SAFETYSENSE LEAFLET 9
WEIGHT AND BALANCE

photo- John Thorpe

1 INTRODUCTION

a) The principles of weight and balance should have been understood by all pilots during their initial training. It is clear that, afterwards, some forget, don't bother or are caught in 'traps' There have been several fatal accidents to UK-registered general aviation aircraft in which overloading, or out-of-limits centre of gravity (cg), were contributory factors.

b) An **overloaded** aircraft may fail to become airborne, while **out-of-limits** centre of gravity seriously affects the stability and controllability. Pilots **must** appreciate the effects of weight and balance on the performance and handling of aircraft, ***particularly*** in combination with performance reducing factors, such as long or wet grass, a 'tired' engine(s), severe or un-coordinated manoeuvres, turbulence, high ambient temperatures and emergency situations (see also Safety Sense Leaflet No 7 – *Aeroplane Performance*).

c) This Leaflet is intended to remind pilots of the main points of weight and balance.

2 THE LAW AND INSURANCE

a) Article 86 of Air Navigation Order 2009 requires the commander of any aircraft registered in the United Kingdom to satisfy himself before the aircraft takes off that the load carried is of such weight, and is so distributed and secured, that it may safely be carried on the intended flight. The CAA has successfully prosecuted pilots who have failed to comply with this Article.

b) In addition ANO 2009 Article 16 requires that all aircraft have a valid Certificate of Airworthiness or Permit to Fly. These documents, either directly, or by reference to a Flight Manual/Pilot's Operating Handbook, specify the weight and centre of gravity limits within which the aircraft must be operated. If these limitations are not observed, the pilot is failing to comply with a legal condition for the operation of his aircraft, thus insurers could reject any claim in the event of a mishap.

3 WEIGHT

a) The effects of overloading include:

- reduced acceleration and increased take-off speed, requiring a longer take-off run and distance to clear a 50 ft obstacle;
- decreased angle of climb reducing obstacle clearance capability after take-off;
- higher take-off speeds imposing excessive loads on the landing gear, especially if the runway is rough;
- reduced ceiling and rate of climb;
- reduced range;
- impaired manoeuvrability;
- impaired controllability;
- increased stall speeds;
- increased landing speeds, requiring a longer runway;
- reduced braking effectiveness;
- reduced structural strength margins; and
- on twin-engined aircraft, failure to climb or maintain height on one engine.

Photo – John Thorpe

b) It **must** be realised that, with many four and six seat aircraft, it is **not** possible to fill all the seats, use the maximum baggage allowance, fill all the fuel tanks **and** remain within the approved weight and centre of gravity limits. You may have to reduce the number of passengers, baggage, or fuel load or possibly a combination of all three. Better that a passenger travels by bus or by train than in an ambulance!

c) The aircraft weight used in the example calculation in the Flight Manual/Pilot's Operating Handbook is for a **new** aircraft usually with little or no equipment. The weight and/or other data used in the example **MUST NOT** be used as the basis for operational weight and balance calculations. Whenever significant equipment is added a new empty weight and cg position must be provided for the Weight and Balance Schedule. This is the **only** valid

source of data. You **must** use this actual equipped weight and be sure whether this includes such items as engine oil, fire extinguisher, first aid kit, life jackets, etc. The actual weight of a well-equipped single-engined aircraft can be as much as 170 lb (77 kg) greater than a basic aircraft – the invisible passenger! Periodic re-weighing of an aircraft is sensible – many owners have been surprised by the increase.

d) Estimating the weight of baggage can result in variations from half to double the correct weight. If there is a remote possibility of being close to the maximum take-off weight, you **must** weigh the baggage. (Pocket-sized spring balances can be obtained from fishing/hardware shops and are a handy standby if 'scales' are not available.) Note that, on some aircraft, if the maximum baggage allowance is used, restrictions are placed on rear seat occupancy. When carrying freight, check for any gross errors in the declared weight. There may also be a weight per unit area limitation on the baggage compartment floor. Make sure the baggage/freight is properly stowed and secured so that it cannot move and does not obstruct exits or emergency equipment.

e) Beware of items such as flammable substances, acids, mercury, magnetic materials, etc. which are classified as Dangerous Goods with special controls that apply even in general aviation aircraft. Further assistance is available from Dangerous Goods Office, phone (01293) 573800 fax (01293) 573991.

f) Again, if the aircraft is anywhere near maximum weight, the passengers **must** be weighed or asked for their weight (even if it means embarrassing your spouse or friends). The risk of embarrassment is a better option than the effect of the aircraft being overweight. Remember, passengers' weight when flying is NOT their stripped weight. Allow for clothes, shoes, wallets and handbags! Check your own weight as equipped for flying and compare it with the weight you admit to.

g) Fuel gauges are often inaccurate and estimates of the weight of part-filled fuel tanks should err on the high side for weight (but **NOT** endurance) purposes. Be careful of mixed units such as litres/pounds/ kilograms/Imp gallons/US gallons.

h) If a long range or extra tank(s) has been fitted, the extra fuel could add a lot to the weight. Check that the contents marked at the filler cap(s) are the same as in the Pilot's Handbook/Flight Manual or Supplement and are **the ones you used for your calculations**.

i) See paragraph 4(g) on weight restrictions of Normal and Utility category.

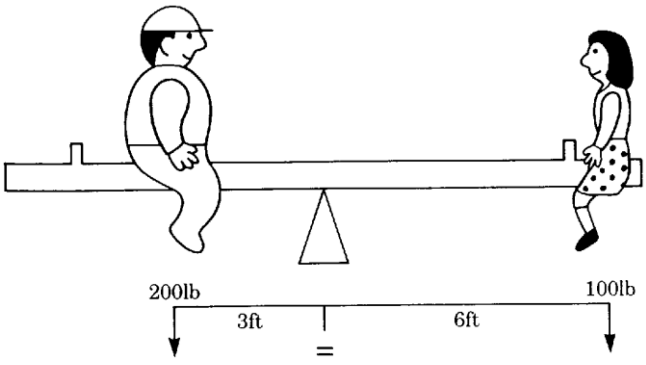
Note:

1 kg = 2.205 lb	1 lb = 0.454 kg
1 inch = 2.54 cm	1 cm = 0.394 inches
1 ft = 0.305 metre	1 m = 3.28 ft
1 Imp gall = 4.546 litres	1 litre = 0.22 Imp gall
1 US gall = 3.785 litres	1 litre = 0.264 USG
1 Imp gall = 1.205 USG	1 USG = 0.83 Imp gall

4 BALANCE (CENTRE OF GRAVITY)

a) Balance refers to the location of the centre of gravity (cg) along the longitudinal axis of the aircraft. The cg is the point about which an aircraft would balance if it were possible to suspend it from that point. There are forward and aft limits established during certification flight testing; they are the extreme cg positions at which the longitudinal stability requirements can be met. Operation outside these limits means you would be flying in an area where the aircraft's handling has not been investigated, or is unsatisfactory. The limits for each aircraft are contained in the Pilot's Operating Handbook/Flight Manual, UK Supplement or Weight and cg Schedule referred to in paragraph 3(c). The aircraft **must not** be flown outside these limits.

b) The cg is measured from a datum reference, which varies from one aircraft type to another - check the Handbook/Flight Manual. The arm is the horizontal distance (defined by the manufacturer) from the reference datum to the item of weight. The moment is the product of the weight of an item multiplied by its arm. Remember the see-saw, where a small weight at a large distance can be balanced by a large weight at a small distance.



c) Exceeding the forward cg limit usually results in:

- difficulty in rotating to take-off attitude;
- increased stall or minimum flying speed against full up elevator;
- extra tail downforce requires more lift from wing resulting in greater induced drag. This means higher fuel consumption and reduced range;
- inadequate nose up trim in the landing configuration necessitating a pull force throughout the approach making it more difficult to fly a stable approach;

- difficulty in flaring and holding the nose wheel off after touchdown. Many modern aircraft have deliberately restricted elevator travel (for stall behaviour reasons). Inability to hold the nose up during a bounce on landing can result in damaged nose landing gear and propeller;
- increased loads on the nose landing gear.

d) Exceeding the aft cg limit usually results in:

- pitch up at low speed and high power, leading to premature rotation on take-off or to inadvertent stall in the climb or during a go-around;
- on a tail wheel type, difficulty in raising the tail and in maintaining directional control on the ground;
- difficulty in trimming, especially at high power;
- longitudinal instability, particularly in turbulence, with the possibility of a reversal of control forces;
- degraded stall qualities to an unknown degree; or

- more difficult spin recovery, unexplored spin behaviour, delayed or even inability to recover.

e) Relatively small, but very heavy, objects can make a big difference, e.g. a tool box or spare parts. Be careful where you stow them and make sure they cannot move.

f) On many aircraft the cg moves as fuel is used; on some aircraft types it could move the cg forward to beyond the forward limit when flying solo. On other types the cg moves rearward with fuel use, thus, on a loaded aircraft the cg could move to beyond the aft limit. Aft-mounted long range tanks have a large effect. Careful cg calculation prior to flight will reveal any likely problems.

g) The following cg terms may be used (mainly on aircraft certificated to US or EASA regulations):

Normal category – normal flying, no spinning or aerobatic manoeuvres, bank angle may be restricted to 60°.

Utility category – manoeuvres in which bank angles exceed 60°, spinning (if permitted). No aerobatics.

h) There may be cg or weight restrictions on certain manoeuvres (e.g. steep turns, spinning, aerobatics etc.) imposed by the Pilot's Operating Handbook, Flight Manual or UK Supplement (e.g. on the Socata Rallye, the rear seats must be removed to remain within the permitted cg range for spinning or aerobatics).

i) Very light (or heavy) pilots flying solo may need ballast or other measures, particularly in some homebuilt and tandem two seat aircraft.

j) Any ballast (permanent or temporary) **must** be securely fixed.

k) When parachute dropping remember the effect of the movement of parachutists prior to and immediately after dropping.

5 CALCULATION

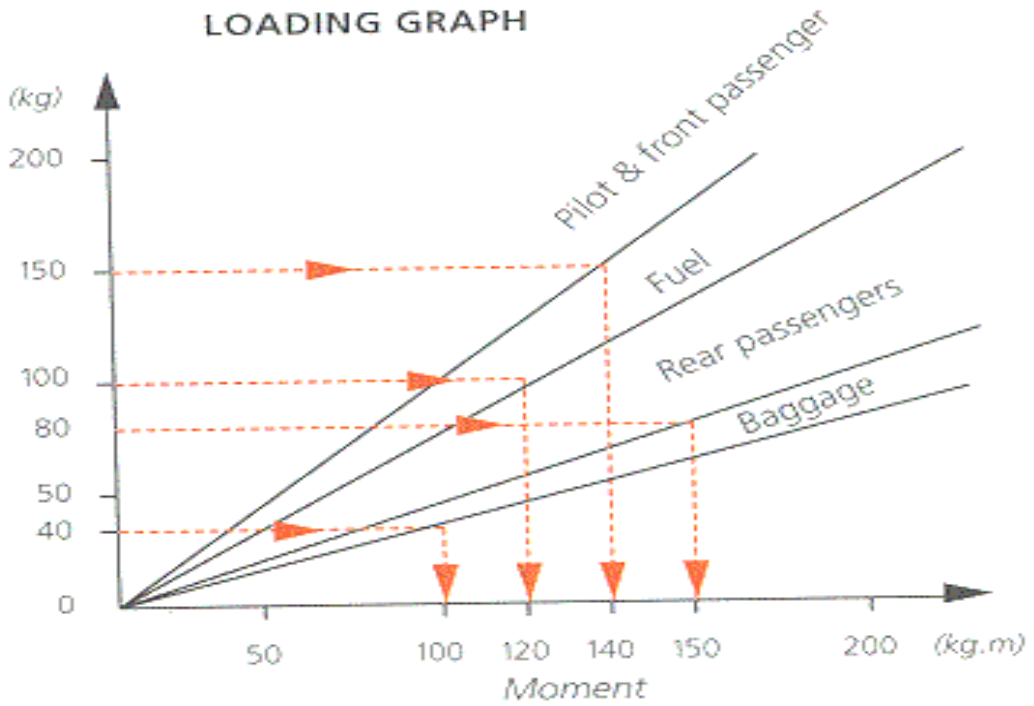
The Pilot's Operating Handbook or Flight Manual contains a Weight and Balance section, with a worked example. The Limitations Section contains the permitted weight and cg limits. (Check to see if there are any CAA Supplements which further restrict weight or cg range.) The presentation varies from aircraft to aircraft and may be diagrammatic, graphical or tabular. You must be familiar with the method for **your** aircraft. Examples follow:

1 SAMPLE LOADING CALCULATION

		Weight (kg)	Moment* (kg.m)
1	Empty weight (includes unusable fuel, full oil and other fluids) as well as extra equipment and navaids	662	663
2	Fuel 139 litres at 0.72 kg/litre (standard tanks)	100	120
3	Pilot and front passenger	150	140
4	Rear passenger	80	150
5	Baggage or child's seat (54 kg max)	40	100
TOTAL WEIGHT AND MOMENT		1032	1173

* *The moments are obtained by applying the known weights to the loading graph in item 2.*

2



4 WEIGHT LIMITATIONS

Normal category

Maximum weight for take-off	1043 kg
Maximum weight for landing	1043 kg
Maximum weight for baggage	
Or optional child seat	54 kg

Utility category

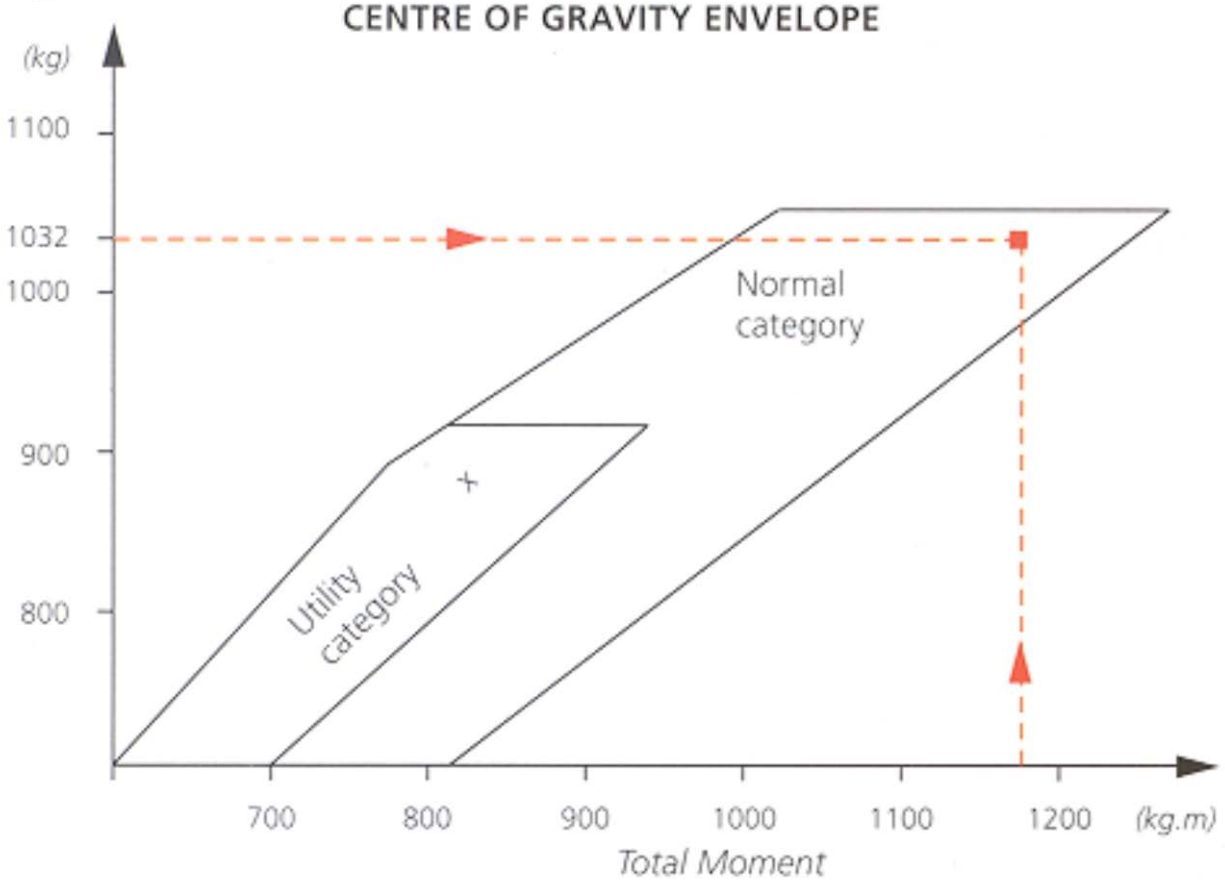
Maximum weight for take-off	907 kg
Maximum weight for landing	907 kg

FUEL CAPACITIES

2 Standard tanks of	81.5 litres	(21.5 US gallons)
Total fuel	163 litres	(43 US gallons)
Total usable fuel	152 litres	(40 US gallons)
Unusable fuel	11 litres	(3 US gallons)

3

CENTRE OF GRAVITY ENVELOPE



+Restricted envelope for aerobatics (if permitted), spinning and other manoeuvres which may include steep turns.

In this example it can be seen that the weight is below the maximum allowed and the cg is within limits.

6 SUMMARY

- Obtain **actual** (not 'typical') empty weight and cg of the **individual aircraft** you are operating from the latest Weight and Balance Schedule.
- Check that the aircraft maximum take-off weight is not exceeded. If it is, you **MUST** reduce the weight by off-loading passengers, baggage or fuel.
- Check that the cg is within limits before take-off and will remain within limits throughout the flight. If it does not stay within the approved range, you **MUST** make some changes to one or more of the following:

  - position of baggage or cargo;
  - allocation of seats according to passenger weight;
  - fuel load and tank position; and
  - planned type of flight.

- Before certain manoeuvres (e.g. spinning or aerobatics) check and if necessary act upon any weight or cg range restrictions.
- **DO NOT** forget the effect of weight changes on runway length requirements and safety factors given in Safety Sense Leaflet 7 – Aeroplane Performance.
- **NEVER** consider flying an aircraft which is outside the permitted weight and cg range.

Note: Weight is used throughout this leaflet but European Regulations may refer to Mass.