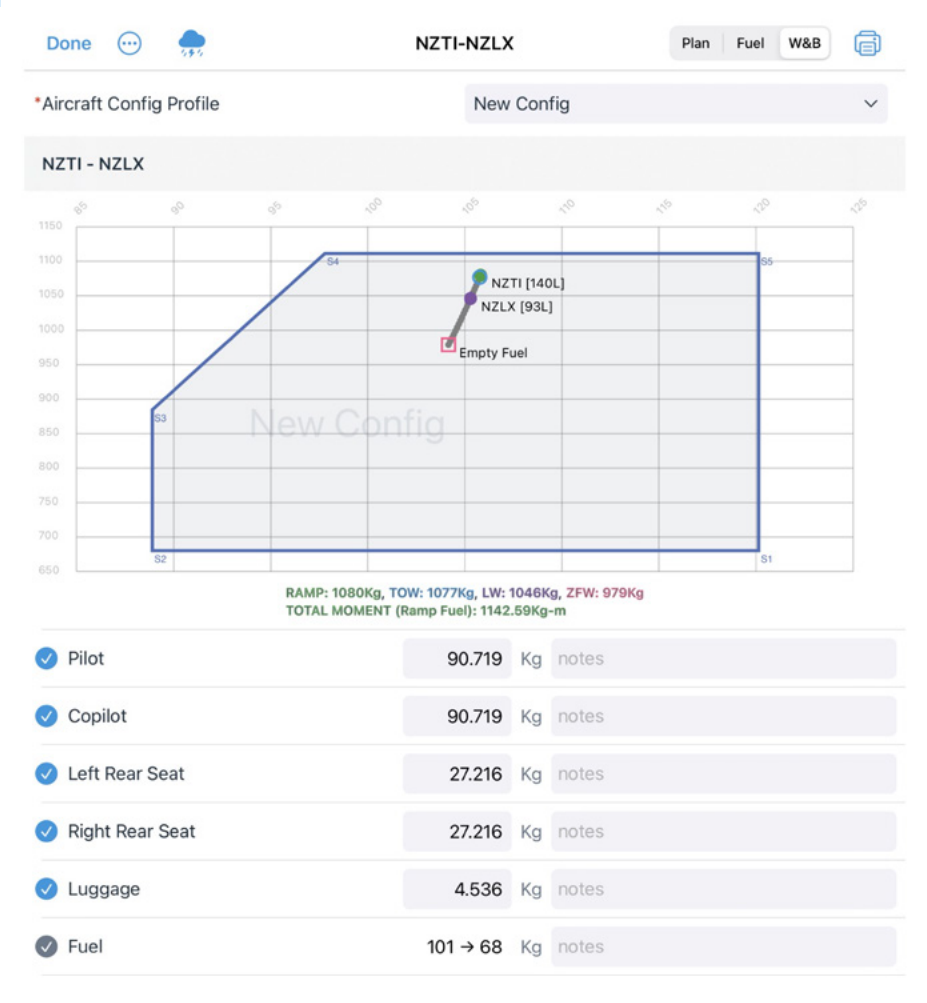


Photo courtesy of Otago Aero Club

Redistribution

After completing your calculations, you may find the C of G is outside the aft or forward limit. In this case, you need to redistribute your load.

You can try moving some of the heavier items and then reworking the calculations. If that doesn't work, you can use the following formula:

$$\text{Distance weight shifted} = \frac{\text{Total weight x change of C of G}}{\text{Weight shifted}}$$

For example, say you've calculated the total weight to be 1055kg, but you find the C of G needs to be moved forward 20mm. You can move 25kg of baggage items forward, and the distance this needs to be shifted is:

$$\text{Distance weight shifted} = \frac{1055 \text{ x } 20}{25}$$
$$= \textbf{844mm}$$

Alternatively, if you already know the distance that items can be moved, and you want to know how much weight to shift that distance, use this version of the formula:

$$\text{Weight shifted} = \frac{\text{Total weight x change of C of G}}{\text{Distance weight shifted}}$$

Using the previous example, but finding you're limited to shifting some baggage 700mm forward, the weight of baggage you need to shift is:

$$\text{Weight shifted} = \frac{1055 \text{ x } 20}{700}$$
$$= \textbf{30.1kg}$$

Remember to secure your load.

Photo: CAA

What units?

Because many aircraft in New Zealand are built in the United States, weight and balance data is often in pounds and inches.

As we are more familiar with kilograms in New Zealand, one solution is to convert and annotate the arm figures with metres (or millimetres) in the aircraft flight manual *weight and balance* section.

This is permissible because this section is not part of the approved aircraft flight manual, but an even better solution would be to produce a customised weight and balance form. Either way, the C of G limits can be copied from the *limitations* section and similarly converted, and shown in metres.

This one-off process is easier – and less prone to error – than having to continually convert passenger, baggage, and fuel weights to pounds.

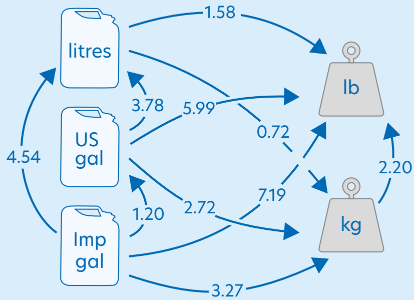
An even simpler alternative is to use kilograms for weight, but continue with inches for the arm. The resultant moment will be in kilogram/inches. It's fine to mix units here, because when the total is divided by the total weight, the resulting figure for the C of G is in inches, and this can readily be checked against the aircraft flight manual *limitations* figures.

Whichever method you use, make sure you know what units are being used, that they are the same units throughout, and that conversion factors are accurately calculated.

AVGAS

For Avgas calculations (SG 0.72):

- follow the arrow and multiply
- backtrack the arrow and divide.



Conclusion

The average general aviation aircraft is not designed to be loaded with full fuel, maximum passengers, and a full baggage compartment, and still be expected to fly safely.

Flying within the correct limits of weight and balance for the aircraft is vital for the safety of you and your passengers.

Accurate Avgas calculations are essential for a safe flight.

Sample weight and balance form

Item	Weight	Arm	Moment
Units	**( ) x**	**( ) =**	**( )**
Empty weight of aircraft			
Fuel			
Front seat occupants			
Rear seat occupants			
Baggage compartment			
Total weight and moment			
C of G position			
Limits	MAUW	C of G range	

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aviation.govt.nz

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