THE GLIDING FEDERATION OF AUSTRALIA INC.

WEIGHT AND BALANCE NOTES

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Weight & Balance Notes

Brief Document Description:

The weight and centre of gravity of an aircraft have a critical influence on the handling characteristics and structural loading of the aircraft. It is therefore very important that the limits set down by the manufacturer are adhered to.

Keywords:

This document is issued by the Gliding Federation of Australia Inc.

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1.23. WEIGHT AND BALANCE

1.23.1. INTRODUCTION

The weight and centre of gravity position of an aircraft have a critical influence on the handling characteristics and structural loading of the aircraft. It is therefore very important that the limits set down by the manufacturer are adhered to.

The weighing of gliders and powered sailplanes is a technical and complex exercise and a level of mathematical ability is required in addition to an understanding of the physical significance of weight and balance.

This section is designed to give an understanding of sailplane weight and balance but it assumes some mathematical knowledge. Persons interested in having Weight and Balance Authorisation should have a prior understanding of the principles of moments and the ability to substitute values into an equation. Persons who do not already have this ability should consult a standard mathematical text at about Year 12 level.

This section is written with a "typical sailplane" in mind. Where a type is significantly different from the typical sailplane, such as flying wings, canards etc the inspector will be expected to understand the differences and derive the appropriate equations from first principles. If an inspector is in any doubt the CTOA should be contacted.

1.23.2. DEFINITIONS

1.23.2.1 MASS

This is the property of all matter which resists acceleration (F = ma) and causes gravity. This is an intrinsic property of matter and is independent of where the matter is. For example if an object has 5 kg mass on the surface of the earth it would continue to have a mass of 5 kg on the surface of the moon or in deep space.

1.23.2.2 WEIGHT

When a mass is brought within a gravitational field (such as the earths gravity) a force is exerted on it and this force is its weight. If an object has a mass of 5 kg then the force (weight) caused by the earths gravity would be 5 kg force. The same object on the moon would weigh only $1/6^{th}$ of is earth weight (the moon's gravity is $1/6^{th}$ of earth's gravity) so its weight would be 0.833 kg force. In deep space (with no gravity acting on it) it's weight would be zero but in all cases it would still have 5 kg mass.

Fortunately on the earths surface (and just above it) weight, expressed in kilograms force, can be taken as equal to the mass of an object and from now on only weight will be discussed.

1.23.2.3 MOMENT

A moment may be thought of as a twisting force (also known as a torque). It is strictly defined as the product of a force multiplied by the perpendicular distance to the point about which moment is being determined. This distance is known as the arm of the moment or moment arm.

1.23.2.4 CENTRE OF GRAVITY

Every body has a point through which the force of gravity seems to act. ie the point on which the body would balance and this is known as the Centre of Gravity (CG).

The centre of gravity can be best demonstrated by suspending an odd shaped body. No matter where the body is suspended from the centre of gravity will be directly beneath the point of suspension. See Figure 1.23.1.

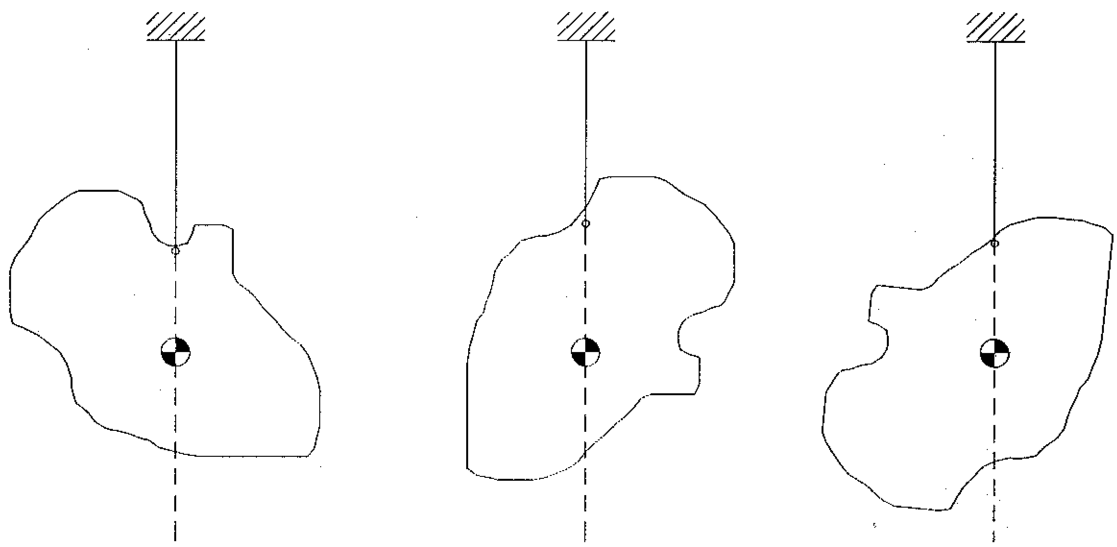


FIGURE 1.23.1 CENTRE OF GRAVITY

1.23.2.5 MAXIMUM WEIGHT

The maximum weight is the greatest weight which the sailplane may be flown for each approved category of operation. Normally there are a number of maximum weights set by the designer. These may include but are not limited to:

a) Maximum weight with water ballast
b) Maximum weight without water ballast
c) Maximum weight for aerobatics
d) Maximum weight for self launching

1.23.2.6 MAXIMUM LANDING WEIGHT

This is applicable to any sailplane that can take off with water ballast, but is not certified to land with it. Because of the possibility of cable breaks all modern sailplanes are designed to be able to land at the greatest maximum weight of the sailplane.

1.23.2.7 STABILITY

Stability is defined as the tendency of an object to return to its original position when it has been disturbed.

The best example of stability is given by a ball resting on a surface as in Figure 1.23.2. For a concave surface (bowl shaped), if the ball is disturbed it will return to its original position. If the surface is flat the ball will continue to move away from its initial position (assuming no friction). If the surface is convex (an upside down bowl) then the ball will accelerate away from its original position. These are examples of the system being stable, having neutral stability and being unstable.

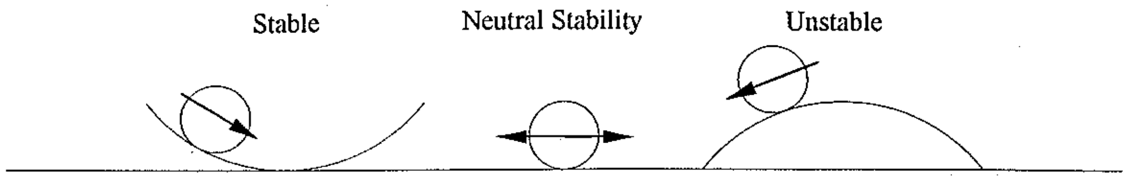


FIGURE 1.23.2 STABILITY

1.23.2.8 CHORD

The chord of a wing is the distance from the leading edge to the trailing edge in the direction of flight.

1.23.2.9 MEAN AERODYNAMIC CHORD (MAC)

The MAC is the chord of the wing which is the 'average' of all the chords. This is not simply half of the root chord and tip chord added together unless the wing is a straight taper. For most configurations it is determined by dividing the wing area by the wing span. This is the basic reference used by designers for stability considerations.

1.23.2.10 CENTRE OF GRAVITY LIMITS

When an aircraft moves through the air its flight characteristics are very dependent on the position of the centre of gravity with respect to the MAC. When a sailplane is designed it is tested to determine the range of centre of gravity positions which result in safe and acceptable behaviour.

1.23.2.10.1 Aft Centre of Gravity Limit

As the centre of gravity moves backwards (by adding weight to the tail or removing weight from the nose) a point is reached where the sailplane becomes unstable and would tumble through the air out of control. Before this point is reached the aircraft exhibits an number of unpleasant handling characteristics.

The first thing the pilot would notice as the CG is moved aft, is the aircraft becoming very sensitive to elevator movements and the amount of force required to move the stick a given amount would reduce (the stick seems to lose its feel). As the CG moves further aft the sensitivity increases and if the sailplane is put into a spin it would not be possible to recover regardless of any actions taken by the pilot.

The designer sets the aft CG limit so that the aircraft has safe flying characteristics.

1.23.2.10.2 Forward Centre of Gravity Limit

As the centre of gravity is moved forward the pilot needs to hold more and more back stick at a given speed to prevent the nose dropping. Ultimately it becomes impossible to stop the from nose dropping. This is worse in turning flight and makes the sailplane unpleasant to fly because of the high stick loads to hold the nose up. Eventually the nose of the sailplane cannot be raised during the flare at normal circuit speed.

The forward Centre of Gravity limit may also be the limiting factor for structural strength of the fuselage. The weight of a heavy front pilot requires a higher down load from the tailplane to balance the glider and this, combined with normal manoeuvring loads may be the limiting case.

To allow the sailplane to be flown properly the designer sets a forward limit for the centre of gravity so that the sailplane can still be controlled even at low speeds.

1.23.2.11 EMPTY WEIGHT

The empty weight of a sailplane is the weight of the sailplane prepared for flight but with the pilot, parachute and removable ballast removed.

1.23.2.12 MAXIMUM WEIGHT OF NON LIFTING PARTS (MWNLP).

In some designs, especially those which carry waterballast, the designer sets the Maximum Weight of Non Lifting Parts. This is necessary because loading the sailplane to the Maximum Weight with water ballast, with the waterballast payload located in the fuselage would overload the wings. Operation at the Maximum Weight with water ballast A higher weight is permitted only because the weight is in the wings and provides bending relief.

The MWNLP is the maximum permitted combined weight of the fuselage, tailplane and any payload in the fuselage (pilot, parachute, drinking water etc.)

1.23.2.13 BALLAST - REMOVABLE

Weights, generally constructed from lead or steel, which can be fitted/removed as required for varying pilot weights. These may be fitted near the seat pan, in the nose or in the tail.

1.23.2.14 BALLAST - FIXED

Weights which are permanently secured to the sailplane to obtain a desired weight and balance effect and are included in the empty weight.

1.23.2.15 PAYLOAD

Payload is the total weight of pilots, baggage, parachutes etc. It does not include waterballast.

1.23.2.16 MAXIMUM FUSELAGE LOAD

The maximum weight that can be carried in the fuselage, composed of all pilots, parachutes, baggage and removable ballast.

1.23.2.17 SEAT LIMIT

All sailplanes have a maximum seat load. This is determined by the strength of the seat and the strength of the harness and its attachments. If the designer does not set down a maximum seat load then the value of 110 kg should be used.

1.23.2.18 DATUM

Every sailplane has a datum which is the reference for any measurements along the longitudinal axis. Most sailplanes use the Wing Root Leading Edge as the datum however a significant number use other datum points. The location of the datum must be ascertained before it is used.

1.23.2.19 SIGN CONVENTION

If a measurement is taken from the datum aft along the sailplane the sign is positive. If the measurement is forward from the datum the sign is negative. Some designers try to eliminate these negative numbers by placing the datum forward of the aircraft's nose, however most designers use the wing root leading edge and so persons performing weight and balance calculations must understand the effects of the negative numbers.

Figure 1.23.3 shows the position of items as they are in a 'typical' sailplane. Inspectors should be aware that, for example, if the pilot's CG is behind the datum then the pilot's moment arm will be positive and if (as is usual) the pilot's CG is in front of the datum the pilot arm will be negative.

1.23.3. SYMBOLS

Throughout this document a standard set of symbols are used to ensure consistency.

G = Empty weight.

G_1 = Front scale reading.

G_2 = Rear scale reading.

(therefore $G = G_1 + G_2$)

G_3 = Empty fuselage plus tailplane (Empty weight of non flying parts).

G_4 = Maximum allowable weight of non flying parts.

G_5 = Maximum weight - no water ballast.

G_6 = Maximum weight.

G_L = Total weight for a given loading condition.

P_1 = Front pilot weight (or left hand pilot).

P_2 = Rear pilot weight (or right hand pilot).

B_F = Fixed ballast weight.

B_R = Removable ballast weight.

O = Oxygen system weight.

X = Empty CG distance from datum.

X_{P1} = Front pilot distance from datum (or left hand pilot).

X_{P2} = Rear pilot distance from datum (or right hand pilot).

X_{BR} = Removable ballast distance from datum.

X_{BF} = Fixed ballast distance from datum.

X_A = Distance of aft CG limit from datum.

X_{ASAFE} = Safe aft Centre of Gravity limit (See Section 1.23.1.23.5.2).

X_F = Distance of forward CG limit from datum.

X_O = Oxygen system distance from datum.

X_L = CG distance from Datum for a given loading condition.

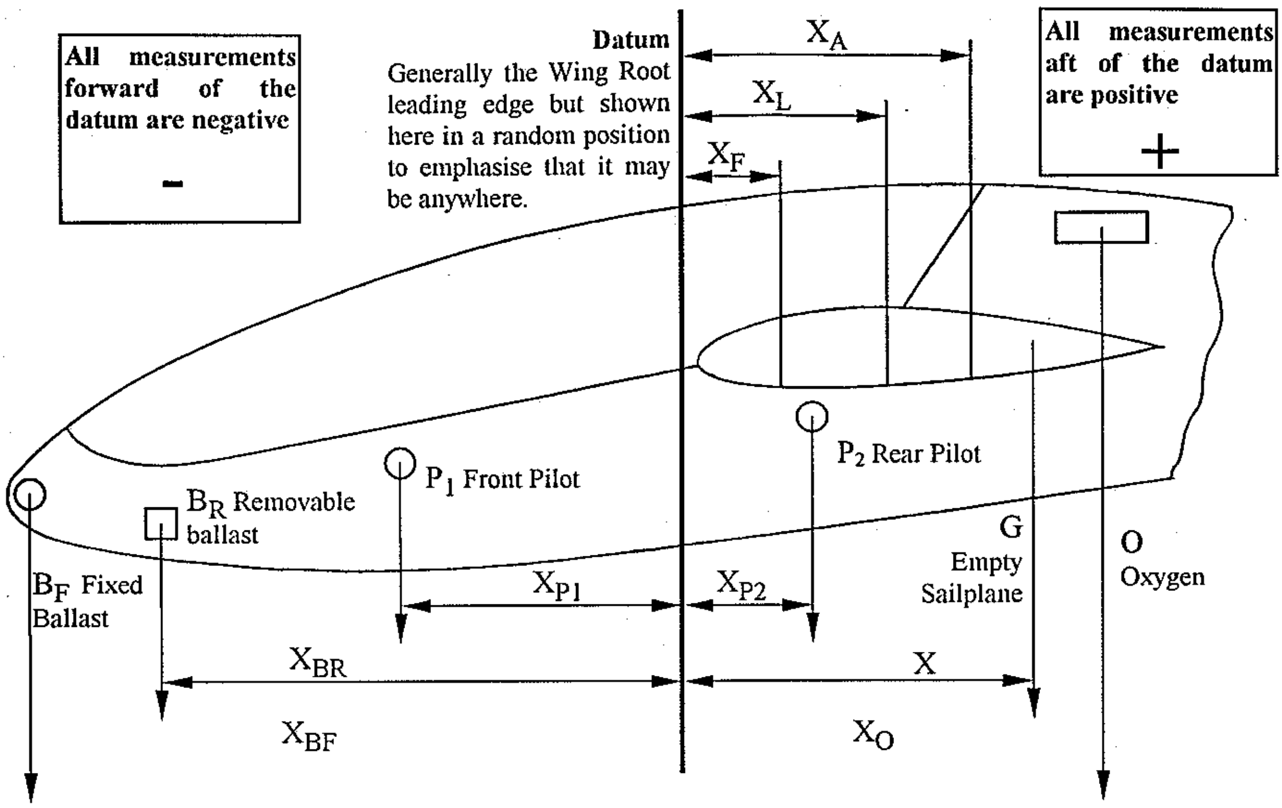


FIGURE 1.23.3

1.23.4. WEIGHING A SAILPLANE

Weighing a sailplane is an experiment to determine the weight and centre of gravity of the sailplane and is subject to a number of potential experimental errors. The procedures which must be followed are designed to reduce these errors however everybody who weighs a glider needs to be aware that the results are subject to a degree of uncertainty.

The uncertainty can be kept to a minimum by taking special care that all measurements are as accurate as possible.

1.23.4.1 TYPE DATA

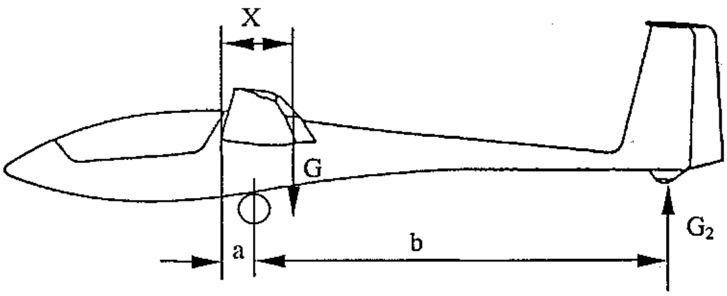
The first step when weighing a sailplane is to obtain the relevant type data such as the correct level, the datum, the CG limits, weight limits etc. This information is summarised on the GFA Type Data Sheet which has been issued for most types. This data sheet can be obtained form the GFA Secretariat and inspectors should ensure that they are using the latest issue.

Where a data sheet does not exist the data must be obtained from the manufacturer's manuals or in the case of amateur built aircraft from the drawings.

When in doubt about type data do not guess. If a glider is weighed using the wrong datum for instance then the weighing is invalid and must be repeated.

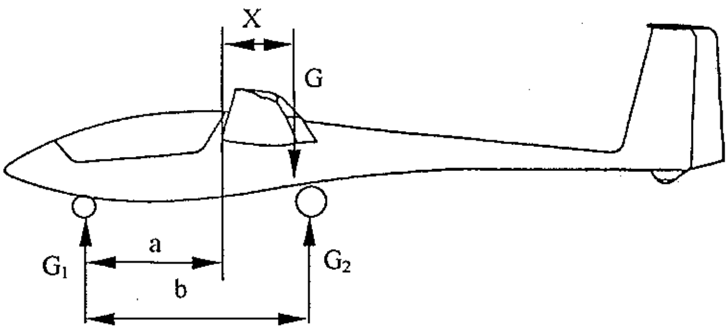
1.23.4.2 WEIGHING MODEL

There are three basic weighing models. The correct model for a particular sailplane is determined by the balance of the glider on the main wheel when it is correctly levelled (see Section 1.23.1.23.4.3). If the empty sailplane sits on the main and the tail wheel then model 1 should be used. If the empty sailplane sits on the main wheel and the nose wheel then model 2 should be used. If a forward skid contacts the ground before the sailplane is level model 3 should be used ensuring the main wheel is clear of the ground.



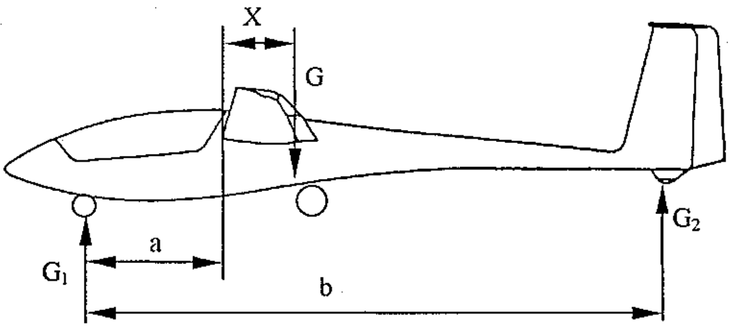
$$X = \frac{(G_2 \times b)}{G} + a \qquad \text{Equation 1}$$

FIGURE 1.23.4 MODEL 1



$$X = \frac{(G_2 \times b)}{G} - a \qquad \text{Equation 2}$$

FIGURE 1.23.5 MODEL 2



$$X = \frac{(G_2 \times b)}{G} - a \qquad \text{Equation 3}$$

FIGURE 1.23.6 MODEL 3

The sign of the dimensions 'a' and 'b' are positive as shown in the drawings. Some gliders which look like model 1 actually have the main wheel in front of the datum. When this happens the inspector should use weighing model 3 or remember that 'a' is negative.

1.23.4.3 LEVELLING

When a sailplane is weighed it must be placed in a standard position to ensure that there is constancy between the measured results and the manufacturers limits. There are a number of common ways a designer may define the sailplane is level.

a) The slope of the top of the rear fuselage may be defined. This is the most common method of levelling used and is almost universal in newer sailplanes.

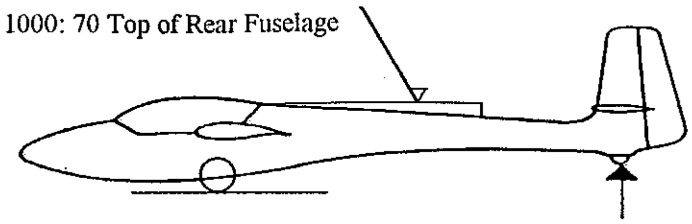


FIGURE 1.23.7 EXAMPLE OF REAR FUSELAGE SLOPE.

b) The underside or top of the rear fuselage may be used as the level.

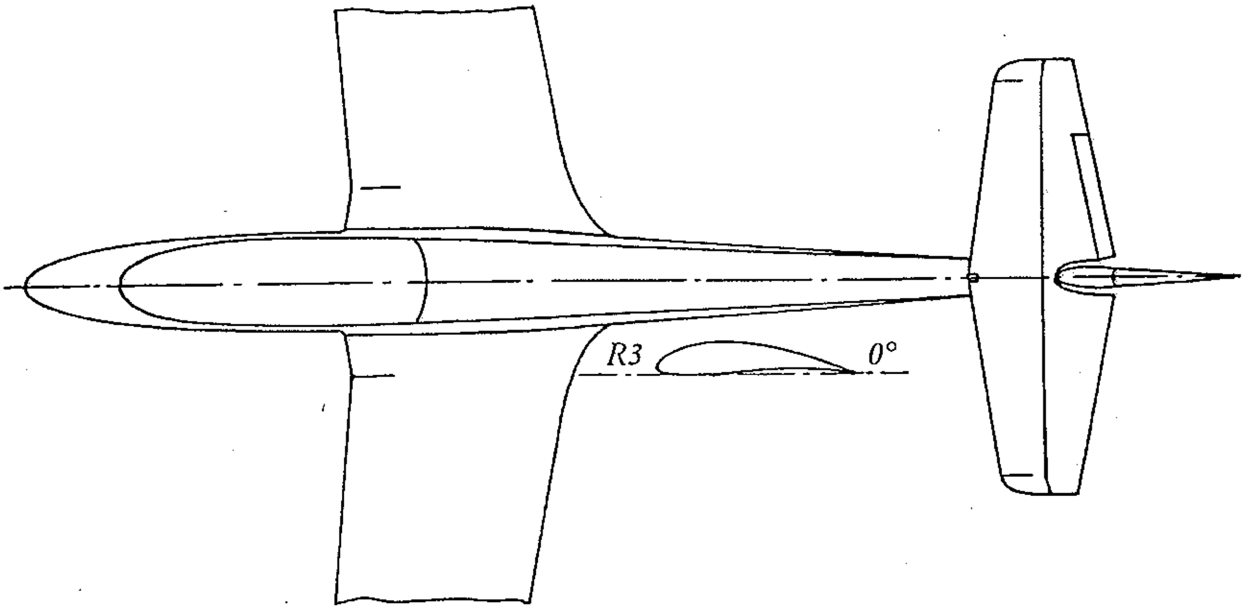


FIGURE 1.23.8 LOWER RIB SURFACE LEVEL

c) Some designers use the underside of a particular rib as the level reference.

d) Some designs, such as the Bergfalke IV, define level as when the trailing edge is higher that the lowest point on the wing section at the chosen rib. From the Bergfalke manual:

"Levelling of Sailplane. - The position of the sailplane is of such kind that the trailing edge of rib 2 lies 55 mm above a horizontal tangent to the bottom of the rib."

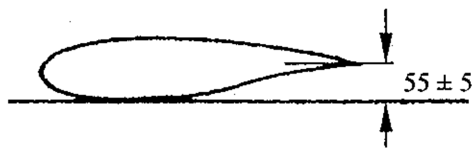


FIGURE 1.23.9 BERGFALKE LEVELLING

e) Some sailplanes, such as the Blanik and most Polish types, require that a set of datum points along the fuselage are level or set up in some defined geometry eg. rear mark 500 mm above front mark. It is essential that these marks are preserved and if necessary restored at each annual inspection and after repainting.

Regardless of the aircraft the level reference must be determined in the aircraft's manuals or on the GFA approved Type Data Sheet for the type before weighing can commence.

1.23.4.3.1 LEVELLING - SPECIAL CONSIDERATIONS

When levelling a sailplane the inspector needs to be aware that there may be a fault with the datum which can cause errors in the weighing. If a sailplane has had major repairs on the rear fuselage it is possible for the fuselage to be misaligned making the level reference invalid. If the inspector is concerned about this type of fault the CTOA should be contacted.

It is common that fuselage structures in homebuilt sailplanes are sufficiently inaccurate for them to be unusable as a level reference.

1.23.4.3.1.1 Progressive Deformation

Some sailplanes (such as the AS-K 13) with steel tube rear fuselage structures can, over long periods during which heavy landings, ground loops, etc are experienced, show a geometry change in their rear fuselage alignment. This, because it may not be sudden, is something to be kept in mind when working with older sailplanes, particularly if there is some unexplainable difference between this and previous weighings.

1.23.4.3.2 LEVELLING - USE A MANOMETER

A water tube manometer consists of a length of clear plastic tubing filled with water. To make the water level more obvious use food dye to colour the water. It is also helpful to add a small amount of dish washing liquid to the water, before pouring it into the tubing, as this lowers the surface tension of the water and gives a more accurate reading. Be careful not to shake the tube as the froth will make accurate readings impossible.

Other equipment such as an incidence board or a dumpy level can be used to check aircraft geometry however this equipment is generally less available than a water tube manometer.

When measuring the geometry of a sailplane that has undergone substantial repairs use a good steel tape measure to measure distances to ensure the aircraft is symmetrical.

When using the manometer, as shown in Figure 1.23.10, using the actual chord (width) of the wing, instead of L, will result in negligible error if the angle is less than 5 degrees.

H/L= tangent of angle of incidence.

If H/L is less than 0.15 then the angle of incidence in degrees equals H/L*57.24.

Dimension L is best measured using two plumb bobs, one at the leading edge and one at the trailing edge and measuring between the two.

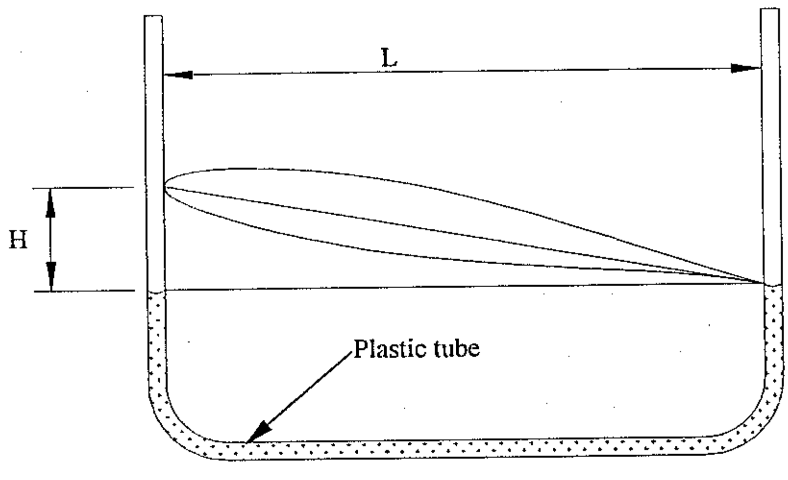


FIGURE 1.23.10 TYPICAL SET-UP FOR MEASURING WING INCIDENCE

1.23.4.4 SCALE CALIBRATION

Scales should be checked and re-calibrated at no more than 12 month intervals. Scales should be able to measure with an accuracy of ±0.1 kg in the range 0 to 100 kg and ±1 kg above 100 kg.

Bathroom scales are not acceptable as they have considerable error and are generally only accurate to ± 2 kg.

1.23.4.5 WEIGHING PROCEDURE

1.23.4.5.1 Work Practices

Weighing a sailplane requires certain practices to be followed to ensure that a high standard is achieved.

(a) The weighing is best done indoors on level ground. If the weighing must be done outdoors the wind must be less than 5 kts as the wind on the wings can have a significant effect on the scale readings.

(b) The battery should be fully charged or use the 12 volt car cigarette lighter plug from a car to power the scales. A minimum of 10 minutes warm up time is required to allow the scales to stabilise.

(c) Zero the scales with the selector on fine. Then stand on the load cells in turn. Each reading should be the same and be a reasonable estimate of your weight. There will be differences because the manufacturers of bathroom scales always seem to make them so they read low!

(d) Place any chocks or supporting devices (such as cushions under wings) which need to be used on the load cells before zeroing them. If the sailplane has a skid then a rod should be placed under the skid to provide a point load.

(e) When placing the sailplane on the load cells it should be positioned so that the cells do not tilt to one side.

(f) Work in the metric system, reading to the nearest millimetre and the nearest 0.1 kg for the tail weight G_2 and the nearest 1 kg for all other weights.

(g) Double check all scale reading and measurements. A helper should be used to reduce the effects of dyslexia!

(h) Ensure the tape does not have a "short" end. To remove errors caused by damaged tape ends start at the 100 mm point on the tape and subtract 100 mm from the measurement.

(i) Check that each scale returns to zero when the sailplane is removed. If the reading does not return to zero, re-zero the scales and repeat the measurement. If the error persists the scales require overhaul.

1.23.4.5.2 Weighing a Sailplane

The following procedure is a guide to the critical points of weighing a sailplane using "Ruddweigh" electronic scales. Where other scales are used, care must be taken to observe specific features of those scales.

These steps are a guide and it may be more efficient to measure the weight of non lifting parts at a different point in the sequence. It is assumed the sailplane is derigged at the start of the weighing.

(a) The sailplane must be fully equipped representing the way it will be operated The equipment list on the weighing record (GFA Form W1) should be completed.

(b) Where a sailplane has a Maximum Weight of Non Lifting Parts limitation, the fuselage, with rudder, elevators and tailplane must be weighed separately form the wings. In this case levelling is not necessary as you only want total empty weight of non lifting parts.

Note, it is sometimes easier to weigh the wings and then subtract the wing weight from the total empty weight to find the weight of non lifting parts.

(c) If necessary rig the sailplane.

(d) Zero the scales on coarse.

(e) Wheel the glider on to two scales, chock and take a total empty weight reading. This will be the weight shown on the indicator which automatically adds the 2 load cells together. Ensure the load cells are reasonably level.

(f) Enter the weights and dimensions onto GFA Form W1 as you go. Ensure the entries are clear and easily read.

(g) Take the sailplane off the two load cells.

(h) Obtain the levelling reference from the Data Sheet or the flight and service manuals.

(i) For Model 1. Chock the mainwheel and level the sailplane with one load cell under the tail wheel/tailskid. With the scales set to fine read G_2.

For Model 2. Chock the mainwheel and level the sailplane with the scale under the nose wheel/skid. With the scales set to fine read G1. It is possible that G1 will exceed the limits of the scales in the fine setting, in which case the coarse scale should be used. Do not forget to re-zero after the change of range.

For Model 3. The load cell must be placed under the most convenient support. The scales will almost certainly need to be in the coarse range but if one support allows the scales to be set to fine then the scale should be under that support.

(j) When weighing, always take one reading, then disturb the aircraft. Take a second reading and average the two for a result.

(k) Keep the sailplane balanced laterally. There should be no force on the wing tip during the weighing.

(l) Using the datum supplied in the data sheet, measure the distances "a" and "b" as per the relevant weighing model. Use a long tape and a plumb bob. To remove any parallax error the plumb bob should be used on both sides of the sailplane.

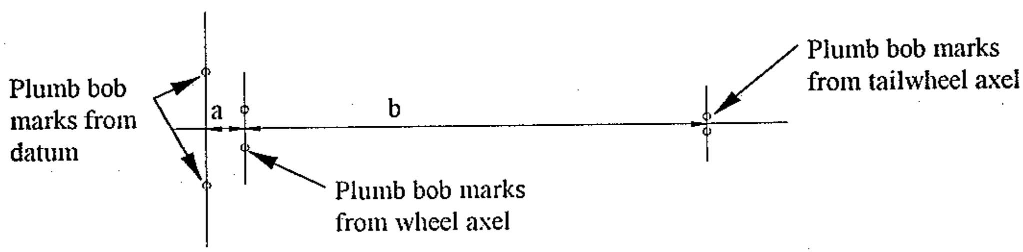


FIGURE 1.23.11 MEASURING 'a' AND 'b' FOR MODEL 1

(m) Calculate the distance of the empty CG from the datum point.

(n) Compute minimum and maximum pilot weights and amend cockpit placards as necessary.

(o) Enter the results into the weight and balance section of the logbook - complete with an equipment list.

(p) Any major difference between the empty weight and the CG position and the weight and CG position from a previous weighing must be justifiable by estimation. If it cannot be justified, the results must be viewed with suspicion and re-weighing must be considered.

1.23.5. DETERMINING THE SAILPLANE LOADING

Once the sailplane has been weighed it is necessary to carry out a number of calculations to determine the allowable pilot weight limits and the weight of other payload which can be carried.

1.23.5.1 EMPTY CENTRE OF GRAVITY POSITION

The first calculation is to determine the empty centre of gravity position. Using Equation 1, Equation 2 or Equation 3 the values measured are substituted and X calculated.

1.23.5.2 SAFE AFT CENTRE OF GRAVITY POSITION

The weighing of the sailplane is an experiment and like any experiment is subject to a certain amount of error. If these errors accumulate in the wrong way the aircraft may be flown outside its aft limit even though the calculations indicate all is well. To allow for these experimental uncertainties and to allow for the slight day to day variations in weight which each person experiences a safety factor must be applied. The normal method of allowing for this error is to use a Safe Aft Centre of gravity limit which is slightly further forward than the true aft limit.

The usual allowance is 5% of the allowable centre of gravity range which may be calculated as follows:

$$X_{ASAFE} = X_A - 0.05 \times (X_A - X_F) \qquad \text{Equation 4}$$

Throughout the rest of this section the calculated vale for X_{ASAFE} should be substituted for X_A.

1.23.5.3 THE MINIMUM PILOT WEIGHT

The minimum pilot weight is determined from the aft centre of gravity limit.

The Minimum pilot weigh is calculated using the following equation:

$$P_{1MIN} = \frac{G \times (X - X_A)}{(X_A - X_{P1})} \qquad \text{Equation 5}$$

1.23.5.4 THE MAXIMUM PILOT WEIGHT

The Maximum Pilot Weight is the lowest of the Maximum Pilot Weights calculated from Equation 6 through to Equation 9 and the seat limit.

1.23.5.4.1 Maximum Weight

All sailplanes have a maximum weight and this must not be exceeded.

$$P_{1MAX} = G_6 - G \qquad \text{Equation 6}$$

1.23.5.4.2 Maximum Weight No Water Ballast

Some sailplanes have a maximum weight with no waterballast. The maximum allowable pilot weight based on this limit is determined by:

$$P_{1MAX} = G_5 - G \qquad \text{Equation 7}$$

1.23.5.4.3 Maximum Weight of Non-Lifting Parts

Most sailplanes have a maximum weight of non lifting parts. The maximum pilot weight based on this limit is determined by the following formula:

$$P_{1MAX} = G_4 - G_3 \qquad \text{Equation 8}$$

1.23.5.4.4 Forward Centre of Gravity

If a heavy pilot flies a typical sailplane the centre of gravity is further forward than for a light pilot. A heavy pilot may cause the centre of gravity may be forward of the front limit. The maximum pilot based on centre of gravity position is determined by:

$$P_{1MAX} = \frac{G \times (X - X_F)}{(X_F - X_{P1})} \qquad \text{Equation 9}$$

1.23.5.5 TWO SEATER PILOT WEIGHTS

Two seater sailplanes must comply with all the above limits and the combined effect of two pilots must be taken into account.

To produce the Pilot Loading Placard, required by the MOSP Part 3 Section 5.3, it is necessary to a series of front pilot weights and then determine the minimum and maximum rear pilots to keep the sailplane within all limits. As before, the minimum weight in the rear seat is determined by aft centre of gravity considerations and the maximum weight is the lowest of the limits determined by the maximum weight(s), maximum weight of non lifting parts, forward CG limit and seat limit.

The minimum weight can be determined by:

$$P_{2MIN} = \frac{(G \times X) + (X_{P1} \times P_1) - (X_A \times G) - (X_A \times P_1)}{(X_A - X_{P2})} \qquad \text{Equation 10}$$

The equation for determining the maximum rear pilot weight based on maximum weight is:

$$P_{2MAX} = G_6 - G - P_1 \qquad \text{Equation 11}$$

If there is a maximum weight dry the value for G_5 should be substituted for G_6.

If the sailplane has a Maximum Weight of Non Lifting Parts then this limit must also be considered and the following equation should be used:

$$P_{2MAX} = G_4 - G_3 - P_1 \qquad \text{Equation 12}$$

To ensure the forward CG limit is not exceeded the formula is:

$$P_{2MAX} = \frac{(G \times X) + (X_{P1} \times P_1) - (X_F \times G) - (X_F \times P_1)}{(X_F - X_{P2})} \qquad \text{Equation 13}$$

The seat limit must also be considered.

Once the minimum and maximum rear pilot weights have been determined for the first front pilot weight in the sequence the weight should be increased by 5 kg and the limits recalculated. This process is repeated until all valid weight combinations have been determined and a placard of pilot weight combinations can be prepared. A sample placard is shown:

VH-XXX NORMAL CATEGORY		
Front kg	Rear Min.	Rear Max.
45	95	110
50	75	110
55	60	110
60	40	110
65	20	110
70	0	110
75	0	110
80	0	110
85	0	105
90	0	100
95	0	95
100	0	90
105	0	85
110	0	60
Minimum Solo		70 kg
Maximum Solo		110 kg
Max. Fuse Load		190 kg

From the placard it is clear that quite large increases in rear pilot weights are needed to balance a small decrease in front pilot weight. As the front pilot gets heavier a rear pilot is no longer needed to balance the sailplane but the maximum rear pilot weight starts to be limited by the maximum weight and finally with very heavy front pilots the rear pilot is limited by the forward CG limit.

1.23.5.6 WATER BALLAST

Many sailplanes allow carriage of waterballast in the wings to improve gliding performance. The maximum water ballast which can be carried for a given payload must be determined. The following formula determines the maximum waterballast for a given payload:

$$Waterballast_{MAX} = G_6 - G - Payload \qquad \text{Equation 14}$$

Again this is done for all valid payload weights and a placard prepared. A sample placard is:

Water Ballast Combinations

Payload (kg)	Max Water (l)
70	190
75	185
80	180
85	175
90	170
95	165
100	160
105	155
110	150

The addition of waterballast moves the centre of gravity forward in all existing designs and the designers allow sufficient extra forward centre of gravity limit so that this need not be considered unless explicitly required by the manufacturer.

1.23.5.6.1 Tail Waterballast

Tail ballast was originally designed to counteract the forward CG movement caused by the addition of waterballast in the wings. When the manufacturer designs such a system they prepare a chart showing how much tail ballast to add for a given amount of waterballast.

Some pilots however try to use the tail waterballast to adjust the Centre of Gravity to allow for pilots heavier than the minimum. This has a number of problems.

a) How much tail ballast can be added without moving outside the sailplanes limits?

b) As the tail tank must dump when the main tanks dump valve is open to prevent a dangerous aft CG the dropping of the water will cause the CG to move forward away from the optimum.

c) If a heavy pilot prepares a sailplane for the day but due to a change of plans a light pilot flies it the possibility exists that the CG will be behind the aft limit.

If only one pilot flies a glider, the best solution is to secure fixed ballast and re-placard the sailplane with the new limits. If many pilots fly the sailplane then the pilot will have to accept the consequences of dropping ballast knowing it is better to climb away with a forward CG than land with an optimum CG.

The required tail ballast to increase the minimum pilot weight to a given pilot weight is given by:

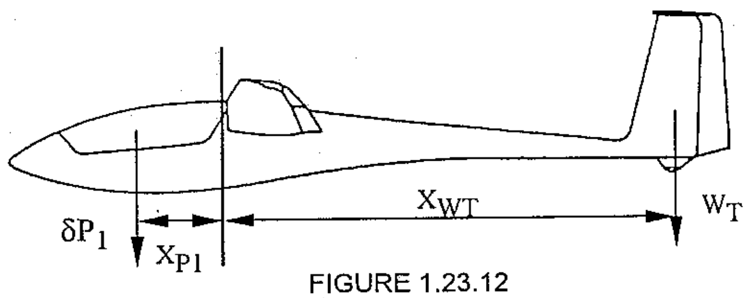


FIGURE 1.23.12

$$\delta P_1 = P_1 - P_{1MIN}$$ Equation 15

$$W_T = \frac{\delta P_1 \times (X_A - X_{P1})}{X_{WT} - X_A}$$ Equation 16

It may also be desirable to prepare a placard showing how much each litre of tail waterballast increases the minimum pilot weight. The increase in the minimum pilot weight for 1 litre of tail water ballast is given by:

$$\delta P_1 = \frac{(X_{WT} - X_A)}{(X_A - X_{P1})}$$ Equation 17

1.23.5.7 FIXED BALLAST

Fixed ballast is installed to move the centre of gravity of the empty aircraft to a more favourable position. Nose ballast is installed to move the CG forward allowing lighter pilots to fly the sailplane without Removable Ballast. Tail Ballast may be fitted to move the centre of gravity aft for a particular pilot to improve the performance and handling of the sailplane.

The addition of fixed ballast is a permanent change in the sailplanes weight and balance and must be reflected in the cockpit placards. The weight and position of any fixed ballast must be recorded in the sailplane's log book.

1.23.5.7.1 Nose Ballast

Nose ballast is generally added to achieve a nominated minimum solo pilot weight, usually 70 kg. The ballast required to achieve a given minimum pilot weight can be determined by:

$$B_F = \frac{G \times (X - X_A) + P_1 \times (X_{P1} - X_A)}{(X_A - X_{BR})} \qquad \text{Equation 18}$$

1.23.5.7.2 Tail Ballast

When installing tail ballast for a particular pilot it is necessary to determine the ballast required to place the centre of gravity at a particular place, usually at 95% of the allowable in flight range. First determine the desired CG position and calculate the require ballast using:

$$B_F = \frac{G \times (X - X_L) + P_1 \times (X_{P1} - X_L)}{(X_L - X_{BR})} \qquad \text{Equation 19}$$

The addition of tail ballast has other effects including a considerable increase in the gliders rotational moment of inertia. This can affect the spin recovery of a sailplane even if the CG is within limits. For this reason the maximum amount of tail ballast must be kept below 10 kg unless the manufacturer specifically approves a larger balancing mass.

1.23.5.7.3 Recalculating Placards

Once the required amount of ballast has been determined, new placards must be calculated. To do this, first calculate the new empty centre of gravity position and empty weight with the ballast installed and then recalculate all placards as shown above.

The new Empty Weight can be determine as follows:

$$G_{NEW} = G_{OLD} + B_F \qquad \text{Equation 20}$$

To calculate the new Centre of Gravity position use the following:

$$X_{NEW} = \frac{B_F \times X_{BF} + G_{OLD} \times X_{OLD}}{G_{NEW}} \qquad \text{Equation 21}$$

If the ballast is in the fuselage and the sailplane has a Maximum Weight of Non Lifting Part then the new weight of the fuselage and tailplane must be determined by:

$$G_{3NEW} = G_3 + B_F \qquad \text{Equation 22}$$

1.23.5.8 REMOVABLE BALLAST

It is often desirable for pilots who are lighter than the minimum pilot weight to fly the sailplane. To achieve this removable ballast must be installed in the sailplane so that it is within all limits.

The simplest method of achieving this is to add ballast to the seat so that the sum of the ballast and the pilot weight equals the minimum pilot weight. The ballast must be firmly secured. Unsecured ballast can move in flight, possibly jamming the controls and people have received serious back injuries in accidents from unsecured ballast. Ballast on the seat can also be uncomfortable ruining the carefully designed seat posture. If a pilot weighed 50 kg and the minimum pilot weight was 70 kg then 20 kg of lead on the seat is required to balance the sailplane which is a lot of lead and can be difficult to restrain.

Most aircraft have properly designed removable ballast installations. When the sailplane is weighed (removable ballast blocks not fitted) the weight of the ballast blocks is determined and the reduced minimum pilot weight can be calculated for each combination of blocks. These blocks are mounted forward of the pilot so less lead is required to achieve the desired balance. They are mounted in the aircraft on specially designed fittings which have been tested to be strong enough.

The new minimum pilot weight for a given amount of removable ballast can be calculated using Equation 23. Remember to use the correct sign for the moment arms. If the ballast or the pilot are ahead of the datum then the arm is negative.

$$W_{P1} = \frac{G \times (X - X_A) + B_F \times (X_{BR} - X_A)}{(X_A - X_{P1})} \qquad \text{Equation 23}$$

1.23.5.9 ADDING/REMOVING EQUIPMENT

Whenever equipment is added or removed from a sailplane, the effect on the weight and balance of the sailplane must be considered and, if necessary, new placards prepared. If the change is large or there have been many changes since the sailplane was last weighed then a full reweigh is required.

In other cases the change to the weight and balance can be calculated. This can be done using Equation 20 and Equation 21 to determine the changed empty weight and centre of gravity position and then new placards can be calculated.

1.23.6. DETERMINING PILOT AND BALLAST ARMS

Sometimes the pilot arm for a given type will be unknown or equipment will be added at a new position. If the sailplane is not fully reweighed it is necessary to determine the centre of gravity position of the object or pilot.

1.23.6.1 DETERMINING PILOT MOMENT ARMS

To obtain a pilot arm accurate enough to use with confidence the sailplane should be weighed with the pilot sitting in the normal position. The results of this weighing is then used to calculate the pilot arm. Because all pilots are different a number of pilots of various shapes and sizes should be weighed in the sailplane as that will allow the safest pilot arm to be determined.

When carrying out this exercise be aware of the influence of adjustable seats or adjustable seat backs, since that may require pilot weight versus seat position to be placarded.

The recommended procedure for determining a pilot arm is: -

a) Weigh the empty sailplane.

b) Weigh the pilot with chute if one is normally worn.

c) The pilot sits in the sailplane in the normal flight position. It is recommended that harnesses be fastened and rudder pedals be adjusted to make the seating position as normal as possible.

d) Ensure that the sailplane is level and record either the G_1 or G_2 (whichever is easier). Note that if the sailplane is fitted with suspension the dimensions a and b will need to be remeasured with each pilot sitting in the sailplane.

e) Repeat the procedure with a number for all volunteers. Between three and five pilots is best provided they give a range of sizes and shapes.

The pilot arm for each pilot may then be calculated using the following equation for weighing model 1:

$$X_P = \frac{b \times G_2 - G \times (X - a)}{P} + a \qquad \text{Equation 24}$$

Or for models 2 and 3:

$$X_P = \frac{b \times G_2 - G \times (X + a)}{P} - a \qquad \text{Equation 25}$$

The most conservative of the pilot arms calculated is then selected as the pilot arm for all subsequent calculations. As in all of these calculations special care must be taken with the sign of the numbers. The pilot is generally in front of the datum thus the pilot arm is negative and that removing a weight makes it a negative.

Inspectors should also be aware that sailplanes which rotate onto their nose when the pilot gets in require a different weighing model for determining pilot arms that that used for weighing the empty sailplane. The sailplane must be re-levelled and new measurements of 'a' and 'b' are required.

1.23.6.2 DETERMINING OTHER ARMS

The position of the centre of gravity of most items can be determined with sufficient accuracy by estimating the centre of gravity of the item and then measuring the distance from that CG to the datum. A sufficiently accurate determination of a small item's CG can be done by balancing it on a rod.

Sometimes when a part has an irregular shape or a very precise measurement is required the arm must be determined by weighing the sailplane with and without the item. Once the sailplane has been weighed the item is added (or removed) and the tail weight remeasured. As long as the weight of the item is known its arm may be determined using the following equations.

Model 1:

$$X_B = \frac{G_2 \times b - G \times (X - a)}{B} + a \qquad \text{Equation 26}$$

Model 2 and 3:

$$X_B = \frac{G_2 \times b - G \times (X + a)}{B} - a \qquad \text{Equation 27}$$

If the item is in front of the datum the arm is negative and that if the item is removed the weight needs to be entered as a negative number.

1.23.7. SPECIAL CASES

The above equations and considerations apply to all sailplanes provided special care is taken with the sign of the numbers (negative in front of datum and removed weights) however the physical significance of many items may change. For example if the pilot sits behind the aft CG limit then heavier pilots will cause the CG to move aft and inspectors need a good understanding of the physics of weight and balance to allow for these situations.

1.23.7.1 WEIGHING THE IS28/IS29/IS30/IS32 SERIES

The method of manufacture of these sailplanes means that the wing sweep can vary slightly from one aircraft to the next. Therefore it is therefore necessary to measure the wing sweep each time a sailplane is weighed and the centre of gravity limits are calculated relative to the datum so that the limits as a percentage of the MAC are the same for all examples.

The details for determining the correct CG limits for each of these types is contained in the GFA Type Data Sheet and inspectors should ensure they have the latest version.

1.23.7.2 FLYING WINGS

Flying wings are relatively rare amongst gliders however some exist. Inspectors who weigh them should already have considerable weight and balance experience and take into account the following points.

a) Flying wings are very short, which puts emphasis on scale calibration, scale levelling and measurement accuracy.

b) The CG range may be short (as little as 45 mm).

c) Adjustment of the pilot's seating position, thereby changing the pilot arm may be used to trim the sailplane before takeoff. Placarding will have to state this.

d) Ideally, a flying wing should fly at a fixed CG position, so removable ballast may be more extensively used.

1.23.8. POWERED SAILPLANES

Powered sailplanes require additional consideration because factors such as the fuel load must be accounted for. The loading of the sailplane must remain within all limits at all times. When preparing powered sailplane placards the maximum weight and maximum weight of non lifting parts must not be exceeded with fuel on board and the centre of gravity must remain within limits.

To simplify the operation of powered sailplanes, a placard should be provided which shows the maximum quantity of fuel for a given seat and baggage load as in the following example.

Because of the large number of possible combinations of fuel and cockpit loads which must be considered, inspectors who prepare placards for powered sailplanes should have considerable experience in weight and balance and have the ability to derive the necessary equations from first principles. Where an inspector is unsure the CTOA must be contacted.

AMT-200
VH-ABC

COMBINED SEAT AND BAGGAGE LOADS (kg)	MAXIMUM FUEL (l)
30 to 150	90
160	79
170	65
180	51
190	37
200	23
210	9
217	0

Maximum Payload (Pilots + Baggage + Fuel) = 217 kg
10 *l* of fuel = 7.2 kg
Maximum load per seat = 110 kg

1.23.8.1 GENERAL CONSIDERATIONS

When weighing powered sailplanes the method in the manufacturer's manuals must be followed. This will normally require that all fuel tanks are empty.

1.23.8.2 FORWARD ENGINES.

When preparing placards for a powered sailplane with a forward engine the following must be considered:

a) Pilots can be located such that as pilot weight increases, the aft CG limit may be exceeded because the pilot is positioned behind the aft CG limit.

b) Use of fuel needs to be considered. Fuel may be positioned in either the fuselage or the wings. Fuel in the fuselage must be added to the weight of non-lifting parts. Fuel in the wings may be allowed for the same way as waterballast.

c) Use of the baggage compartment, in combination with fuel and pilot/s must be considered.

1.23.8.3 EXTENDING ENGINES

Powered sailplanes with extending engines need the following special considerations:

a) In most cases the manual requires that the sailplane be weighed with the engine retracted. Most designers allow ample forward CG range to allow for the CG shift when the engine extends. However some designers give an amount of CG change on extending the engine. Where this information is available the forward CG limit must be checked with the engine extended.

b) Fuel may be in the wings, the fuselage or both and so the relevant limits of Maximum Weight and Maximum Weight of Non-Lifting Parts must be considered.

c) Some of these sailplanes have been designed to be operated with the engine removed. If this is the case placards should be prepared allowing for this possibility.

1.23.9. PLACARDING

The minimum placarding requirements are given in Section 5.3 of the Manual of Standard Procedures - Part 3 - Airworthiness.

The layout of the placards should be similar to the samples shown in this section to allow standardisation across the sailplane fleet.

1.23.9.1 ROUNDING

When performing the calculations the answer may have many digits after the decimal place. Obviously when preparing the placards an accuracy greater than the nearest kg are meaningless as a pilots weight will vary by more than that during a normal day. When performing calculations the full precision should be maintained through intermediate steps until the final answer is obtained. Only then should rounding occur.

When preparing the placards it is essential that the placards keep the sailplane within all limits. For this reason normal rounding is not used as rounding a maximum pilot weight of 102.8 kg gives 103 kg which exceeds the manufacturer's limit. Therefore round down for maximum weight (102.8 → 102) and round up for minimum weights (70.2 → 71).

1.23.9.2 MANUFACTURER'S PLACARDS

Most manufacturers prepare a set of standard placards which assume a standard aircraft. This has two flaws. Firstly, the standard placard may be unnecessarily restrictive and prevent the sailplane using its full loading potential and, secondly, the standard placard may permit operation outside the weight and balance limits for the sailplane.

It is recommended that manufacturers standard placards be ignored and that new placards prepared from an actual weighing of the aircraft be prepared to ensure that the sailplane may be used both efficiently and safely.

1.23.10. LOG BOOK ENTRIES

A weight and balance is incomplete until the log book entries have been made.

It is recommended that the form W1 be glued in the log book so that future inspectors can check the equipment list to ensue that a reweigh is not due. When making entries in the log book ensure that the empty weight and CG positions have been entered and all changes to the weight and balance of the sailplane since the last weighing are recorded.

1.23.11. WORKED EXAMPLES

1.23.11.1 ASTIR CS

The following is an example of the weighing of an Astir CS.

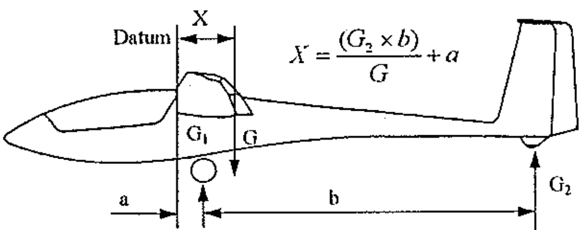
SAILPLANE WEIGHING RECORD

GFA FORM W1

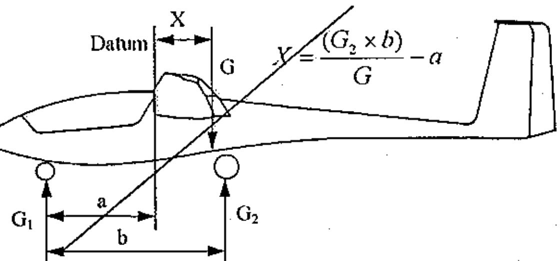
TYPE: ASTIR CS .... S/NO:1305 .... REG VH - ABC ....
PLACE: BROKEN HILL .... SCALES RUDDWEIGH ....
DATUM: WRLE .... LEVEL REFERENCE: 1000:40 TOP OF REAR FUSE

EQUIPMENT LIST

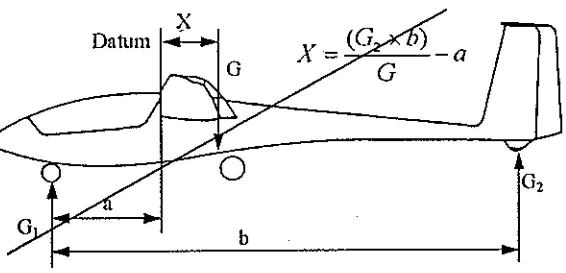
QTY		QTY		QTY	
1	ASI	1	CUSHION	1	COMPASS
1	ALTIMETER	0	CLOCK	0	OXYGEN
2	VARIO & FLASK	1	TIE DOWN KIT	0	RIGGING TOOL
0	TURN AND BANK	1	RADIO	2	BATTERY
0	MICROPHONE	2	CAMERA	0	G METER
0	FUEL	0	OIL		



MODEL 1



MODEL 2



MODEL 3

Weighing Model	1
a	99 mm
b	4130 mm
Empty Weight G	288 kg
Rear Weight G2	37.3 kg
Front Weight G1	251 kg
Fuselage plus Tailplane G3	146.7 kg
Right Wing	70.4 kg
Left Wing	71.2 kg

Empty Centre of Gravity:

$$\frac{37.3 \times 4130}{288} \pm 99 = 633.89$$

SIGNED: BILL MUGGS .... 1109 G:5555 .... DATE: 28-8-1997

DATE OF ISSUE: 4 JULY, 1997 ISSUE NO: 3 FORM W1

Issue No: 2.
Date of Issue: 30 May, 1997

TYPE DATA SHEET

TYPE: ASTIR CS SERIAL NUMBERS 1002-1437	
MAXIMUM FLYING WEIGHT Wet Dry	450 kg 380 kg
MAXIMUM WEIGHT OF NON LIFTING PARTS	240 kg
C of G LIMITS FORWARD AFT OF DATUM AFT	250 mm 425 mm
DATUM:	WING ROOT LEADING EDGE
LEVEL:	1000:40 TOP OF REAR FUSELAGE 300 mm FORWARD OF FIN/FUSELAGE JUNCTION
PILOT ARM/MAXIMUM SEAT LOAD	-475 mm/110 kg
REMOVABLE BALLAST ARM	-1000 mm
WATER BALLAST CAPACITY	100 *l*
WING INCIDENCE	2°
TAILPLANE INCIDENCE	0°
MAXIMUM SPEED SMOOTH AIR V_{NE}	135 kts IAS
MAXIMUM SPEED ROUGH AIR V_{RA}	135 kts IAS
MANOEUVRING SPEED V_A	92 kts IAS
MAXIMUM AEROTOW SPEED V_T	92 kts IAS
MAXIMUM WINCH/AUTOTOW SPEED V_W	64 kts IAS
WEAK LINK AEROTOW	500 kg
WEAK LINK WINCH/AUTOTOW	500 kg
CATEGORY	UTILITY
PERMITTED AEROBATIC MANOEUVRES LAZY EIGHT, LOOP, CHANDELLE, STEEP TURN, SPIN.	

NOTE: THIS DATA SHEET IS ACCURATE TO THE BEST AVAILABLE KNOWLEDGE AT THE DATE OF ISSUE, AFTER WHICH IT MAY BE SUBJECT TO CHANGE WITHOUT NOTIFICATION

The empty CG has been calculated on the form as 633.34 mm aft of the datum. Note that the equipment list has been completed so that future inspectors can determine if the weighing is still valid. The correct data sheet is used - serial numbers of the Astir CS higher than 1437 have different wings and so different CG limits.

The first step is to determine the safe aft CG limit using Equation 4.

$$X_{ASAFE} = 425 - 0.05 \times (425 - 250) = 416.25 \text{ mm} \qquad \text{Equation 4}$$

Step 2 is to calculate the minimum pilot weight based on the safe aft centre of gravity limit using Equation 5.

$$P_{1MIN} = \frac{288 \times (633.34 - 416.25)}{(416.25 - (-475))} = 70.3\ \text{kg} \qquad \text{Equation 5}$$

If the pilot sits in front of the datum the pilot arm is negative and subtracting a negative number is the same as adding.

Step 3 is to determine the maximum pilot weight using Equation 6 through Equation 9.

All sailplanes have a maximum weight and this must not be exceeded.

$$P_{1MAX} = 450 - 288 = 162\ \text{kg (Max Weight Limit)} \qquad \text{Equation 6}$$

$$P_{1MAX} = 380 - 288 = 92\ \text{kg (Max Weight Limit No Water Ballast)} \qquad \text{Equation 7}$$

$$P_{1MAX} = 240 - 146.7 = 93.3\ \text{kg (MWNLP Limit)} \qquad \text{Equation 8}$$

$$P_{1MAX} = \frac{288 \times (633.34 - 250)}{(250 - (-475))} = 152.5\ \text{kg (Forward CG Limit)} \qquad \text{Equation 9}$$

The limiting case is the Maximum Weight Dry Equation 7) which gives a maximum pilot weight of 92 kg. The maximum seat load due to the harness limit is 110 kg and this is not exceeded.

Step 4 is to determine the maximum permitted waterballast across the allowable range of pilot weights. Equation 14 is used starting with the minimum pilot weight and stepping up in 5 kg increments until the maximum allowable payload is reached.

$$Waterballast_{MAX} = 450 - 288 - 71 = 91\ \text{kg} \qquad \text{Equation 14}$$

Repeating this for higher payload weights allows the following table to be produced:

Payload (kg)	Max Water (l)
71	91
75	87
80	82
85	77
90	72
91	71

Using the above information and using the rules for safe rounding to the nearest kilogram, a set of placards can now be prepared:

Minimum Pilot Weight	71 kg
Maximum Pilot Weight	92 kg
Maximum Fuselage Load	92 kg

In addition to this the Astir CS has a removable ballast installation at -1000 mm (forward of datum). It has been checked that in this case there are four ballast bars and that each weighs 1.5 kg (this must be checked for each aircraft) then Equation 23 may be used to calculate the minimum pilot weight with removable ballast installed.

$$W_{P1} = \frac{288 \times (633.34 - 416.25) + 1.5 \times (-1000 - 416.25)}{(416.25 - (-475))} = 67.9 \text{ kg} \quad \text{Equation 23}$$

This is repeated until the minimum pilot weight for all possible removable ballast combinations have been determined. It is also necessary to ensure that the sailplane does not move outside the forward centre of gravity limit or that the maximum weight is not exceeded.

Removable Ballast (kg)	Minimum Pilot Weight (kg)	Maximum Pilot Weight (kg)
1.5	68	90
3.0	66	88
4.5	64	87
6.0	61	85

1.23.11.2 BLANIK L13

The weighing of a two seat glider is the same as a single seat glider and the only difference is that when calculating the pilot limits the effect of the second pilot must be considered.

SAILPLANE WEIGHING RECORD

GFA FORM W1

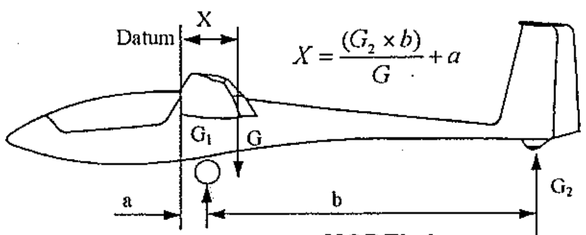
TYPE: BLANIK L13............................ S/NO: 174526..................... REG VH - XYZ ....

PLACE: LAVERTON.......................... SCALES RUDDWEIGH..

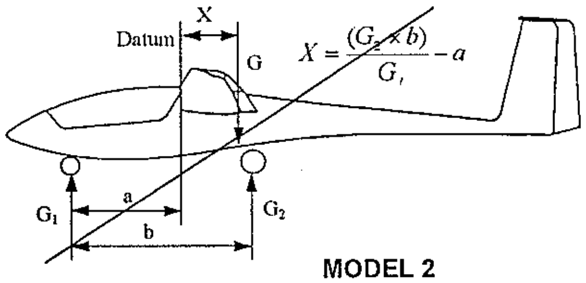
DATUM: WRLE .... LEVEL REFERENCE: DATUM POINTS LEVEL ....

EQUIPMENT LIST

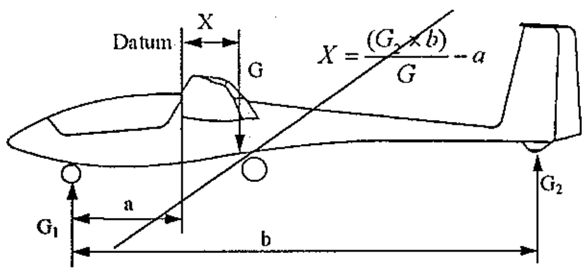
QTY		QTY		QTY	
2	ASI	4	CUSHION	2	COMPASS
2	ALTIMETER	0	CLOCK	0	OXYGEN
4	VARIO & FLASK	0	TIE DOWN KIT	1	RIGGING TOOL
2	TURN AND BANK	1	RADIO	1	BATTERY
1	MICROPHONE	0	CAMERA	0	G METER
0	FUEL	0	OIL		



MODEL 1



MODEL 2



MODEL 3

Weighing Model	1
a	95 mm
b	5500 mm
Empty Weight G	310 kg
Rear Weight G2	29.9 kg
Front Weight G1	280.1 kg
Fuselage plus Tailplane G3	N/A
Right Wing	N/A
Left Wing	N/A

Empty Centre of Gravity:

$$\frac{29.9 \times 5500}{310} + 95 = 625.48$$

SIGNED: B. LANIK-WEIGHER .... 1109 G: 8888 .... DATE: 23-12-1997......

DATE OF ISSUE: 4 JULY, 1997 ISSUE NO: 3 FORM W1

Issue No: 3.
Date of Issue: 9 May, 1995

TYPE DATA SHEET

TYPE: BLANIK L13 AND BLANIK L13A1	
MAXIMUM FLYING WEIGHT NORMAL AEROBATIC	500 kg 400 kg
MAXIMUM WEIGHT OF NON LIFTING PARTS	N/A
C of G LIMITS FORWARD AFT OF DATUM AFT	112 mm 300 mm
DATUM:	WING ROOT LEADING EDGE
LEVEL:	FUSELAGE DATUM POINTS LEVEL
PILOT ARM/MAXIMUM SEAT LOAD FRONT REAR	-1232 mm/110 kg -112 mm/110 kg
WING INCIDENCE	4° AT WING ROOT
TAILPLANE INCIDENCE	-3°
MAXIMUM SPEED SMOOTH AIR V_{NE} FLAPS EXTENDED	136 kts IAS 60 kts IAS
MAXIMUM SPEED ROUGH AIR V_{RA}	78 kts IAS
MAXIMUM MANOEUVERING SPEED V_A	78 kts IAS
MAXIMUM AEROTOW SPEED V_T	76 kts IAS
MAXIMUM WINCH/AUTOTOW SPEED V_W FLAPS EXTENDED	65 kts IAS 54 kts IAS
WEAK LINK AEROTOW MIN MAX	400 kg 600 kg
WEAK LINK WINCH/AUTOTOW MIN MAX	500 kg 800 kg
CATEGORY	NORMAL AEROBATIC
PERMITTED AEROBATIC MANOEUVRES AT NORMAL WEIGHT (500 kg): SPIN, LOOP, ROLL OF THE TOP OF A LOOP, STALL TURN, HALF ROLL AND LOOP AT AEROBATIC WEIGHT (400 kg): AS PER NORMAL WEIGHT PLUS SLOW ROLL AND INVERTED FLIGHT	

NOTE: THIS DATA SHEET IS ACCURATE TO THE BEST AVAILABLE KNOWLEDGE AT THE DATE OF ISSUE, AFTER WHICH IT MAY BE SUBJECT TO CHANGE WITHOUT NOTIFICATION

The empty centre of gravity position has been calculated as 625.48 mm aft of the wing root leading edge. The correct data sheet is also available. In every case the data sheet should be checked, by a quick call to the GFA Secretariat, that it is the latest issue.

As for the single seater the first step is to determine the safe aft CG limit.

$$X_{ASAFE} = 300 - 0.05 \times (300 - 112) = 290.6 \text{ mm} \qquad \text{Equation 4}$$

The second step is to calculate the minimum pilot weight using Equation 5.

$$P_{1MIN} = \frac{310 \times (625.48 - 290.6)}{(290.6 - (-1232))} = 68.2 \text{ kg say 69 kg.} \qquad \text{Equation 5}$$

Like the single seater the maximum pilot weight must be found. In the case of the Blanik the maximum weight no water ballast is not relevant and there is no maximum weight of non lifting parts. Therefore the maximum pilot weight calculations only need to consider limits due to Maximum Weight, Forward Centre of Gravity and the Seat Limit.

The Blanik is certified in two categories, Normal and Aerobatic, and so has two different Maximum Weights depending on the type of manoeuvres it is intended to perform. The example will be completed for the Normal category. For Aerobatic Category the sums need to be repeated substituting the appropriate Maximum Weight.

$$P_{1MAX} = 500 - 310 = 190 \text{ kg (Max Weight Limit)} \qquad \text{Equation 6}$$

$$P_{1MAX} = \frac{310 \times (625.48 - 112)}{(112 - (-1232))} = 118.4 \text{ kg (Forward CG Limit)} \qquad \text{Equation 9}$$

The maximum seat limit for the Blanik is 110 kg and this is the maximum solo pilot weight.

It is now necessary to calculate the minimum and maximum rear pilot weights for each allowable front pilot weight.

1.23.11.2.1 Combined Pilot Limits

There are two limits which must be considered when determining the minimum rear pilot weight needed to balance the sailplane with a given front pilot. These are the safe aft centre of gravity limit and the maximum seat load.

The Minimum Rear Pilot Weight due to CG limitations may be determined from Equation 10. It is necessary to input the front pilot weight and calculate the weight in the rear cockpit necessary to balance the sailplane at the safe aft CG limit. The front pilot mass is then increased by 5 kg and the calculation repeated. Initially the required rear pilot weight will exceed the seat limit and these values must be ignored as impractical. The process is repeated with higher front pilot weight until, at some point the balancing rear pilot weight will be within all other limits and a valid rear pilot weight has been calculated.

Once the front pilot weight reaches the minimum solo pilot weight it is not necessary to continue as a the minimum rear pilot weight is zero. Starting with a 20 kg front pilot weight:-

$$P_{2MIN} = \frac{(310 \times 625.48) + (-1232 \times 20) - (290.6 \times 310) - (290.6 \times 20)}{(290.6 - (-112))} \qquad \text{Equation 10}$$

$$P_{2MIN} = 182.2176 \text{ kg}$$

Increasing the front pilot weight to 25 kg gives the following result:

$$P_{2MIN} = \frac{(310 \times 625.48) + (-1232 \times 25) - (290.6 \times 310) - (290.6 \times 25)}{(290.6 - (-112))} \qquad \text{Equation 10}$$

$$P_{2MIN} = 163.308 \text{ kg}$$

This process is continued until all valid rear pilot weights have been calculated. The results are found in column 2 of Table 1.23.1.

It is then necessary to consider the Maximum Weight limit. Using Equation 11 the maximum rear pilot weight can be calculated:

$$P_{2MAX} = 500 - 310 - 20 = 170 \text{ kg} \qquad \text{Equation 11}$$

As before this calculation is repeated with higher front pilot weights up to the maximum front pilot weight.

In the Blanik the rear pilot is in front of the forward centre of gravity limit. Because of this a heavy rear pilot combined with a heavy front pilot may take the glider outside the forward centre of gravity limit. The rear pilot weight necessary to move the centre of gravity to the forward limit may be calculated using Equation 13.

$$P_{2MAX} = \frac{(300 \times 625.48) + (-1232 \times 20) - (112 \times 310) - (112 \times 20)}{(112 - (-112))} \qquad \text{Equation 13}$$

$$P_{2MAX} = 590.61 \text{ kg}$$

As can be seen with a 20 kg front pilot there is no danger of exceeding the forward centre of gravity limit but at higher front pilot weights the situation changes. For example if the front pilot weight is 110 kg then Equation 13 becomes:

$$P_{2MAX} = \frac{(300 \times 625.48) + (-1232 \times 110) - (112 \times 310) - (112 \times 110)}{(112 - (-112))} \qquad \text{Equation 13}$$

$$P_{2MAX} = 50.619 \text{ kg}$$

Front Pilot	Min Rear CG limit	Max Rear MW Limit	Max Rear CG Limit
20	182.2176	170	590.6196
25	163.308	165	560.6196
30	144.3984	160	530.6196
35	125.4888	155	500.6196
40	106.5792	150	470.6196
45	87.66965	145	440.6196
50	68.76006	140	410.6196
55	49.85047	135	380.6196
60	30.94088	130	350.6196
65	12.0313	125	320.6196
70	-6.87829	120	290.6196
75	-25.7879	115	260.6196
80	-44.6975	110	230.6196
85	-63.6071	105	200.6196
90	-82.5166	100	170.6196
95	-101.426	95	140.6196
100	-120.336	90	110.6196
105	-139.245	85	80.61964
110	-158.155	80	50.61964

TABLE 1.23.1

Thus, with a 110 kg pilot in the front, a 51 kg rear pilot will take the glider outside the forward CG limit. Column 4 of Table 1.23.1 shows the maximum rear pilot weight for a given front pilot weight due to centre of gravity limitations.

At this point common sense must be applied to eliminate the invalid loading combinations. Each seat can hold no more than 110 kg and so front pilot weights less than 40 kg cannot be carried regardless of the rear pilot weight. With a front pilot 70 kg or above no rear pilot is required. Up to a front pilot weight of 80 kg the maximum weight on the rear seat is limited by the seat limit. With a front pilot weight between 80 an 100 kg the maximum load on the rear seat is limited by the maximum flying weight. Above 100 kg the rear seat load is limited by the forward centre of gravity limit.

Applying all of these limits the loading placard shown below can be produced.

VH-XYZ NORMAL CATEGORY		
Front kg	Rear Min.	Rear Max.
40	107	110
45	88	110
50	69	110
55	50	110
60	31	110
65	13	110
70	0	110
75	0	110
80	0	110
85	0	105
90	0	100
95	0	95
100	0	90
105	0	80
110	0	50
Minimum Solo		69 kg
Maximum Solo		110 kg
Max. Fuse Load		190 kg

When preparing this placard it should be noted that all minimum pilot weights have been rounded upwards to the nearest kilogram and the maximum weights have all been rounded downwards to the nearest kilogram.

The only thing left is to prepare the placard for the Aerobatic Category. For the Blanik the only difference is the Maximum Weight is reduced to 400 kg. This effectively reduces the glider to a single seater as the combined pilot weights could be no more than 90 kg. The placard for Aerobatic Category would be:

VH-XYZ AEROBATIC CATEGORY	
Minimum Pilot Weight	69 kg
Maximum Pilot Weight	90 kg
Maximum Fuselage Load	90 kg

1.23.11.3 TWIN ASTIR

The Twin Astir brings together almost all items which must be considered when preparing placards for a glider. Only a powered sailplane is likely to be more complex.

SAILPLANE WEIGHING RECORD

GFA FORM W1

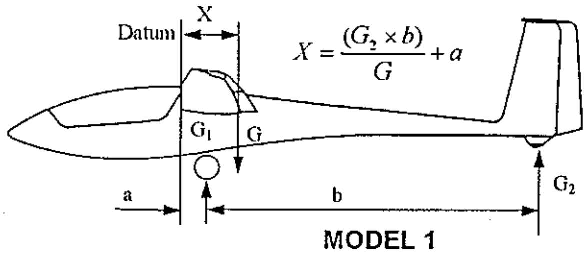
TYPE: TWIN ASTIR .... S/NO: 3000.............................. REG VH - ZZZ...........

PLACE: NARROMINE................. SCALES RUDDWEIGH..

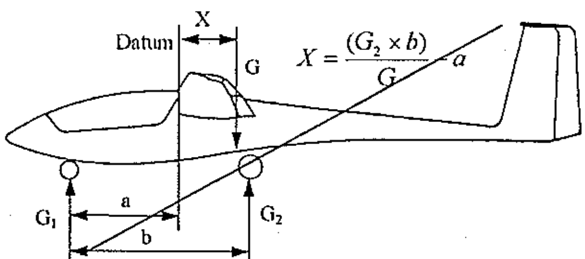
DATUM: WRLE .... LEVEL REFERENCE: 1000:40 TOP OF REAR FUSE...

EQUIPMENT LIST

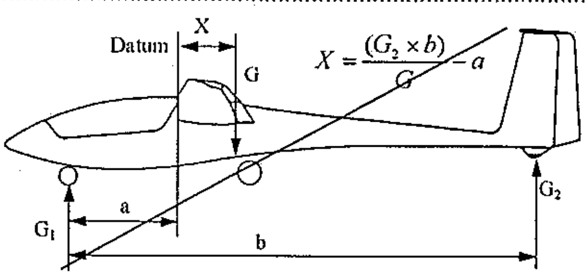
QTY		QTY		QTY	
2	ASI	0	CUSHION	1	COMPASS
2	ALTIMETER	0	CLOCK	0	OXYGEN
2	VARIO & FLASK	0	TIE DOWN KIT	0	RIGGING TOOL
2	TURN AND BANK	1	RADIO	1	BATTERY
2	MICROPHONE	0	CAMERA	0	G METER
0	FUEL	0	OIL		
		2	ELEC VARIO		



MODEL 1



MODEL 2



MODEL 3

Weighing Model	1
a	173 mm
b	4570 mm
Empty Weight G	414.7 kg
Rear Weight G2	49.3 kg
Front Weight G1	365.4 kg
Fuselage plus Tailplane G3	216.1 kg
Right Wing	99.8
Left Wing	99.0

Empty Centre of Gravity:

$$\frac{49.3 \times 4570}{414.7} \pm 173 = 716.29$$

SIGNED: J. BLOGGS....................... 1109 G: 0000 .... DATE: 7-8-1997..........

DATE OF ISSUE: 4 JULY, 1997 ISSUE NO: 3 FORM W1

Issue No: 2.
Date of Issue: 6 May, 1997

TYPE DATA SHEET

TYPE: TWIN ASTIR	
MAXIMUM FLYING WEIGHT	650 kg
MAXIMUM WEIGHT OF NON LIFTING PARTS	470 kg
C of G LIMITS AFT OF DATUM FORWARD / AFT	260 mm 460 mm
DATUM:	WING ROOT LEADING EDGE
LEVEL:	1000:40 TOP OF REAR FUSELAGE 150 mm FORWARD OF FIN
PILOT ARM/MAXIMUM SEAT LOAD FRONT / REAR	-1140 mm/110 kg 11 mm/110 kg
REMOVABLE BALLAST ARM	-1600 mm
WATER BALLAST CAPACITY	100 *l*
WING INCIDENCE	2° 30' ± 15'
TAILPLANE INCIDENCE	0° ± 15'
MAXIMUM SPEED SMOOTH AIR V_{NE}	135 kts IAS
MAXIMUM SPEED ROUGH AIR V_{RA}	108 kts IAS
MANOEUVRING SPEED V_A	92 kts IAS
MAXIMUM AEROTOW SPEED V_T	92 kts IAS
MAXIMUM WINCH/AUTOTOW SPEED V_W	65 kts IAS
WEAK LINK AEROTOW	600 kg ± 30 kg
WEAK LINK WINCH/AUTOTOW	600 kg ± 30 kg
CATEGORY	UTILITY
PERMITTED AEROBATIC MANOEUVRES LOOP, STALL TURN, LAZY EIGHT, CHANDELLE, SPIN.	

NOTE: THIS DATA SHEET IS ACCURATE TO THE BEST AVAILABLE KNOWLEDGE AT THE DATE OF ISSUE, AFTER WHICH IT MAY BE SUBJECT TO CHANGE WITHOUT NOTIFICATION

From the form W1 the empty centre of gravity is 716.29 mm aft of the wing root leading edge and the data sheet is the latest version (at the time of writing).

The safe aft centre of gravity limit is calculated from Equation 4.

$$X_{ASAFE} = 460 - 0.05 \times (460 - 260) = 450 \text{ mm} \quad \text{Equation 4}$$

The second step is to calculate the minimum pilot weight using Equation 5.

$$P_{1MIN} = \frac{414.7 \times (716.29 - 450)}{(450 - (-1140))} = 69.5 \text{ kg which rounds up to 70 kg.} \qquad \text{Equation 5}$$

To determine the maximum pilot weight the Maximum Weight, Maximum Weight of Non Lifting parts, Forward Centre of Gravity and Seat limits must be considered.

$$P_{1MAX} = 650 - 414.7 = 235.3 \text{ kg (Max Weight Limit)} \qquad \text{Equation 7}$$

$$P_{1MAX} = 470 - 216.1 = 253.9 \text{ kg (MWNLP Limit)} \qquad \text{Equation 8}$$

$$P_{1MAX} = \frac{414.7 \times (716.29 - 260)}{(260 - (-1140))} = 135.2 \text{ kg (Forward CG Limit)} \qquad \text{Equation 9}$$

The seat limit for the Twin Astir is 110 kg and this is the maximum solo pilot weight.

1.23.11.3.1 Combined Pilot Limits

The calculation of the minimum rear pilot weight is similar to the calculations for the Blanik.

$$P_{2MIN} = \frac{(414.7 \times 716.29) + (-1140 \times 20) - (450 \times 414.7) - (450 \times 20)}{(450 - 11)} \qquad \text{Equation 10}$$

$$P_{2MIN} = 179.1127 \text{ kg}$$

Increasing the front pilot weight to 25 kg gives the following result:

$$P_{2MIN} = \frac{(414.7 \times 716.29) + (-1140 \times 25) - (450 \times 414.7) - (450 \times 25)}{(450 - 11)} \qquad \text{Equation 10}$$

$$P_{2MIN} = 161.0033 \text{ kg}$$

This process is continued until all valid rear pilot weights have been calculated. The results are found in column 2 of Table 1.23.2.

It is then necessary to consider the Maximum Weight and the Maximum Weight of Non Lifting Parts limits. Using Equation 11 and Equation 12 the maximum rear pilot weight can be calculated:

$$P_{2MAX} = 650 - 414.7 - 20 = 215.3 \text{ kg} \qquad \text{Equation 11}$$

$$P_{2MAX} = 470 - 216.1 - 20 = 233.9 \text{ kg} \qquad \text{Equation 12}$$

As before this calculation is repeated with higher front pilot weights up to the maximum front pilot weight.

The rear pilot weight necessary to move the centre of gravity to the forward limit is calculated using Equation 13.

$$P_{2MAX} = \frac{(414.7 \times 716.29) + (-1140 \times 20) - (260 \times 414.7) - (260 \times 414.7)}{(260 - 11)} \qquad \text{Equation 13}$$

$$P_{2MAX} = 647.4838 \text{ kg}$$

These calculations are repeated for different values of the front pilot weight until the maximum solo pilot weight is reached. The results are shown in Table 1.23.2

Front Pilot	Min Rear CG	Max Rear CG	Max Rear MW	Max Rear MWNLP
20	179.1127	647.4838	215.3	233.9
25	161.0033	619.3713	210.3	228.9
30	142.894	591.2589	205.3	223.9
35	124.7847	563.1464	200.3	218.9
40	106.6753	535.034	195.3	213.9
45	88.56597	506.9215	190.3	208.9
50	70.45664	478.8091	185.3	203.9
55	52.3473	450.6966	180.3	198.9
60	34.23796	422.5842	175.3	193.9
65	16.12862	394.4717	170.3	188.9
70	-1.98072	366.3593	165.3	183.9
75	-20.0901	338.2468	160.3	178.9
80	-38.1994	310.1344	155.3	173.9
85	-56.3087	282.0219	150.3	168.9
90	-74.4181	253.9095	145.3	163.9
95	-92.5274	225.797	140.3	158.9
100	-110.637	197.6846	135.3	153.9
105	-128.746	169.5721	130.3	148.9
110	-146.855	141.4597	125.3	143.9

TABLE 1.23.2

Again some common sense must be applied to eliminate the invalid loading combinations. Each seat can hold no more than 110 kg so front pilot weights less than 40 kg cannot be carried regardless of the rear pilot weight.

The Twin Astir is a very good load carrier and so the maximum load on the rear seat is governed by the seat limit of 110 kg. With a front pilot of 70 kg or more no rear pilot is required.

Applying all of these limits the loading placard shown below can be produced.

VH-ZZZ NORMAL CATEGORY		
Front kg	Rear Min.	Rear Max.
40	107	110
45	89	110
50	71	110
55	53	110
60	35	110
65	17	110
70	0	110
75	0	110
80	0	110
85	0	110
90	0	110
95	0	110
100	0	110
105	0	110
110	0	110
Minimum Solo		69 kg
Maximum Solo		110 kg
Max. Fuse Load		235 kg

1.23.11.3.2 Water Ballast

The carriage of waterballast must be allowed for. Equation 14 is used however the effect of the second pilot must be considered. When preparing the placard the tank capacity must also be considered as it makes no sense to placard the allowable ballast as 130 *l* if the tanks only hold 100 *l*.

WATER BALLAST
VH-ZZZ

Combined pilot and baggage weight (kg)	Maximum permitted waterballast (*l*)
70 to 135	100
140	95
145	90
150	85
155	80
160	75
165	70
170	65
175	60
180	55
185	50
190	45
195	40
200	35
205	30
210	25
215	20
220	15
225	10
230	5
235	0

1.23.11.3.3 Removable Ballast

The Twin Astir is fitted with a removable ballast position at -1600 mm (in front of datum). These normally hold six blocks of 1.5 kg each (It must be checked for each individual aircraft as the original factory blocks may have been replaced.)

Using Equation 23 the reduction in the minimum pilot weight for each block or combination of blocks can be determined.

$$W_{P1} = \frac{414.7 \times (716.29 - 450) + 1.5 \times (-1600 - 450)}{(450 - (-1140))} = 67.5\,\text{kg} \qquad \text{Equation 23}$$

With a second ballast bar the minimum pilot weigh is:

$$W_{P1} = \frac{414.7 \times (716.29 - 450) + 2 \times 1.5 \times (-1600 - 450)}{(450 - (-1140))} = 65.6\,\text{kg} \qquad \text{Equation 23}$$

This is repeated for all the ballast bars and a placard prepared:

REMOVABLE BALLAST
VH-ZZZ

Ballast Block Number	Block Weight (kg)	Total Ballast (kg)	Minimum Pilot Weight (kg)	Maximum Solo Pilot Weight (kg)
0	0.0	0.0	70	110
1	1.5	1.5	68	110
2	1.5	3.0	66	110
3	1.5	4.5	64	110
4	1.5	6.0	62	110
5	1.5	7.5	60	110
6	1.5	9.0	58	110

1.23.11.4 DISCUS TAIL BALLAST

A pilot has just purchased a Discus a. The sailplane has a valid weight and balance which shows that the empty weight is 231.9 kg, the weight of non lifting parts is 113.7 kg and the empty centre of gravity is 651.88 mm aft of the datum. Based on the weighing the following placards have been prepared.

Minimum Pilot Weight	72 kg
Maximum Pilot Weight	110 kg
Maximum Fuselage Load	126 kg

Payload (kg)	Max Water (l)
72 to 105	184 l (full)
110	183
115	178
120	173
125	168
126	167

The new owner weighs 92 kg with parachute and wished to fly with the centre of gravity further aft to improve the performance and handling of the glider. It has been established that some ballast could be fitted near the tail wheel at a position 4100 mm aft of the datum. It is necessary to determine how much lead must be added and to prepare new placards which reflect the installation of the ballast.

For most sailplanes the optimum centre of gravity position is slightly forward of the aft limit. From the Discus a Data Sheet the forward centre of gravity limit is 260 mm and the aft limit is 400 mm aft of datum. Using Equation 4 the safe aft centre of gravity limit is:

$$X_{ASAFE} = 400 - 0.05 \times (400 - 260) = 393 \text{ mm aft of datum} \qquad \text{Equation 4}$$

It has been decided to set the glider up so that the new owner flies with a centre of gravity 385 mm aft of the datum.

The amount of fixed ballast necessary to achieve this can be determined using Equation 19.

$$B_F = \frac{231.9 \times (651.88 - 385) + 92 \times (-450 - 385)}{(385 - 4100)} = 4.02 \text{ kg} \qquad \text{Equation 19}$$

Once the amount of ballast is known it is necessary to recalculate the placards. To do this the first step is to determine the new empty weight and centre of gravity position using Equation 20 and Equation 21.

$$G_{NEW} = 231.9 + 4.02 = 235.92 \text{ kg} \qquad \text{Equation 20}$$

$$X_{NEW} = \frac{4.02 \times 4100 + 231.9 \times 651.88}{235.92} = 710.64 \text{ mm} \qquad \text{Equation 21}$$

Because the lead is in the fin it forms part of the weight of non lifting parts.

$$G_{3NEW} = 113.7 + 4.02 = 117.72 \text{ mm} \qquad \text{Equation 22}$$

By using the new empty weight and centre of gravity position new placards can be calculated using the procedure shown in Example 1 (Astir CS).

The new placards are shown below:

Minimum Pilot Weight	89 kg
Maximum Pilot Weight	110 kg
Maximum Fuselage Load	122 kg

Payload (kg)	Max Water (*l*)
89 to 105	184 l (full)
110	179
115	174
120	169
122	167