Basics of Sailplane Weight and Balance Theory

Introduction

The booklet "Basic Gliding Knowledge" has a small section on "Weight and Balance". Unfortunately this does not sufficiently cover either topic in enough detail to avoid pilots making serious mistakes. This document adds sufficient information to give new pilots a better appreciation of weight and balance issues, thereby elevating their safety awareness, but does not pretend to be sufficiently rigorous to allow pilots to do their own aircraft weighing and placard creation, for which a special endorsement is required.

The structural strength of an aircraft clearly places upper limits on the weights it can support. The wings are self supporting but the fuselage and its attachments (tailplane, pilot, luggage etc) are suspended from the wings or spar. The designer of the aircraft has placed an upper limit on the weight in the fuselage (or non-lifting parts) which must never be exceeded. However other more critical issues arise when it is realized that the aircraft may not even fly if it is too "nose heavy" or too "tail heavy", that is, if the centre of the mass (centre of gravity (C of G)) is too far forward or too far aft.

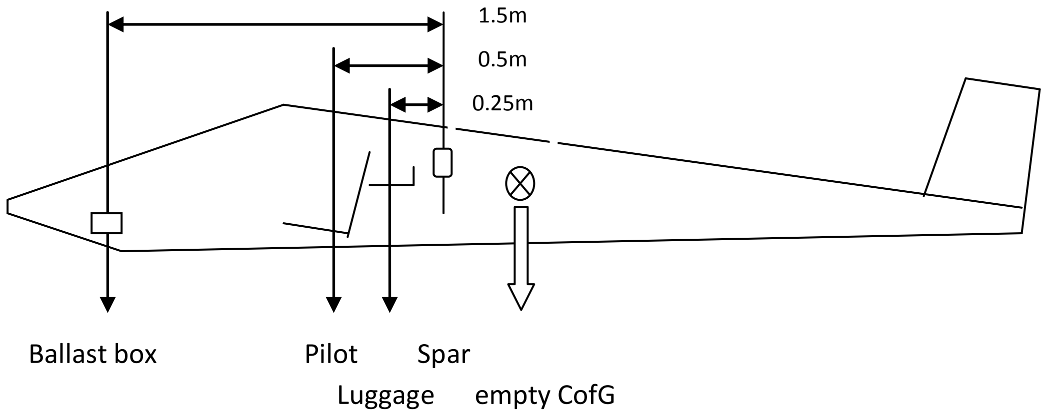
The fuselage is like a see-saw supported by the wing spar. To balance it, the centre of gravity must be very close to the spar and the designers of the sailplane type have calculated the allowable C of G variation for safe flight. This is typically only +/-70mm maximum.

The consequences of too little weight at the front, resulting in a centre of gravity aft of the aft limit, are that the aircraft may pitch up, be unstable, even uncontrollable, impossible to trim, and impossible to recover from a stall/spin. Too much weight in the cockpit will result in a forward out-of-range C of G, making the pilot use full back stick/elevator (beyond trim range) to maintain speed, leaving no capacity to flare on roundout.

To determine a distribution for loading a cockpit, a pilot requires some knowledge beyond the very basic information on the placards. For example a 3kg tie-down kit or battery fastened to the spar will not upset the aircraft balance, whereas a tie-down kit stowed in the tail or nose would substantially upset the balance. Overweight pilots cannot fly, but underweight pilots have the option of appropriately ballasting the aircraft.

Basic Single Seater

Max Pilot:	**95kg**
Min Pilot	**Ballast**
70kg	**0**
64kg	**1**
58kg	**2**



The basic placard will give a minimum (and maximum) pilot weight. The empty glider will have a C of G well behind the spar (and outside the aft limit of C of G). The pilot weight MUST have enough effect to counterbalance this empty weight. A good placard should tell the pilot how many standard ballast weights need to be added to an integrated ballast box for various pilot weights (including chute). However the educated pilot should understand a little more to safely address unusual circumstances (e.g. missing standard weights, broken box, adding luggage etc.).

Placing a weight in the aircraft cockpit creates a tipping "moment" (or torque) around the spar. The magnitude of this moment is measured by multiplying the weight by the distance ("moment arm") ahead of the spar. For example a 2kg weight in the ballast box which is 1.5m ahead of the spar produces a moment of 3kgm (2*1.5) (i.e. "three kilogram metres"). Placing a 6kg weight on the seat pan under the pilot (which is 0.5m (say) ahead of the spar also produces a moment of 3kgm (6*0.5). We see that a single correctly placed 2kg weight can compensate for a pilot who is 6kg underweight. However an inexperienced pilot does not need to do these calculations as the placard designer has done them for him. e.g. min. pilot weight 70 kg, 64kg pilot uses one standard ballast weight (of 2kg), while a 58kg pilot needs two standard weights (4kg) etc. Each glider type will have different moment arms and hence different loading placards.

If the ballast weights are placed in the seat with the same moment arm as the pilot, then 1kg ballast will offset only 1kg pilot shortfall and no calculation is needed, but one needs to weigh any unmarked ballast. Be careful to VERY adequately secure (tie in) weights as they may otherwise move under "g" forces.

It is clear that to add "luggage" a pilot should be conscious of the weight, position (moment arm) and effect on pilot weight limits. For example in this hypothetical glider above, if a pilot of 90kg (say) wanted to carry a tie-down kit (3kg) in spare space in the ballast box giving a moment of 4.5kgm (3*1.5), he would have to realise this would reduce the maximum allowed pilot weight by 9kg (i.e. 4.5kgm/0.5m). The placarded max allowed pilot weight would have to be over 99kg (plus chute) for him to safely fly. Such an addition could not be permanent without reducing the placard to max 86kg (95-9)!

Consider a spare battery (2.5kg), tiedown kit (3kg), three litre water bottle (3kg), torch etc. (1.5kg) for a total of 10kg in a luggage compartment 0.25m in front of the spar, this would create a moment of 2.5kgm (10*0.25) which is equivalent to reduction in max allowable pilot weight at 0.5m of 5kg (because 5*0.5 = 10*0.25). However in this case the total weight of the non-lifting parts could be exceeded unless the pilot weight was the full 10kg below the placarded maximum pilot weight. Our 90kg pilot still can't fly.

No weight should ever be placed aft of the luggage compartment without redoing the placard in case the weights are forgotten. Undocumented weight changes will throw out all placard values and place other pilots at significant risk.

A glider which is slightly out of balance is sometimes said to be "out of trim" because the elevator is used in flight (normally sub-consciously) for small balance corrections, which in turn require small trim lever changes. Using elevator to offset small trim (balance) errors causes more drag and slightly reduced performance.

Basic Two-Seater

The basic placard will give a minimum (and maximum) pilot weight. However with two seats independently loaded, the balance considerations become more complex. We have two primary loading points (seats) with different moment arms. The total moment is the sum of each individual moment. The heavier the rear pilot, the lighter can be the front pilot, but NOT kg for kg! Placards are likely to be more complicated to read than the basic single-seater. If there is ANY uncertainty about the placard limits consult an expert before flight!

As with a single-seater, adding secure (smaller) ballast weights in front of the pilot can work well, but the moment arm difference for the front seat and ballast box is not as pronounced as in a single seater. Generally no separate box is available for the rear seat. Rely on the placard for correct pilot ballasting, or ask for help.

Luggage placement has the same effect as a single-seater and can affect legal pilot weights. Usually a conservative estimate of effect is adequate. For example a water bottle immediately behind the pilot adds to his effective weight kg for kg. If inexperienced, load the aircraft conservatively so as not to introduce difficult to analyse configurations.

From consideration of moment arms it is clear a ballast weight in the back seat cannot effectively compensate for a shortfall in the front seat of the same amount. Typically one needs 30-40kg in the back seat to have the same moment as 10kg in the front seat. Lead ballast weights should always be placed level with, or in front of, the front pilot. Weights MUST be very secure and generally need an engineering design unless on the front seat itself (equal moment arm to pilot).

Aircraft Modifications

As we have shown, adding weight introduces the need for weight and balance knowledge.

When an aircraft is weighed the contents are recorded, as is the structure (e.g. wing tip extensions). Some items are also potentially removable or addable (e.g. batteries, oxygen bottles, instruments etc.). The placards are for a standard configuration which normally includes batteries and semi-permanent additions (e.g. “permanent” tie-down kit). If you want to fly without some standard item then you MUST consider the effect on weight and balance. A tie-down kit on the spar can be temporarily removed safely but one placed far from the spar cannot be left out without expert advice, and must of course be replaced after flight. A forward mounted battery cannot be discarded.

It follows that if you make a permanent change to the weight and balance of an aircraft you are invalidating the placard. Such changes should only be made by authorized persons and must be recorded in the log book along with calculations for a new placard. Changes are not uncommon over the years. For example a repair may add weight to the tail boom dictating a new weighing. Fitting a second (backup) battery or “heavy” instrumentation must be documented correctly, and removal of an oxy-bottle (say) must be likewise documented.

Water Ballast

More advanced gliders carry additional weight in the load bearing parts (wings). This water ballast can enhance performance but also affects the weight and balance of the glider. Water ballast is generally quite close to the spar (0.15m say), but can still introduce a forward movement of C of G. requiring back trim. Some gliders are fitted with an auxiliary tank in the tail to permit a counter balance. The safe limits for water should be in the flight manual. Note that for every kg in the tail tank, the max pilot weight must be reduced by 1kg so as to not exceed the maximum all up weight of the non-lifting parts.

A maximum all-up weight for the glider might be exceeded for a max weight pilot with full ballast tanks. Pilots should study all available charts and limits before using near maximum ballast. Wing tip extensions can result in extra stresses from water ballast such that a 16.6m glider cannot carry as much water as the same aircraft with 15m wingspan. (e.g. Ventus GGH) No pilot should fill the tanks and take off without checking the limits first. Theoretically the max pilot weight may also be affected by the amount of water ballast added because of trim (balance) changes. (e.g. with full tail tank, the max. pilot + luggage + chute in VH-GGH is 84kg (& min. 79kg!))

Tail tank water should rarely be full. Charts based on mathematical balance analysis should be available for various configurations of pilot and wing water ballast weights. Be careful not to leave any water in the tanks after flight. Particularly ensure tail tanks are drained as a light pilot flying with a full tail tank and no main tank water, due to a stuck valve for example, would be highly undesirable. Pay attention to the tanks when doing a Daily Inspection. E.g., to be safe, open valves and remove the tape from the bottom hole in the Ventus (GGH) tail tank.