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AIRW-D011

Weight and Balance of Sailplanes

Airworthiness

UNCONTROLLED WHEN PRINTED

Revision 1.1

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Précis of changes
Change of document format. Added section on sum of moments method.

TABLE OF CONTENTS

1. INTRODUCTION

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

The weighing of sailplanes 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 manual provides an understanding of sailplane weight and balance and it assumes some mathematical knowledge. Persons interested in attaining a Weight and Balance Authorisation must have a prior understanding of the principles of moments and the ability to substitute values into an equation. Candidates should revise the moments and equations in the worked examples provided in the student guide. Whilst not essential, using spreadsheets is a valuable skill for weight and balance. Candidates should consider gaining simple spreadsheet skills prior to applying for a weight and balance rating.

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 Advanced Weight and Balance Authority is required. The Advanced Weight and Balance Authority holder will be expected to understand the differences and derive the appropriate equations from first principles or use an alternative method like the sum of moments. If an inspector is in any doubt the CTO should be contacted.

2. WEIGHT AND BALANCE RESPONSIBILITY

The GFA has a tiered system of responsibilities with each level playing an important part in ensuring flight safety. A failure at any level of responsibility could have serious consequences.

2.1. PILOT IN COMMAND

The pilot in command of a sailplane is responsible for ensuring that the sailplane is loaded within the usable load and balance limits to ensure safety of flight. The pilot in command must ensure that they have sufficient information available eg cockpit placards, a sailplane loading scheme or a sailplane flight manual, to be able to make the correct decisions on sailplane loading. If the available information is not sufficient (eg missing placards) then the flight should not go ahead.

2.2. REGISTERED OPERATOR

The Registered Operator (RO) is responsible for ensuring that all work on their sailplane is certified by appropriately qualified members and that proper records are kept. The RO is also responsible for ensuring that the cockpit placards are up to date. This is particularly important for any weight and balance activities performed outside of the annual inspection. If the RO believes that a change to the sailplane may have a significant effect on weight and balance, an appropriate weight and balance rated person must be consulted.

2.3. ANNUAL INSPECTORS AND SURVEY INSPECTORS

Annual inspectors and survey inspectors are responsible for ensuring the weight and balance for the sailplane they are inspecting is properly controlled.

Annual inspectors and survey inspectors must check and ensure at each annual or survey inspection, and before issuing a new Maintenance Release, that the weight and balance status is and will remain satisfactory for the further period of service. This includes:

a. The ‘empty’ weight, ‘empty’ CG position, and ‘empty’ moment information must be up to date and recorded in the sailplane logbook.

b. The equipment list and modification status records are up to date.

c. Sufficient and up to date information is available in the sailplane to enable the pilot-in-command to determine the usable load and the load distribution limits which will ensure safe flight, either through suitable cockpit placards, a sailplane loading scheme, or the flight manual in the sailplane with the empty weight and balance data up to date.

At annual and survey inspections, the inspector must check and test those components relevant to W&B for proper function to avoid the CG going aft of the aft limit in flight. For example, the fin water tank must dump satisfactorily in timely sequence with the wing tanks, and where the fin tank quantity is controlled by spill holes, all the spill holes must be clear.

When annual inspectors and survey inspectors detect issues with the weight and/or balance status with a particular sailplane or believe that a change to the sailplane may have a significant effect on weight and balance, an inspector with the relevant Weight & Balance authority must be brought in to assist them to resolve the issues. If an inspector with the relevant Weight & Balance authority is not immediately available, contact either the RTOA for your region or the CTOA for assistance.

2.4. BASIC AND ADVANCED WEIGHT AND BALANCE AUTHORITY

An inspector with a Basic Weight and Balance Authority can perform the following:

a. weigh a ‘simple’ sailplane as defined in MOSP 3 Chapter 20.4,

b. calculate the empty weight and centre of gravity position,

c. calculate the pilot loading range for safe operations for both single and dual seat sailplanes,

d. develop cockpit weight placards for both single and dual seat sailplanes, and

e. certify the weight and balance results.

An inspector with an Advanced Weight and Balance Authority can additionally perform:

a. a weigh of any sailplane,

b. calculate the CG shift for varying fuel loads,

c. calculate the allowable removeable or disposable tail ballast for a given pilot weight for safe operations, and for optimal performance,

d. calculate the pilot arm for a specific pilot or a range of pilots,

e. develop the cockpit placards for sailplane with removeable or disposable tail ballast, and

f. certify the weight and balance results for any sailplane.

3. DEFINITIONS

3.1. MASS

Mass is the property of all matter which resists acceleration (F = ma) and leads to gravitational attraction between objects. Mass is an intrinsic property of matter and is independent of where the matter is or the gravity field it is in. 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.

3.2. WEIGHT

When a mass is brought within a gravitational field such as the Earth's gravitational field, a force is exerted on it. This force is its weight. If an object has a mass of 5 kg then the force (weight) caused by the Earth's gravity would be 5 kg force. The same object on the moon would weigh only 1/6" of it's earth weight (the moon's gravity is 1/6 "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 Earth's 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.

3.3. MOMENT AND MOMENT ARM

A moment is the leverage effect of a force applied at a distance from a pivot point. A moment is defined as a force multiplied by the perpendicular distance to the pivot point. The distance from the line of action of the force measured perpendicular to the pivot point is referred to as the **moment arm** or **arm**. A 10 kg force applied at an arm of 500 mm creates a 5,000 kg.mm moment. Similarly, a 5 kg force applied at an arm of 1,000 mm also creates a 5,000 kg.mm moment.

Typical units of moments are kg.mm. However, some sailplane may use kg.m and sailplane using imperial units may use in.lbs or ft.lbs. Whilst the metric system is preferred, it is sometimes easier to use imperial units if the sailplane data is published using inches or feet and pounds. It is important to be consistent and not mix units together eg kg.mm with kg.m.

Many powered sailplanes use a 'moment index' approach. The moment numbers are divided by a fixed constant to create a moment index to aid calculation. This means that powered sailplanes with higher weights and larger moment arm dimensions which would normally produce very large moment numbers, instead produce much smaller and easier managed moment index numbers.

With sailplane weight and balance, all weights are measured vertically and each associated moment arm is measured horizontally. Levelling the sailplane is important so that the moment arm is measured on a consistent, horizontal axis. Refer to Section 3.11 Datum.

3.4. CENTRE OF GRAVITY

Every object has a point through which the summation of all the moments due to gravity forces acting on all the particles in the body, is balanced. This point is known as the Centre of Gravity, CG.

The centre of gravity can be best demonstrated by suspending an odd shaped body at different points around the perimeter. No matter which point the body is suspended from, the centre of gravity will be directly beneath the point of suspension as shown in Figure 1.

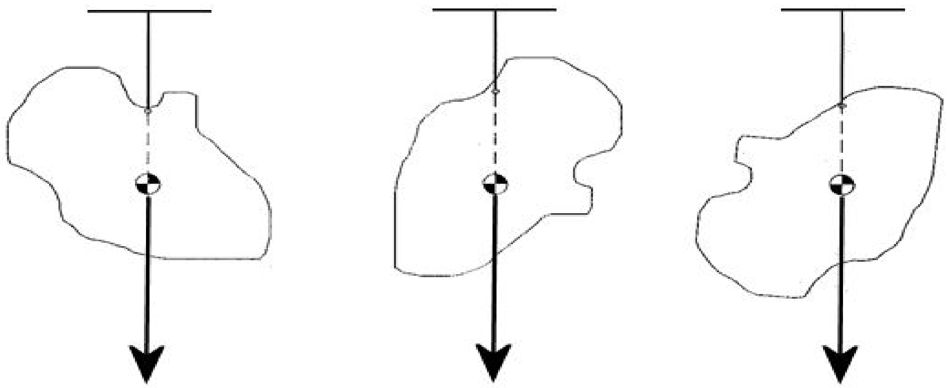

FIGURE 1 CENTRE OF GRAVITY

3.5. MAXIMUM WEIGHT

The maximum weight, often called Max All Up Weight (G_{MAUW}) or Max Take-Off Weight (G_{MTOW}), is the greatest weight which the sailplane may be flown for each approved category of operation (utility category, aerobatic category). 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 particular wingspan option eg 15 m or 18 m.

e. Maximum weight for self launching

3.6. MAXIMUM WEIGHT WITH WATER BALLAST

This is applicable to any sailplane that can take off with water ballast. This maximum weight is often higher than when operating with no wing water because the water ballast weight is distributed along the wing span and this provides wing bending relief in flight. Due to this additional mass in the wings, some sailplanes are not certified to land at this weight.

3.7. MAXIMUM WEIGHT DRY

This may be applicable to any sailplane that can take off with water ballast. This maximum weight is when operating with no wing water ballast.

3.8. MAXIMUM LANDING WEIGHT

This is applicable to any sailplane that can take off with water ballast but is not certified to land with it. If applicable it should be recorded in the TCDS or the Flight Manual. Because of the possibility of launch cable / rope breaks, all modern sailplanes are designed to be able to land at the greatest maximum weight limit of the sailplane.

3.9. MAXIMUM USEABLE LOAD

The useable load is the amount of weight that can be carried in the fuselage. It can be limited by a number of criteria for example: maximum all up weight, maximum weigh of non-lifting parts, seat and baggage limits, etc. The Maximum Useable Load is the lowest of the useable load limits from these criteria.

3.10. 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 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.

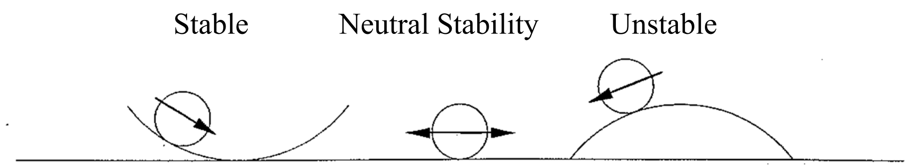

FIGURE 2 STABILITY

In the case of a sailplane, stability is where the sailplane will return to straight and level flight without pilot input when it is disturbed by a gust or similar.

3.11. DATUM

Every sailplane has a prescribed datum which is the reference for any measurements along the longitudinal axis. Viewing the levelled sailplane in side-elevation, the datum is a vertical plane perpendicular to the horizontal axis at a defined fuselage station. All of the moment arms are measured from the datum.

Most sailplanes use the Wing Root Leading Edge as the datum. However there are several that use other datum points like the front face of the engine firewall, the tip of the nose, or specific fasteners in the fuselage. The location of the datum must be known before it is used.

In some sailplane manuals, the translation of captions in diagrams from German manufacturers may still show the datum with a tag 'B.E.' meaning 'Bezugs Ebene' = Reference Plane = Datum.

3.12. WING CHORD

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

3.13. MEAN AERODYNAMIC CHORD (MAC)

The Mean Aerodynamic Chord (MAC) is the basic reference used by designers for stability and other aerodynamic design calculations. The MAC is a weighted average of the wing chord and is calculated by integrating the square of the chord across the span and then dividing by the area. It should not be confused with the Mean Geometric Chord which is the wing area divided by the wing span. An example calculation can be found at:

> Vittorio Pajano, "SAILPLANE DESIGN A Guide for Students and Designers", Appendix Calculation Example 3 "Geometric and Aerodynamic Mean Chord Determination" pages 381 to 383 and Fig 1 E-1 p.371.

Some sailplanes will have their centre of gravity limits specified as being a percentage range of the MAC eg 23% to 45%, together with the distance the leading edge of the MAC is positioned relative to the datum plane. For these cases the MAC will be recorded in either the Type Certificate Data Sheet or Flight / Maintenance Manuals.

Examples:

1. The L13 Blanik has forward sweep of the wing leading edge. Hence the offset of the leading edge of the MAC forward of the WRLE datum is negative. The amount of the

offset is determined at the spanwise wing station where the MAC is located (the leading edge of the MAC and the wing are co-incident).

2. Pipistrel Taurus with Rotax 503 engine:
Mean Aerodynamic Chord is 868 mm
Leading Edge 39 mm aft of the WRLE datum.
Centre of Gravity limits: 23% to 45% of the MAC.
Fwd Limit = 39 + 23% x 868 = 239 mm.
Aft Limit = 39 + 45% x 868 = 429 mm.

Some sailplane types eg IS28B2, the MAC position relative to the datum may change due to hard operational use, such that the wing sweep is changed slightly. The position of the wing leading edge at the MAC location may need to be checked during a weigh.

3.14. CENTRE OF GRAVITY LIMITS

When a sailplane 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 flight behaviour.

With most sailplanes the centre of gravity limits are fixed values independent of sailplane weight. However, some sailplanes have centre of gravity limits that depend on the weight of the sailplane. An example would be a sailplane where the aft centre of gravity limit moves forward at high operating weights. These sailplanes will require an iterative approach in calculating allowable pilot weights.

3.14.1. AFT CENTRE OF GRAVITY LIMIT

As the centre of gravity moves backwards (by adding weight to the tail or removing weight from the nose) the sailplane becomes very sensitive to elevator movements with small control column inputs producing increasingly large nose attitude changes. The pilot would also need to have the stick increasingly forward in order to maintain level flight. Continuing to shift the CG further aft leads to the sailplane becoming unstable in pitch and less stable in yaw such that a small bump or gust may result in the pilot losing control over the sailplane. The situation would be uncontrollable regardless of the pilot inputs.

The designer sets the aft CG limit so that the sailplane has safe flying and handling characteristics without requiring exceptional piloting skill.

3.14.2. 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 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 downwards load from the tailplane to balance the sailplane 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.

3.15. EMPTY WEIGHT

The empty weight of a sailplane is defined in CS 22 as the weight of the sailplane prepared for flight (ie batteries, oxygen and cushions installed) but with the pilot, parachute, baggage, fuel and removable ballast removed. Unusable fuel is included in the empty weight.

The word 'empty' in the term 'empty weight' is somewhat misleading as the sailplane is not 'empty' but rather it has **a repeatable configuration** that enables consistent weighing. The sailplane Maintenance Manual may list aspects of the weighing 'empty' configuration, for example: the position of controls. Batteries are required minimum equipment as is an oxygen bottle if installed permanently but not if a temporary fitment.

3.16. WEIGHT OF NON-LIFTING PARTS (WNLP)

The weight of the sailplane fuselage and tailplane in the 'empty' configuration. Some sailplane types include the weight of the main pin in the weight of non-lifting parts. It is important to check the sailplane manuals to verify whether the main pin is included or not.

3.17. MAXIMUM WEIGHT OF NON-LIFTING PARTS (MWNLP).

In most designs, especially those which carry water ballast, the designer sets the Maximum Weight of Non-Lifting Parts G_{MWNLP}. The value may be absent for some vintage sailplane certified to old design standards. The MWNLP is the maximum permitted combined weight of the fuselage, tailplane and any payload in the fuselage (pilot, parachute, drinking water etc.).

The limit is necessary as it limits the amount of bending in the spars at the wing root. Operating the sailplane at Maximum All Up Weight with water ballast distributed in the wings can be permitted because the additional weight in the wings does not contribute to the bending in the spars at the wing root whilst in flight.

> **CAUTION**
>
> Most sailplanes include tail ballast in MWNLP. However, some sailplanes exclude tail ballast from the MWNLP. This varies amongst manufacturers and even between sailplane models made by the same manufacturer. Consult the weight and balance section of the sailplane manuals carefully to determine whether tail ballast is included or excluded.

Most sailplanes have a fixed MWNLP. However, some modern sailplanes have a MWNLP depending on the in flight CG location, with a higher MWNLP if the CG is further aft (as less downforce is required at the tailplane to balance the sailplane which causes less wing bending). These sailplanes will need an iterative approach to determine pilot weights.

3.18. BALLAST – REMOVABLE

Weights, generally constructed from brass, 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.

3.19. 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.

3.20. BALLAST – EXPENDABLE (DISPOSABLE)

Ballast that can be jettisoned in flight (typically water) which serves to increase the wing loading and consequently the speed of the sailplane.

3.21. PAYLOAD

Payload is the total weight of pilots, baggage, parachutes etc. It does not include water ballast or usable fuel.

3.22. MAXIMUM FUSELAGE LOAD

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

Maximum Fuselage Load = Payload + Usable Fuel + Fuselage Water and Removable Ballast

3.23. 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.

For most modern sailplanes the seat limit is 110 kg. However, there are some designs which may go as high as 140 kg. Many vintage sailplanes will have a seat limit of only 90 kg or 100 kg depending on the design standard they were certified to. Despite all of the other limits, the seat limit must not be exceeded or else it risks compromising the structural integrity of the seat, the harness and harness attachments in the event of a heavy landing or a crash landing.

3.24. PILOT ARM(S)

The pilot arm is the horizontal distance from the datum to the CG of the pilot seated in the sailplane. The arm for each pilot is usually found in the Type Certificate Data Sheet. Note that the EASA Type Certificate Data Sheets often do not provide pilot arm data and the pilot arm information is in the sailplane flight or maintenance manuals.

Whilst the EASA TCDS format often excludes pilot arm data, it usually includes a comment in the equipment list such as “1 Back cushion (thickness approx. 10 cm / 3.94 in. when compressed) when flying without parachute” or “Other equipment - refer to Manuals”. For example: the SZD-51 Junior manual refers to using a parachute or a 10 cm cushion, the L-S8 series refers to a 5 cm / 2 in cushion. This information needs to be checked.

Generally, the pilot arms are fixed values. Some sailplanes may specify a pilot arm for a particular seat back position, or with a particular cushion thickness in lieu of a parachute, in the sailplane manual. A few modern sailplanes may provide a pilot arm value using an equation or table based on the pilot weight. These typically assume that lighter pilots are shorter and have the seat back rest further forward. Greater care is required with weight and balance calculations that use variable pilot arms.

Procedures to determine pilot arms from sailplane weighs are given in Section 7.1.

3.25. SIGN CONVENTION

The conventions adopted with sailplane W&B work are:

1. The sailplane fuselage is illustrated in side-elevation view with the fuselage nose to the left and fuselage tail to the right,
2. Moment arms measured from the datum towards the tail have positive values,
3. Moment arms measured from the datum towards the nose have negative values,
4. A downward weight acting aft of the datum creates a positive moment with clockwise rotation, and
5. A downward weight force acting forward of the datum creates a negative moment with an anti-clockwise rotation.

Some designers try to eliminate moment arms having negative values by placing the datum at or forward of the sailplane’s nose. However, most designers use the Wing Root Leading Edge (WRLE) as the datum and so inspectors performing weight and balance calculations must understand the effects of the negative numbers.

Four potential cases are illustrated below in Table 1.

	Weight (kg)	Arm (mm)	Moment, (kg.mm)
Case 1: **Add** weight at location **aft** of datum	+ 10	+ 500	+ 5,000
Case 2: **Remove** weight at location **aft** of datum	- 10	+ 500	- 5,000
Case 3: **Add** weight at location **forward** of datum	+ 10	- 500	- 5,000
Case 4: **Remove** weight at location **forward** of datum	- 10	- 500	+ 5,000

TABLE 1 MOMENT CALCULATIONS

Note Case 4 where a weight is removed forward of the datum creates a clockwise (positive or nose up) moment. (-ve) x (-ve) = (+ve) moment.

Figure 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 aft of the datum then the pilot’s moment arm will be positive and if the pilot’s CG is in front of the datum then the pilot’s moment arm will be negative.

4. SYMBOLS

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

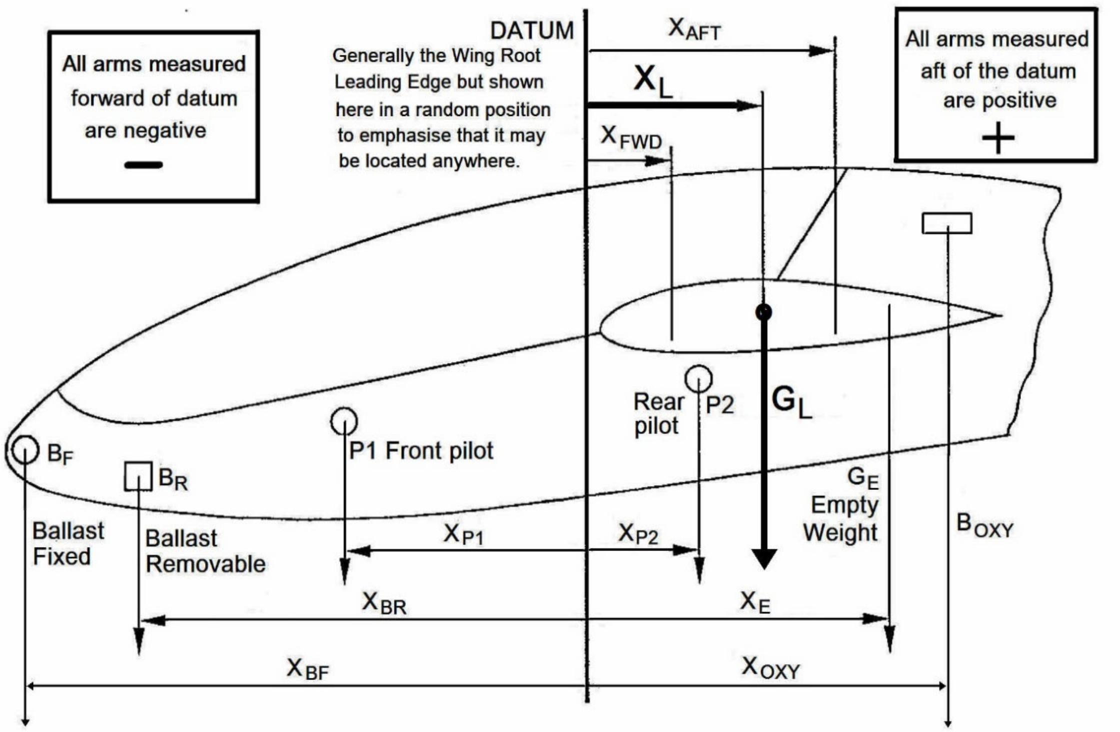

FIGURE 3 SYMBOLS

G_E = Empty weight = G_1 + G_2

G_1 = Front scale reading or the combined weight of both mainwheels for a motorglider with two legged undercarriage

G_2 = Rear scale reading

G_{WF+T} = Empty fuselage plus tailplane (Empty weight of non-lifting parts)

G_{MWNLP} = Maximum allowable weight of non-lifting parts

G_{MWDRY} = Maximum weight dry – no wing water ballast

G_{MAUW} = Maximum all up weight

G_{WINGS} = Empty weight of both wings

G_L = Total weight for a given loading condition L

P_1 = Front pilot weight (or left hand pilot)

P_2 = Rear pilot weight (or right hand pilot)

B = Weight of item

B_B = Baggage weight

B_F = Fixed ballast weight

B_R = Removable ballast weight

B_T = Tail ballast weight

B_{TW} = Tail water ballast weight

B_{FUEL} = Weight of fuel in the particular fuel tank being considered

B_{OXY} = Oxygen system weight

X_E = 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_B = Arm of item from datum

X_{BB} = Arm of baggage from datum

X_{BF} = Fixed ballast distance from datum

X_{BR} = Removable ballast distance from datum

X_{BT} = Tail ballast distance from datum

X_{TW} = Tail ballast water tank CG distance from datum

X_{AFT} = Arm of TCDS aft CG limit from datum

$X_{SAFEAFT}$ = Safe aft Centre of Gravity limit at 5% of the permitted flight CG range forward of the aft TCDS limit (See Section 6.2)

X_{FWD} = Arm of TCDS forward CG limit from datum

X_{FUEL} = Fuel tank contents CG distance from the datum for the fuel tank being considered

X_{OXY} = Arm of Oxygen system from datum

X_L = Arm of sailplane CG from datum for a given loading condition L

M_E = Total moment with respect to the datum with sailplane in the empty weight condition

5. WEIGHING A SAILPLANE

This measurement process determines the sailplane total weight and the total moment with respect to the datum which enables the calculation of the centre of gravity of the sailplane in the specified configuration. The process is subject to a number of potential measurement errors and configuration issues.

This uncertainty due to potential errors is kept to a minimum by following procedures that:

a. ensure that all measurements are as accurate as reasonably achievable or at least within measurement allowed tolerances,

b. ensure the sailplane configuration is appropriate to the measurement task, and

c. accurately record the configuration (equipment and options fitted, etc).

5.1. 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 Type Certificate Data Sheet which has been issued for most types. This data sheet can be obtained from the website of the Airworthiness Authority of the country of origin of the sailplane. For most European sailplanes this will be the EASA website. 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 sailplane from the drawings.

WARNING

When in doubt about type data, do not guess! Contact an RTOA or the CTO for assistance. If a sailplane is weighed using the wrong type data, the weighing is invalid and must be repeated using the correct data.

5.2. WEIGHING MODEL

There are four basic weighing models as shown in Figure 4 below. The correct model for a particular sailplane is determined by the balance of the sailplane on the main wheel when it is correctly levelled (see Section 5.3). If the empty sailplane sits on the main and the tail wheel, then Model 1 or 1a 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.

If a sailplane is essentially balanced on the main wheel when level, it will result in very light tail wheel or nose wheel loads. In this instance Model 3 should be used to improve accuracy.

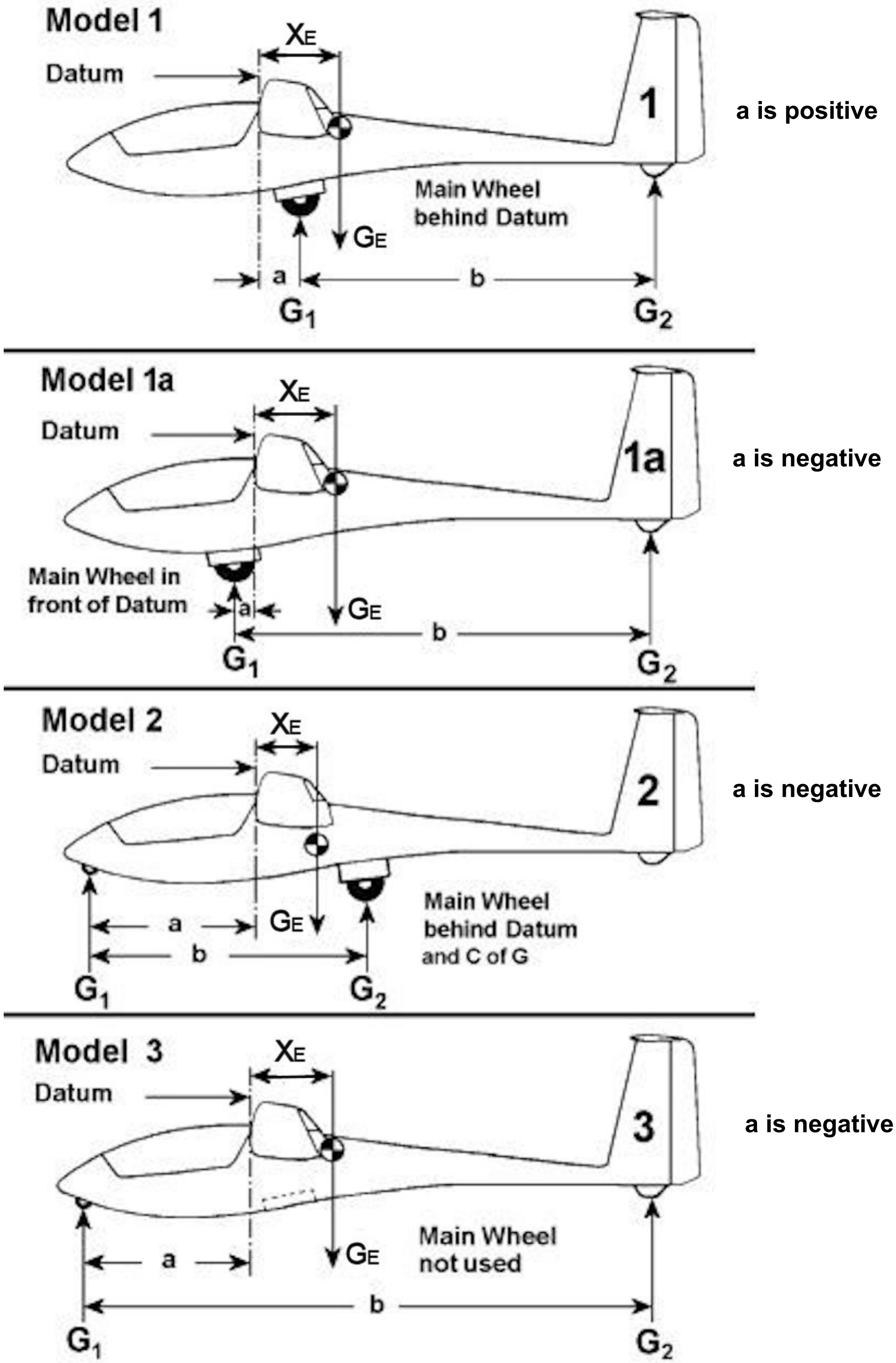

FIGURE 4 WEIGHING MODELS

The sign of the dimension 'a' is as shown in the weighing models shown in Figure 6. Dimension 'b' is always the distance between G_1 and G_2 and is positive. Some sailplanes which look like Model 1, actually have the main wheel in front of the datum as shown in Model 1a. When this happens the inspector must remember that 'a' is negative with Model 1a. In all models the CG position is calculated by:

$$G_E = G_1 + G_2 \qquad \text{(Equation 1)}$$

$$X_E = \frac{(G_2 \times b)}{G_E} + a \qquad \text{(Equation 2)}$$

5.3. LEVELLING

When a sailplane is weighed it must be placed in a standard attitude or level to ensure that there is consistency 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.

The underside or top of the rear fuselage may be used as the level ie similar to the above but without any slope.

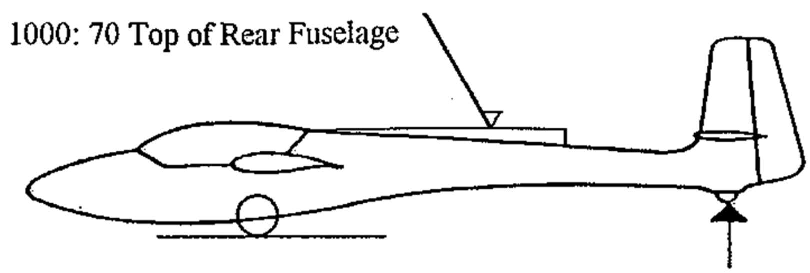

FIGURE 5 EXAMPLE OF REAR FUSELAGE SLOPE.

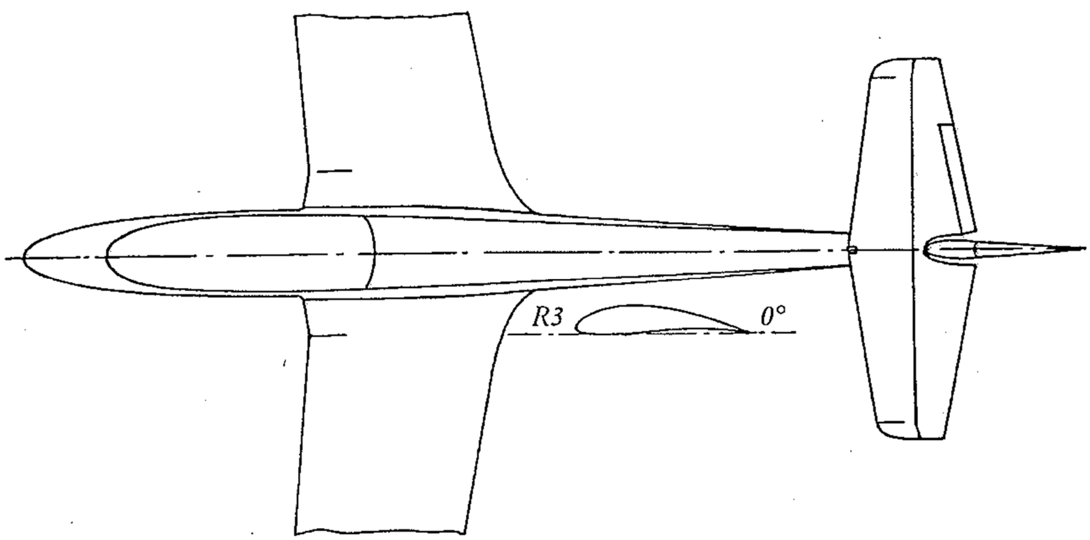

FIGURE 6 LOWER RIB SURFACE LEVEL

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

c. 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 ie similar to the above but with a defined offset. An example 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 7 BERGFALKE LEVELLING

d. 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 sailplane, the level reference must be determined from the TCDS, the sailplane's manuals or on the GFA approved Type Data Sheet (for older vintage types) before weighing can commence. Distances 'a' and 'b' must be measured whilst the sailplane is level.

In a different approach, Jonker Sailplanes are originally measured with the wheels on the ground. A calculated correction is then used to achieve the levelled measurements.

5.3.1. LEVELLING – SPECIAL CONSIDERATIONS

When levelling a sailplane, the inspector needs to be aware that there may be a fault with the level reference 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 CTO should be contacted.

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

Some sailplanes 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 weighs. If the inspector is concerned about this type of fault the CTO should be contacted.

When measuring the geometry of a sailplane that has undergone substantial repairs use a good steel tape measure to measure distances to ensure the sailplane is symmetrical. With the sailplane levelled appropriate measurements can be made eg measuring each wing tip to tail distance to check symmetry of wings to fuselage. Avoid sag errors in the measuring tape by using a plumb bob to mark points on the ground (masking tape and a pen / pencil works well on concrete floors) and measure the distance between the marks with the measuring tape flat on the ground.

5.3.2. 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 reduces the curve of the meniscus which 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 surveyor's level can be used to check sailplane geometry. However, this equipment is generally less available than a water tube manometer.

The accuracy required in measurements is better than 1 part in 500. Example: For a 1000 mm long spirit level, this means less than 2 mm. The more accurate your measurements are, the better the weight and balance results will be.

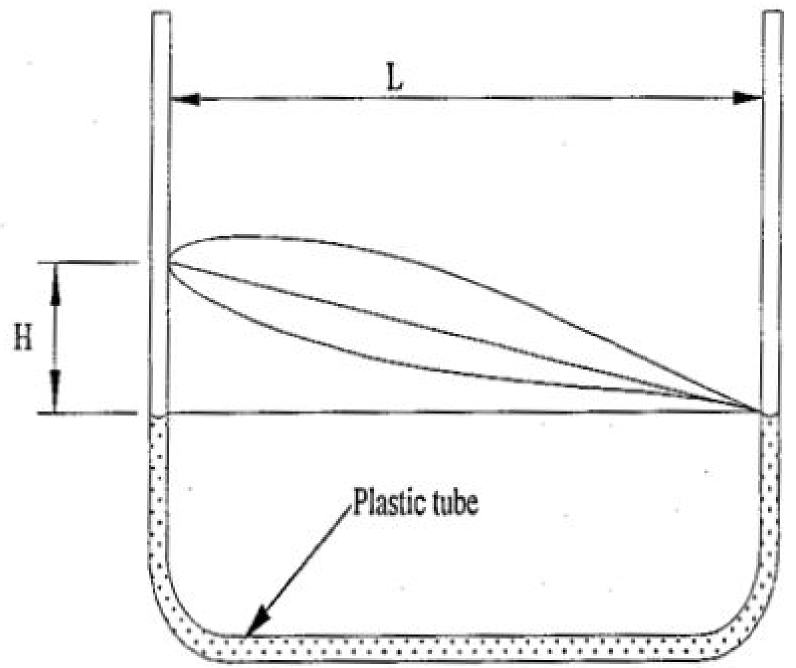

FIGURE 8 LEVELLING USING A MANOMETER

The level reference may specify the height H or the angle of incidence, alpha, of the wing chord.

When H is needed for use with the water manometer, and only the angle alpha is provided, then translate the angle alpha to height H using:

H= L x tangent of angle of incidence α.

If H/L is less than 0.15 then the use H = L x (α in degrees / 57.296)

When using the manometer, as shown in Figure 8, using the actual chord (width) of the wing, instead of L, will result in negligible error if the angle is less than 5 degrees. 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.

5.4. SCALES

5.4.1. SCALE CALIBRATION

Scales must be checked and re-calibrated at no more than 24 month intervals. Refer to MOSP 3 Section 20.3 for current calibration requirements. When conducting a sailplane weigh, the Weight and Balance authority holder must have knowledge of the last calibration date of the scales and whether or not a calibration chart or table resulted from that calibration process.

> **NOTE**
>
> The custodian of the scales should store a copy of the calibration results in a second secure location to prevent loss of vital data.

If the scale performance is not 1 to 1 across the range ie 230.8 kg indicated is 230.8 kg actual, to the extent that the calibration process produces a correction chart, then **the correction chart**

must be available and used to correct indicated scale readings to actual values eg 230.8 kg indicated under reads by 0.4 kg and is 231.2 kg actual.

Bathroom scales are not acceptable as they have unknown calibration, often have considerable errors, and likely to lack repeatability.

In the event of discrepancy between MOSP 3 and this manual, MOSP 3 is the authoritative document.

5.4.2. SCALE ACCURACY

Scales must be able to measure with an accuracy of ± 0.1 kg in the range 0 to 50 kg and ± 0.2% of applied load above 50 kg. Refer to MOSP 3 Section 20.3 for current accuracy requirements.

In the event of discrepancy between MOSP 3 and this manual, MOSP 3 is the authoritative document.

Sailplanes with very narrow CG range may require consideration of scales with higher accuracy than the above. These typically benefit from greater precision in measurement. For example:

1. Sailplanes with high aspect ratios and narrow chord wings like the JS-3 with CG range of 85mm at AUW.
2. Some vintage and amateur built sailplanes like the Hütter H17a with CG range of 40mm, Pascoe EP2 with CG range of 58mm and Woodstock with CG range of 84mm.

5.4.3. SCALE CAPACITY

The Weight and Balance authority holder must use scales with capacities that are appropriate to the respective weight being measured. Scales are often most accurate in the middle of the operating range and less accurate at the ends. High capacity scales should not be used for measuring small weights. Similarly, scales operating near the upper end of their capacity should not be used.

5.5. SAILPLANE CONFIGURATION

The configuration and equipment fitted in the sailplane at the time of the weigh should be thoroughly recorded. This is essential for tracking changes to weight and CG position.

Common causes for weight and balance changes between weighs include instruments being added or updated and not recorded, changing battery technology from sealed lead acid to LiFePO4, oxygen cylinders being changed from steel to aluminium or composite, and changes to the tie down kit.

Some sailplanes have explicit instructions in their manuals as to the sailplane configuration for the ‘empty’ weigh, including the position of the controls.

The Form W1 includes a configuration record sheet to record what was fitted at the time of the weigh. The configuration sheet does not need to be returned to GFA at the completion of the weigh but is to be kept with the weigh results in the sailplane records.

5.6. WEIGHING PROCEDURE

5.6.1. WORK PRACTICES

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

a. Environment: The weighing is best done in a closed hangar to avoid air movements affecting scale readings. A hard horizontal surface is preferred to facilitate accurate dimensions.

b. Sailplane Configuration: The sailplane should be dry with no water ballast and all removable ballast removed. Fuel tank should be empty or at unusable fuel (consult the manuals), whilst other engine fluids (oil, coolant) should be full. Fill out the configuration record at the rear of Form W1.

c. Equipment: Check the scales are suitable and within the calibration date.

d. Power Supply: If the scales are powered by a rechargeable battery, ensure the battery is fully charged. Alternatively 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.

e. Confidence Checks: Zero the scales. In the case of Ruddweigh scales set 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. Carry out a similar check using a small known weight on the tail scales. Ensure that there is nothing obviously wrong with the function of the scales.

f. Appropriate Supports: If the sailplane has a skid (eg. a nose or tail skid) then an upturned 'angle' cross-section support must be placed under the skid to provide a point load at a specific, marked, repeatable and measurable location.

g. Before Zeroing the Scales: Place any wheel chocks or supporting devices (such as cushioning under wings or angles under skids) which need to be used on the load cells and then zero the scales.

h. Load the Scales Centrally: When placing the sailplane on the long bar type load cells it should be positioned so that the load bars / cells do not tilt to one side.

i. Successive Weighs: The empty weight and empty weight CG must be determined from the results of 2 consecutive and independent weighs. The load must be completely removed from the scales between each weighing. Calculate the average of G_1 and G_2 from the two consecutive weighs. If the individual weigh results exceed +/- 1 kg on the mains and +/- 0.1 kg on the tail **from the average**, then further weighs must be performed until the results of 2 consecutive and independent weighs agree within those tolerances. If the two weighs are within tolerance, use the average value for G_1 and G_2 on the Form W1.

j. Double checks: All scale readings and distance measurements need to be checked. A helper should be used to minimise parallax reading errors and reduce the hazards of misreading a number.

k. Working in the metric system: Weigh G_1 to the highest accuracy the scales can deliver. Tail weight G_2 must be weighed to the nearest 0.1 kg. Measure distances to the nearest millimetre.

l. Use a steel tape measure that has an accurate zero point at the end. If forced to use the single available tape with an inaccurate or damaged end, then start at the 100 mm point on the tape, but **you must then subtract 100 mm** from the measurement.

m. 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.

5.6.2. WEIGHING A SAILPLANE

The following procedure is a guide to the critical points of weighing a sailplane using generic electronic scales. Care must be taken to observe specific features of the scales being used.

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 procedure form is included at the end of this section. Use of this form will particularly aid in step (k).

a. The sailplane must be representative of the way it will be operated. The configuration list on the weighing record Form W1 should be completed.

b. Where a sailplane has a Maximum Weight of Non-Lifting Parts limitation, the complete fuselage and complete tailplane must be weighed in the empty condition separately from the wings. In this case levelling is not necessary as you only want total empty weight of non-lifting parts, for later calculation of the available disposable load as limited by the MWNLP.

> **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. Ensure the load cells are reasonably level. If the scales have coarse / fine settings, set the scales to coarse. Zero the scales with chocks / supports (if used) on the scales. This prevents the weight of the chocks / supports being included in the sailplane weight.

d. Wheel the fuselage onto two scales, chock the wheel and take a total empty weight reading. This may be the weight shown on the indicator which automatically adds the 2 load cells together or the sum of the individual scales. Keep the sailplane balanced laterally. There should be absolute minimal force on the fuselage to keep it upright during the weighing. For safety, heavy fuselages should be weighed on a suitable cradle and the scales zeroed with the cradle in situ.

e. Enter the weights onto the procedure form or GFA Form W1 as you go. Ensure the entries are clear and easily read.

f. Take the sailplane off the load cells.

g. Rig the sailplane with the wings.

h. Obtain the levelling reference from the Data Sheet or the flight or maintenance manual.

i. For Model 1 and 1a. Chock the mainwheel and level the sailplane with one load cell under the tail wheel/tailskid. With the scales set to fine (if required) measure 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 (if required) read G_1. It is possible that G_1 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. Keep the sailplane balanced laterally using absolutely minimum hand force at the wing tip.

k. When weighing, always take one reading then remove the sailplane. Check the zero of the scales and reposition the sailplane on the scales. Check the sailplane for correct level. Take a second reading. Calculate the average of G_1 and G_2 from the two consecutive weighs. The individual weigh results will need to be +/- 0.2% of the weight on the mains and +/- 0.1 kg on the tail **from the average** to be acceptable. If the readings are acceptable take the average of the two readings and write the result in Form W1.

l. With the sailplane in the level attitude and 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 to produce floor marks as shown below.

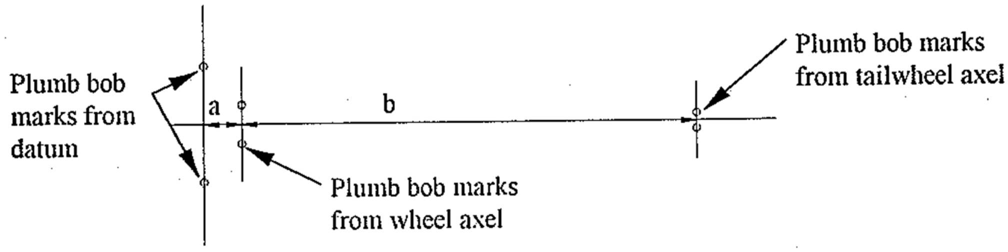

FIGURE 9 MEASURING 'A' AND 'B' FOR MODEL 1

m. Calculate the empty weight, the empty moment and then the distance of the empty CG from the datum point.

n. 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 to the inspectors satisfaction, the results must be viewed with suspicion and re-weighing must be considered.

> **NOTE**
>
> Previous weigh results have been found to be erroneous in some cases. The responsibility is on the Weight and Balance Authority holder to determine what is currently correct.

o. Determine the sailplane loading as per Section 6 below.

5.7. WEIGHT AND BALANCE PROCEDURE FORM

SCALES	Make and Model	Owner	Max Capacity	Resolution	Calibration Date
Main(s)					
Tail					

What steps were taken to check and ensure scale performance on the day? ………………………………

……..

RAW DATA – Component Weights for obtaining G_{WNLP}**:** Weigh wings OR Fuselage and Tailplane

	Wing - Port		Wing - Starboard		Main Spar Pin(s)	Fuselage	Tailplane
	Inner	Outer	Inner	Outer			
Weigh 1	kg	kg	kg	kg	kg	kg	kg
Weigh 2	kg	kg	kg	kg	kg	kg	kg
Average	kg	kg	kg	kg	kg	kg	kg

RAW DATA – Rigged Sailplane: Averages go to Form W1 and check sum. Check on meeting weighing accuracy requirement. The consecutive Weigh 1 & Weigh 2 'empty' weigh readings for G_1 & G_2 must be within the tolerances detailed in MOSP 3 Section 20 dated 2021 (or later).

		G_1		G_2	Total
Weigh 1		kg		kg	
Weigh 2		kg		kg	
Average		kg		kg	kg
Check Weigh 1 and Weigh 2 within tolerances	1.002 x G_1 Avg	kg	G_2 Avg + 0.1	kg	
	0.998 x G_1 Avg	kg	G_2 Avg - 0.1	kg	

MEASURE DIMENSIONS 'a' AND 'b':

Dimension a (Datum to G1) a is negative if fwd of datum	mm
Dimension b (G1 to G2) b is always positive	mm

RESULTS:

	Date	Weight empty	CG	a	b
Previous Weigh		kg	mm	mm	mm
Current Weigh		kg	mm	mm	mm

Compare the measured a and b with the previous values to validate the a and b used. Discrepancies may require remeasuring to determine the issue(s) or consulting earlier weighs (if available).

Do the changes between the new weigh and the previous weigh have reasonable explanation? ………

Independent checking of results and placards caried out? ……………………………………………………

6. 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 items of payload and disposable load which can be carried.

A side view diagram of the sailplane displaying the configuration, loads, arms and limits is valuable to ensure correct results of calculations, particularly with balance problems where the positioning of loads relative to the flight CG limits must be understood clearly. With a motor glider or unusual sailplane configuration such a diagram is **essential**.

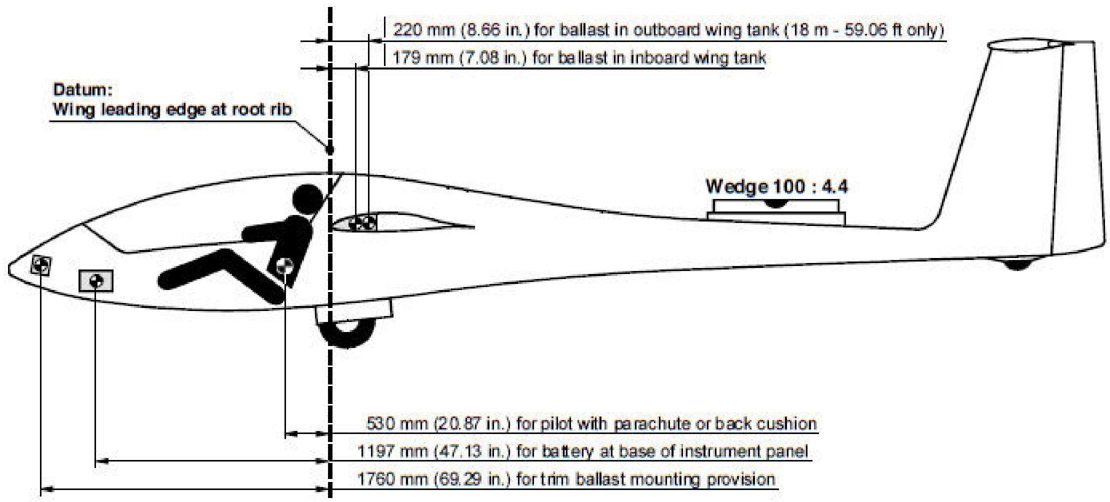

FIGURE 10 LOADING DIAGRAM FOR SIMPLE SAILPLANE

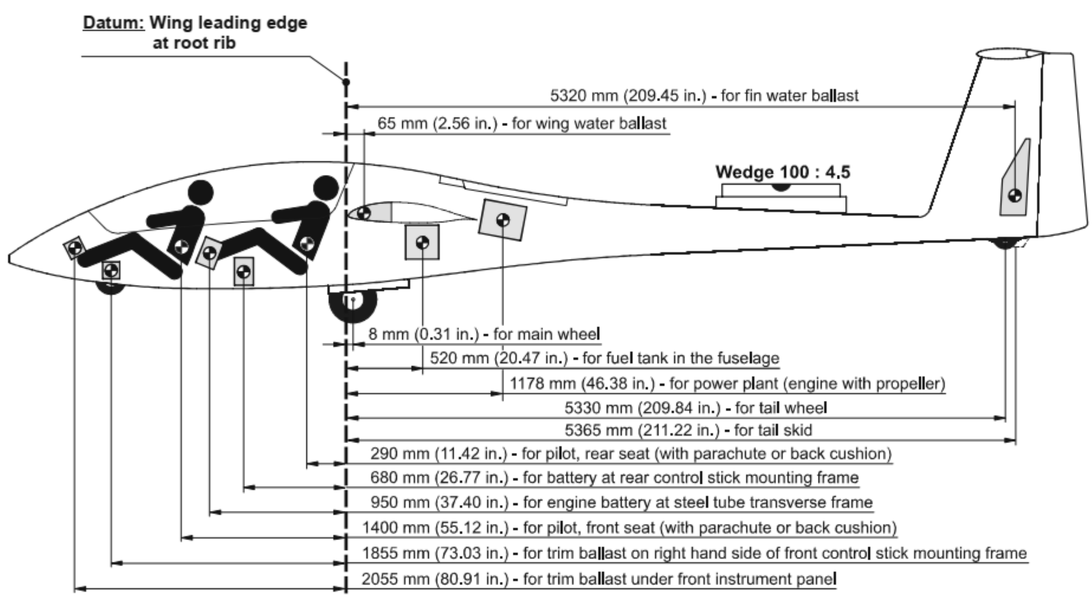

FIGURE 11 LOADING DIAGRAM FOR COMPLEX SAILPLANE

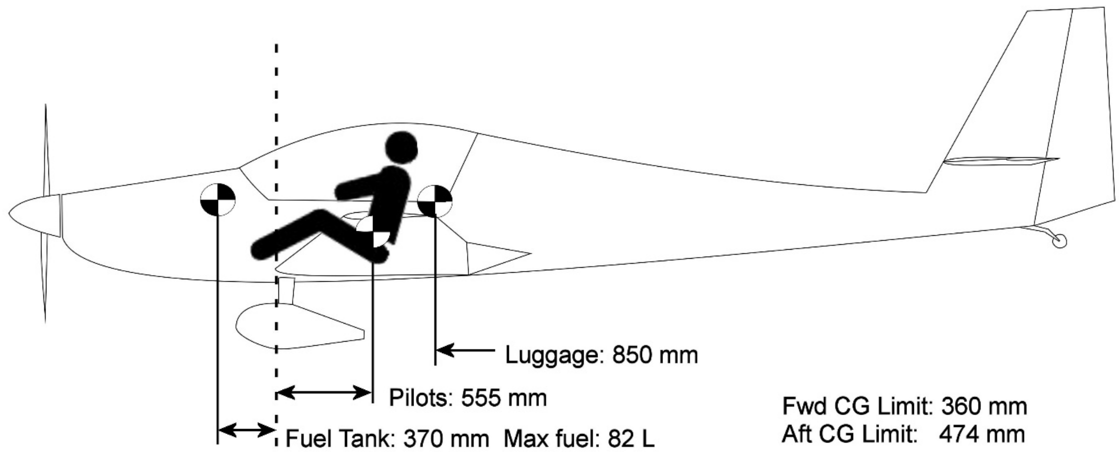

FIGURE 12: MOTOR GLIDER WITH PILOTS BEHIND AFT CG LIMIT

The equations developed in this section of the manual are based on a conventional sailplane layout with pilot(s) forward of the forward flight limit. With complex sailplanes, particularly touring motor gliders with the pilots behind one or both of the CG limits as shown above in Figure 12, you must ensure that the equation(s) remain relevant. If the equations are not relevant, they need to be replaced with appropriate equation(s) or use the sum of moments method. The diagram is very valuable with making that assessment.

6.1. EMPTY CENTRE OF GRAVITY POSITION

The first calculation is to determine the 'empty' Centre of Gravity position, X_E. Using equations 1 and 2 and the data on Form W1 enter the values measured for 'a', 'b', G_1, G_2 and calculate G_E and X_E.

$$G_E = G_1 + G_2 \qquad \text{(Equation 1)}$$

$$X_E = \frac{(G_2 \times b)}{G_E} + a \qquad \text{(a is negative if } G_1 \text{ is forward of datum)} \qquad \text{(Equation 2)}$$

To verify your results, use the sum of moments method as described in Section 11.1 or use the check boxes near the bottom of Page 2 of the Form W1.

6.2. SAFE AFT CENTRE OF GRAVITY POSITION

The weighing of the sailplane is subject to a certain amount of error despite best efforts. There are additional uncertainties when it comes to operating the sailplane with pilots not knowing their weight, pilot's individual CG arm from the datum, and pilot loss of fluid in flight. If these errors accumulate in the wrong way the sailplane may be flown outside its aft limit even though the calculations indicate all is well.

To apply risk mitigation for these errors and uncertainties, it is necessary to have an additional safety margin to the aft CG limit. Accordingly, the additional margin is achieved by using a Safe Aft Centre of Gravity limit which is slightly further forward than the TCDS aft limit. This requirement is defined in Section 20.4 of MOSP 3 and is **mandatory for sailplanes:**

a. **Used for training, Air Experience Flights, and / or passenger carrying, and**

b. **Club sailplanes where a wide range of pilots use the sailplane.**

The application of the safety margin to all other sailplanes is strongly recommended.

NOTE

Pilots operating close to the manufacturers aft centre of gravity limit without using the 5% safety margin on X_{AFT} should have their specific pilot arm determined IAW Section 7.1 to reduce the uncertainty.

The additional margin is 5% of the allowable centre of gravity range ahead of the aft limit. This is calculated as follows:

$$X_{SAFEAFT} = X_{AFT} - 0.05\,(X_{AFT} - X_{FWD}) \qquad \text{(Equation 4)}$$

Throughout the rest of this manual equations involving consideration of flight aft CG limit cases show and employ X_{AFT} as symbol for the aft CG limit. Where $X_{SAFEAFT}$ is mandated, you must substitute the value of $X_{SAFEAFT}$ for X_{AFT}. Where $X_{SAFEAFT}$ is used, the value of $X_{SAFEAFT}$ is to be recorded in the sailplane logbook with the weigh results.

6.3. SINGLE SEAT SAILPLANES

The limiting loading conditions derive either from keeping the loaded sailplane CG within the forward and aft CG limits or keeping the weight below various limits. It is standard practice to round up the pilot minimum weight and to round down the pilot maximum weight.

Advice on balancing the sailplane for optimum performance is at Section 6.9.

6.3.1. THE MINIMUM PILOT WEIGHT

For conventional sailplanes with the pilot seated forward of the flight CG range the minimum pilot weight P_{1MIN} is determined from the aft centre of gravity limit. Take care with the calculation of pilot minimum weight as operating at the aft limit can result in adverse handling characteristics of the sailplane. The weight and balance authorised inspector can set their own aft limit if desired, provided it is forward of the relevant $X_{SAFEAFT}$ / X_{AFT} limit. Whilst this may limit the range of pilot weights or require additional nose ballast, it can improve the sailplane handling qualities and overall enjoyment of the sailplane.

The Minimum pilot weight is calculated using the following equation:

$$P_{1MIN} = \frac{G_E \times (X_E - X_{AFT})}{(X_{AFT} - X_{P1})} \qquad \text{(Equation 5)}$$

For sailplanes (some motorgliders and unconventional sailplanes) with the pilot moment arm aft of the empty centre of gravity, the forward centre of gravity limit determines the minimum pilot weight. In this instance X_{FWD} is used instead of X_{AFT}.

Location of baggage will complicate the equation. If baggage is ahead of the aft limit, baggage is to be zero. However, if baggage is behind the aft limit, the maximum baggage should be included.

The location of the fuel tank will also complicate the equation. For the example sailplane in Figure 14 with the fuel tank ahead of the CG, the minimum pilot weight is determined by the forward CG limit with full fuel. If the fuel tank was behind the cockpit, the minimum pilot weight would be determined by the forward CG limit with nil fuel.

6.3.2. THE MAXIMUM USEABLE LOAD

The Maximum Useable Load is the lowest of the Maximum Loads calculated from several criteria and the seat limit(s). For a conventional simple single seat sailplane, the maximum useable load is the maximum pilot weight in the absence of baggage.

For single seat motor gliders and powered sailplanes with fuel tanks in the fuselage, the maximum useable load will include the pilot(s), baggage and the fuel. An increase in allowable pilot weight can sometime be achieved by limiting the amount of fuel or baggage and wing water ballast.

Limited By Maximum All Up Weight

All sailplanes have a maximum all up weight which must not be exceeded. For some sailplanes there may be two or more maximum all up weight numbers depending on whether wing extensions are fitted, aerobatic or utility category etc. Each case will need to be calculated.

For a simple single seat sailplane without baggage or water ballast:

$$P_{1MAX} = G_{MAUW} - G_E \qquad \text{(Equation 6)}$$

Limited By Maximum Weight Dry

Some sailplanes have a maximum dry weight ie with no wing water ballast. For a simple single seat sailplane the maximum allowable pilot weight based on this limit without baggage is determined by:

$$P_{1MAX} = G_{MWDRY} - G_E \qquad \text{(Equation 7)}$$

Limited By Maximum Weight Of Non-Lifting Parts

The maximum weight of non-lifting parts, G_{MWNLP}, is the maximum permitted combined weight of the non-lifting fuselage plus tailplane in ‘empty’ status, G_{WF+T}, plus any payload carried in the fuselage (pilot, parachute, drinking water, removable ballast, etc). The empty weight of the non-lifting parts, G_{WF+T} is often the limiting factor for maximum useable load on many older sailplanes with major repairs to the fuselage.

Because the maximum weight of non-lifting parts defines the maximum wing root bending, some sailplanes may have two or more maximum all up weight numbers depending on whether wing extensions are fitted, aerobatic or utility category etc. Each case will need to be calculated.

For a simple single seat sailplane without baggage:

$$P_{1MAX} = G_{MWNLP} - G_{WF+T} \qquad \text{(Equation 8)}$$

CAUTION

Typically tail ballast is included in the weight of non-lifting parts. However, there are some sailplane types where the weight of tail ballast is excluded from the weight of non-lifting parts. Check the sailplane manuals for details.

Limited By Forward Centre Of Gravity

For a conventional sailplane with the cockpit ahead of the CG, the forward centre of gravity limit will define a maximum pilot weight. An excessively heavy pilot ahead of the CG may cause the centre of gravity to be forward of the front limit.

For a simple single seat sailplane without baggage:

$$P_{1MAX} = \frac{G_E \times (X_E - X_{FWD})}{(X_{FWD} - X_{P1})} \qquad \text{(Equation 9)}$$

For single seat motor gliders and powered sailplanes with fuel tanks in the aft fuselage, the forward centre of gravity limit is with nil fuel. If the fuel tank is in the forward fuselage, the forward centre of gravity limit is with full fuel.

6.4. TWO SEAT SAILPLANES

Two seat sailplanes must comply with all the above limits and the combined effect of two pilots must be considered.

To produce the Pilot Loading Placard, required by the MOSP 3, it is necessary to set 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.

6.4.1. MINIMUM PILOT WEIGHT

For a conventional sailplane with the cockpit ahead of the CG, the minimum P_2 weight for a particular P_1 value can be determined by:

$$P_{2MIN} = \frac{G_E \times (X_E - X_{AFT}) - P_1 \times (X_{AFT} - X_{P1})}{(X_{AFT} - X_{P2})} \qquad \text{(Equation 10)}$$

This determines the trade-off relationship between the front and rear pilot where a heavier rear pilot can allow a lighter front pilot. This equation is repeated for a range of P_1 weights, normally at 5 kg increments, to produce a cockpit loading chart as shown in Figure 13 below.

For sailplanes where the rear seat arm X_{P2} is very close to the aft CG limit X_{AFT}, the influence of the rear pilot weight on balance at the aft CG limit becomes very small as the arm gets very small. The increments in the range of P_1 weight needs to be reduced (eg 1 kg increments) to produce sensible answers. Equation 10 does not work when $X_{P2} = X_{AFT}$.

For motor gliders or unconventional sailplanes with the pilot weight aft of the empty centre of gravity, the forward centre of gravity limit determines the minimum pilot weight. In this instance X_{FWD} is used instead of X_{AFT}.

The location of the fuel tank with motor gliders will also complicate the equation. For the example in Figure 12 with the fuel tank ahead of the forward CG limit, the minimum pilot weight is determined by the forward CG limit with full fuel. If the fuel tank was aft of the aft CG limit, the minimum pilot weight would be determined by the forward CG limit with nil fuel.

6.4.2. THE MAXIMUM USEABLE LOAD

Limited by Maximum All Up Weight

For a conventional sailplane with the cockpit ahead of the empty CG, the equation for determining the maximum rear pilot weight based on maximum weight without baggage or wing water is:

$$P_{2MAX} = G_{MAUW} - G_E - P_1 \qquad \text{(Equation 11)}$$

For two seat motor gliders and powered sailplanes with fuel tanks in the fuselage, the maximum useable load will include the pilot(s), the baggage and the fuel. This equation becomes:

$$P_{2MAX} = G_{MAUW} - G_E - G_{FUEL} - G_{BAG} - P_1 \qquad \text{(Equation 11a)}$$

An increase in the allowable weight of the pilots can sometimes be achieved by limiting the amount of fuel or baggage carried.

Limited by Maximum Weight Dry

If there is a maximum weight dry the value for G_{MWDRY} should be substituted for G_{MAUW} in equation 11 or 11a.

Limited by Maximum Weight of Non-Lifting Parts

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 (assuming nil baggage):

$$P_{2MAX} = G_{MWNLP} - G_{WF+T} - P_1 \qquad \text{(Equation 12)}$$

For two seat motor gliders and powered sailplanes with fuel tanks in the fuselage, the maximum useable load will include the pilot(s), the baggage and the fuel. This equation becomes:

$$P_{2MAX} = G_{MWNLP} - G_{WF+T} - G_{FUEL} - G_{BAG} - P_1 \qquad \text{(Equation 12a)}$$

An increase in the allowable weight of pilots can sometimes be achieved by limiting the amount of fuel or baggage carried.

CAUTION

Typically expendable or removable tail ballast is included in the weight of non-lifting parts. However, there are some sailplane types where the weight of tail ballast is excluded from the weight of non-lifting parts. Check the sailplane manuals for details.

Limited by Forward Centre of Gravity

For a conventional sailplane with the cockpit ahead of the CG, the equation to ensure the forward CG limit is not exceeded is:

$$P_{2MAX} = \frac{G_E \times (X_E - X_{FWD}) - P_1 \times (X_{FWD} - X_{P1})}{(X_{FWD} - X_{P2})} \qquad \text{(Equation 13)}$$

This determines the trade-off relationship between the front and rear pilot where a lighter rear pilot can allow a heavier front pilot. This equation is repeated for a range of P_1 weights, normally at 5 kg increments, to produce a cockpit loading chart as shown in Figure 13 below.

For sailplanes where the rear seat arm X_{P2} is very close to the forward CG limit X_{FWD}, the influence of the rear pilot weight on balance at the forward CG limit becomes very small as the arm gets very small. The increments in the range of P_1 weight needs to be reduced (eg 1 kg increments) to produce sensible answers. Equation 13 does not work when $X_{P2} = X_{FWD}$.

Limited by Seat Limits

The seats, harnesses and harness attachments are designed with a maximum design weight of the pilot. For most modern sailplanes this is 110 kg. However, check the sailplane manuals to confirm the relevant value.

6.4.3. TWO SEAT LOAD PLACARD

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 for a conventional two seat sailplane is shown below at Figure 13.

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		

SAMPLE ONLY

FIGURE 13 CONVENTIONAL TANDEM SEAT COCKPIT LOAD CHART

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 pilot at 110 kg the rear pilot is limited by the forward CG limit.

6.5. WATER BALLAST

Many sailplanes allow carriage of water ballast 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 water ballast for a given payload:

$$Waterballast_{MAX} = G_{MAUW} - G_E - Payload \qquad \text{(Equation 14)}$$

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

SAMPLE ONLY

FIGURE 14 WING WATER BALLAST LOAD CHART

The addition of wing water ballast 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.

6.5.1. TAIL WATER BALLAST

Tail water ballast was originally designed to counteract the forward CG movement caused by the addition of water ballast in the wings. The flight manual should provide a chart or other means by which the pilot can determine how much tail ballast to add for a given amount of wing water ballast.

Some pilots however try to use the tail water ballast to adjust the Centre of Gravity to allow for pilots heavier than the P_1 minimum to fly with the CG near or at the aft limit. This use has a number of problems.

a. How much tail ballast can be added without moving outside the sailplane's aft CG limit?

b. When the main tanks dump valve is open, the tail tank must also dump to prevent a dangerous aft CG.

c. If a heavy pilot prepares a sailplane for the day but due to a change of plans a light weight pilot flies it without dumping tail water, the possibility exists that the CG will be aft of the aft limit.

If only one pilot flies a sailplane, the best solution is to secure fixed ballast and re-placard the sailplane with the new limits.

The required tail water ballast to increase the minimum pilot weight to a given pilot weight while maintaining CG at the aft limit is given by equations 15 to 17.

Refer to Section 6.6.2 for fixed ballast and Section 6.9 for advice on optimal CG position for performance.

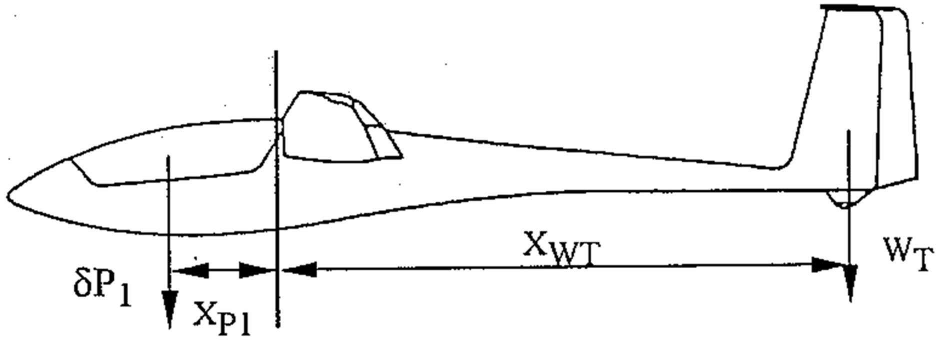

FIGURE 15 ARMS FOR CALCULATING TAIL BALLAST

$$\delta P_1 = P_1 - P_{1MIN} \qquad \text{(Equation 15)}$$

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

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

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

6.6. FIXED BALLAST

Fixed ballast is installed to move the centre of gravity of the empty sailplane 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 heavy 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 (arm) of any additional fixed ballast must be recorded in the sailplane's logbook.

6.6.1. FIXED NOSE BALLAST

Fixed 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:

$$B_F = \frac{G_E \times (X_E - X_{AFT}) - P_1 \times (X_{AFT} - X_{XP1})}{(X_{AFT} - X_{BF})} \qquad \text{(Equation 18)}$$

Ensure that you have the signs for X_{BF} (and other values) correct. For nose ballast, X_{BF} is usually ahead of the datum and is negative.

6.6.2. FIXED TAIL BALLAST

When installing fixed tail ballast for a particular pilot it is necessary to determine the ballast required to place the centre of gravity at a particular place X_L, usually at 80 to 95% aftwards within the allowable flight range. First determine the desired CG position X_L and calculate the require ballast B_F using:

$$B_F = \frac{G_E \times (X_L - X_E) + P_1 \times (X_L - X_{P1})}{(X_{BF} - X_L)} \qquad \text{(Equation 19)}$$

The addition of fixed tail ballast has other effects including a considerable increase in the sailplane's 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 additional fixed tail ballast must be kept below 10 kg unless the manufacturer specifically approves a larger balancing mass.

Ensure that you have the signs for X_{BF} (and other values) correct. For tail ballast, X_{BF} is usually far aft of the datum and is positive.

6.6.3. 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 determined as follows:

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

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

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

If the ballast is in the fuselage and the sailplane has a Maximum Weight of Non-Lifting Parts limit then the new weight of the fuselage and tailplane must be calculated using equation 22 below. The increase in G_{WF+T} leads to a reduced payload. Accordingly locate fixed ballast as far forward or aft as practical in order to minimise the detriment to payload.

$$G_{WF+T\ NEW} = G_{WF+T} + B_F \qquad \text{(Equation 22)}$$

6.7. 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 because unsecured (or inadequately secured) ballast can move in flight, possibly jamming the controls. Furthermore, it can simply be extremely uncomfortable by altering the seat shape. If a pilot weighed 60 kg and the minimum pilot weight was 70 kg then 10 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 modern sailplanes have removable ballast installations built in or available as an option. Modification to install such forward removable ballast capacity is strongly recommended either based on manufacturer's data and parts or in accordance with an approved design.

With the sailplane weighed empty and the weight of the ballast determined separately, the reduced minimum pilot weight can be calculated for each combination of ballast. Typically the ballast is in the form of blocks which are mounted forward of the pilot so less weight is required to achieve the desired balance. They are mounted in the sailplane 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 removable ballast B_R and /or the pilot P_1 are ahead of the datum then the respective arms X_{BR} and X_{P1} are negative.

$$P_{1MIN} = \frac{G_E \times (X_E - X_{AFT}) - B_R \times (X_{AFT} - X_{BR})}{(X_{AFT} - X_{P1})} \qquad \text{(Equation 23)}$$

6.8. 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 the pilot weight(s) are changed, new placards prepared. Use Form W2 to calculate the change in weight and moment.

If the change is large or there have been many changes since the sailplane was last weighed then a full reweigh is required. Section 20 of MOSP 3 defines when a sailplane must be reweighed.

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 for pilot weight(s) and water ballast.

6.9. BALLASTING THE SAILPLANE CG FOR BEST PERFORMANCE

Many competition pilots want to optimise the performance of their sailplane by having the operating CG at a particular point. A popular myth with many competition pilots is that flying with the CG very aft yields the best performance. Unfortunately this arises from these pilots only having a basic grasp of aerodynamic concepts. Operating at the aft CG limit has a greater risk of spinning and takes greater concentration. There is no magic position for the in-flight CG position which is a single point optimum for ultimate performance but rather there is a modest range of CG positions within the allowed flight CG limts which yields best performance.

The ideal solution to sailplane performance arises when the tailplane has minimum drag. Many interpret this as the tailplane having zero load which results in the least tailplane induced drag and a minor decrease in wing induced drag (in most circumstances). However, this neglects to consider the profile drag from the elevator deflection. At higher speeds the tailplane induced drag will be very low whilst the tailplane profile drag will be significantly greater.

To achieve zero tailplane induced drag, the pitching moment of the wing must be balanced by the sailplane mass pitching moment around the 25% MAC. As the pitching moment of the wing will change depending on angle of attack, the balance point for the sailplane CG will shift either forward or backward to compensate. This gets further complicated if the sailplane has flaps, as the flap position will significantly affect the wing pitching moment and hence the balance point for the sailplane CG.

Calculation of the elevator deflection and resultant profile drag is difficult and time consuming. With modern sailplanes it can be difficult to get the aerodynamic data for the custom designed airfoil used on the tailplane. However, some simplifying assumptions can be made.

Many modern sailplane flight manuals have a section that discusses optimal CG position for performance. It is recommended these be consulted prior to adjusting the sailplane CG for competitions.

6.9.1 NON-FLAPPED SAILPLANES.

It will surprise many pilots that the optimum CG for slow or thermalling flight is likely to be the forward end of the CG range depending on the sailplane type. At higher angles of attack, the wing pitching moment is only slightly nose down and the CG needs a shorter arm around the 25% MAC to balance to achieve zero tailplane load for zero tailplane induced drag. However, a very forward CG will require a lot of up negative (upwards) elevator deflection which has a lot of profile drag. The minimum total drag of the tailplane will be around the 10% to 20% position of the CG range depending on the sailplane type.

At cruising speed with a lower angle of attack the wing produces a greater nose down pitching moment and the optimum CG will be further aft in order to find the compromise between tailplane induced drag and tailplane profile drag. At these speeds the tailplane induced drag is very small and the tailplane profile drag will be significantly larger. With the CG at the aft CG limit, the elevator will require more positive (downwards) deflection and hence greater profile drag. The minimum total drag of the tailplane will be around the 80% to 90% position of the CG range depending on the sailplane type.

The best position for cross country performance will be a compromise depending on what percentage of the flight is spent cruising and what percentage is spent thermalling. As a generalisation, optimal in flight CG position is approximately 70% of the CG range depending on the sailplane type and the soaring conditions. If weaker conditions with a greater precentage of the flight spent thermalling are expected, the CG should be adjusted further forwards. If stronger conditions or if streeting is expected with greater time spent cruising, the CG can be tweeked a little aftwards.

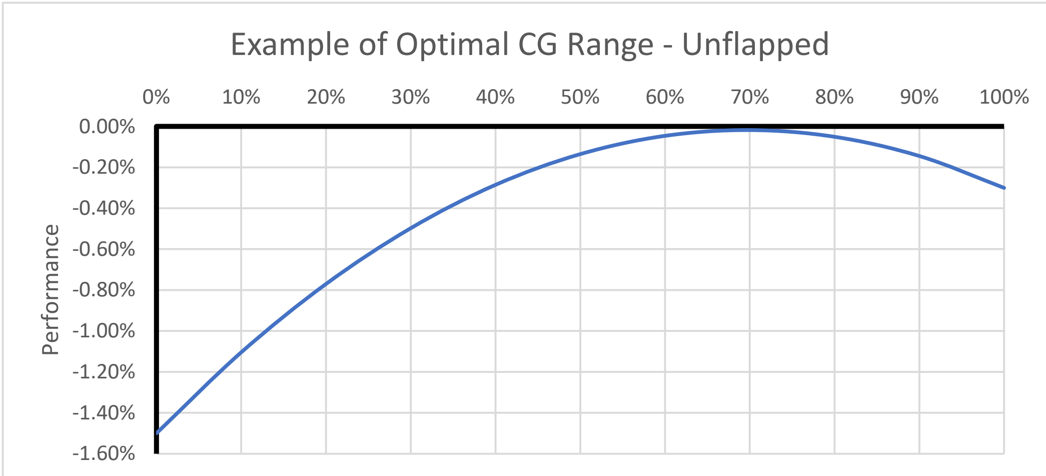

FIGURE 16 EXAMPLE OF UNFLAPPED OPTIMAL CG LOCATION

6.9.2 FLAPPED SAILPLANES.

Flapped wings operate over a small angle of attack range and the flaps are altered to change the sailplane lift coefficient instead of angle of attack. The flaps themselves produce a significant change in pitching moment and have an opposite result for optimal CG compared to non-flapped sailplanes. With positive flap, the flap produces a nose down pitching moment. Consequently, for slow flight and thermalling the optimum CG is in the middle to aft CG range. In addition to balancing the pitching moment for least tailplane induced drag, the middle to aft CG reduces the elevator deflection and reduces the tailplane profile drag.

However, at negative flap angles, the flap produces a nose up pitching moment. As a result, the optimal CG range is well forward, sometimes towards the 10% to 20% position of the CG range on some types. In addition to balancing the pitching moment for least tailplane induced drag, the forward CG reduces the elevator deflection and reduces the tailplane profile drag.

The best position for cross country performance will be a compromise depending on what percentage of the flight is spent cruising and what percentage is spent thermalling. . As a generalisation, optimal in flight CG position for a flapped sailplane is approximately 30% to 40% of the CG range for stong conditions depending on the sailplane type. For moderate conditions, the optimal CG is towards the middle of the CG range.

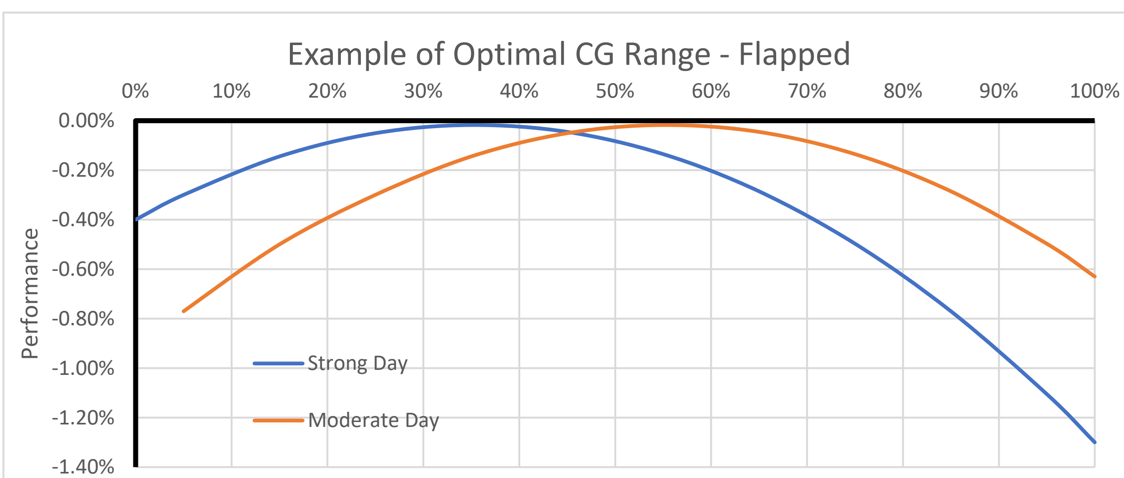

FIGURE 17 EXAMPLE OF FLAPPED OPTIMAL CG LOCATION

6.10. REWEIGHING

Section 20 of MOSP 3 defines when a sailplane must be reweighed and should be checked for updated requirements. A sailplane must be physically reweighed:

a. prior to the initial issue of a Certificate of Airworthiness,

b. if the sailplane has a logbook statement where the sailplane is being maintained IAW the manufacturers system of maintenance and the sailplane's Maintenance Manual requires it,

c. after refinishing of a major component or components of the airframe,

d. after any substantial major repair has been carried out,

e. at each survey or life extension inspection,

f. if the empty weight has changed by more than 2% of the Empty Weight,

g. if the Empty Weight centre of gravity position has changed by more than 5% of the maximum permissible centre of gravity range,

h. whenever an RTO-A or the holder of a Weight Control Authority has reasonable doubt of the accuracy if the current weight data.

i. if the CAD or DCAD (in accordance with MOSP3 Chapter 16) directs that a sailplane be reweighed.

The above circumstances cannot be met by calculation alone.

In the event of discrepancy between MOSP 3 and this manual, MOSP 3 is the authoritative document.

7. DETERMINING PILOT AND BALLAST ARMS

The published pilot arm is a generic number for an average body shape and average seat position. Sometimes the pilot arm for a given type will be unknown or the arm for a particular pilot will need to be determined. Sometimes equipment will be added at a new position without knowing the exact arm. This chapter outlines the method to determine the centre of gravity position (arm) of the pilot or equipment relative to the datum.

7.1. DETERMINING PILOT MOMENT ARMS

To obtain a pilot moment arm accurate enough to use with confidence the sailplane should be weighed with the pilot sitting in the normal position. The results of this weigh along with the results of a concurrent empty weigh without the pilot is then used to calculate the pilot moment arm by calculating the change in CG position. 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.

> **NOTE**
>
> Adjustable seats or adjustable seat backs can have a significant effect on pilot arm. Some sailplanes may require pilot weight versus seat position to be placarded.

> **NOTE**
>
> When a measured pilot arm is used to calculate minimum and maximum pilot weights, the pilot arm must be recorded in the sailplane logbook.

It is important to record in the sailplane logbook the configuration of the pilot(s) and seating arrangement(s) when measured. This enables the results to be recreated at a future weigh. For example:

1. Is the pilot wearing a parachute? What is the parachute model and weight?
2. Is a backrest cushion being used? What is its compressed thickness?
3. Is the backrest adjustable? What is the seatback position?

If the sailplane is being fine tuned for a specific pilot, only weigh the sailplane with that particular pilot. The above seating configuration information may need to be placarded in the cockpit, particularly if the pilot intends to operate near the aft CG limit.

7.1.1. SAILPLANES WITH RIGID UNDERCARRIAGE (NO SUSPENSION)

For a sailplane without suspension on the undercarriage, the recommended procedure for determining a pilot arm is: -

a. Level and weigh the empty sailplane. These results are denoted with the subscript E for Empty Weight eg G_{1E}, G_{2E} and G_E.

> **NOTE**
>
> It is important that weighs without and with the pilot are conducted on the same day sequentially. If done on different days, **strict configuration control is needed** to ensure that the only difference between the two weighs is the pilot (and parachute if worn).

b. Weigh the pilot (with parachute if one is normally worn) separately. Pilot weight = P.

c. The pilot sits in the levelled sailplane with their parachute (if normally worn) and cushions and the seat back adjusted with the canopy shut. It is recommended that harnesses be fastened, and rudder pedals be adjusted to make the seating position normal.

d. Ensure that the sailplane is level and record either the new G_{1N} and G_{2N} according to whether equation 24 or 25 is to be used. These are denoted by the subscript N to indicate the new weight with the pilot.

e. Check that $G_{1N} + G_{2N} = G_E + P$ (allowing for scale measurement accuracy).

f. If not determining the moment arm of a specific pilot, then repeat the procedure with a number of volunteers. Four or more 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 Models 1, 1a and 3:

$$X_P = \frac{b \times (G_{2N} - G_{2E})}{P} + a \qquad \text{(Equation 24)}$$

Equation 24 is also valid for model 2. However greater accuracy may be achieved by using the longer distance from the datum to the nose wheel / skid support point:

$$X_P = \frac{-b \times (G_{1N} - G_{1E})}{P} + a + b \qquad \text{(Equation 25)}$$

NOTE

Sailplanes fitted with suspension will result in changes to dimensions ‘a’ and ‘b’ when the pilot is in the cockpit. Use the calculation method described below and equation 26.

Sailplanes which rotate onto their nose when the pilot gets in require a different weighing model for determining pilot arms than that used for weighing the empty sailplane. The sailplane must be re-levelled and new measurements of ‘a’ and ‘b’ are required. Use the calculation method described below and equation 26.

7.1.2. SAILPLANES WITH SPRUNG UNDERCARRIAGE

For sailplanes with suspension on the undercarriage or sailplanes that tip onto the nose wheel / skid with a pilot on board but sit on a tail wheel / skid when empty, a different equation is used.

a. Level and weigh the empty sailplane. Determine the empty CG position. These results will be denoted with the subscript E for Empty Weight eg G_E and X_E.

b. Weigh the pilot (with parachute if one is normally worn) separately. Pilot weight = P.

c. The pilot sits in the levelled sailplane with their parachute (if normally worn) and cushions, and the seat back adjusted with the canopy shut. It is recommended that harnesses be fastened, and rudder pedals be adjusted to make the seating position normal.

d. Ensure that the sailplane is level and weigh the sailplane with pilot. Calculate the new G_N and X_N. These are denoted by the subscript N to indicate the new weight with the pilot.

e. Check that $G_N = G_E + P$ (allowing for scale measurement accuracy).

f. If not determining the moment arm of a specific pilot, repeat the procedure with a number for all volunteers. Four or more pilots is best provided they give a range of sizes and shapes.

For all weigh models:

$$X_P = \frac{G_N \times X_N \; - G_E \times X_E}{P} \qquad \text{(Equation 26)}$$

For determining the moment arm for a range of pilots, calculate the arm or each pilot weighed. The most conservative of the pilot arms calculated is then selected as the pilot arm for all subsequent calculations. Special care must be taken with the sign of the arms, X. The pilot is generally in front of the datum and thus the pilot arm is usually negative.

7.1.3. EXAMPLE CALCULATION

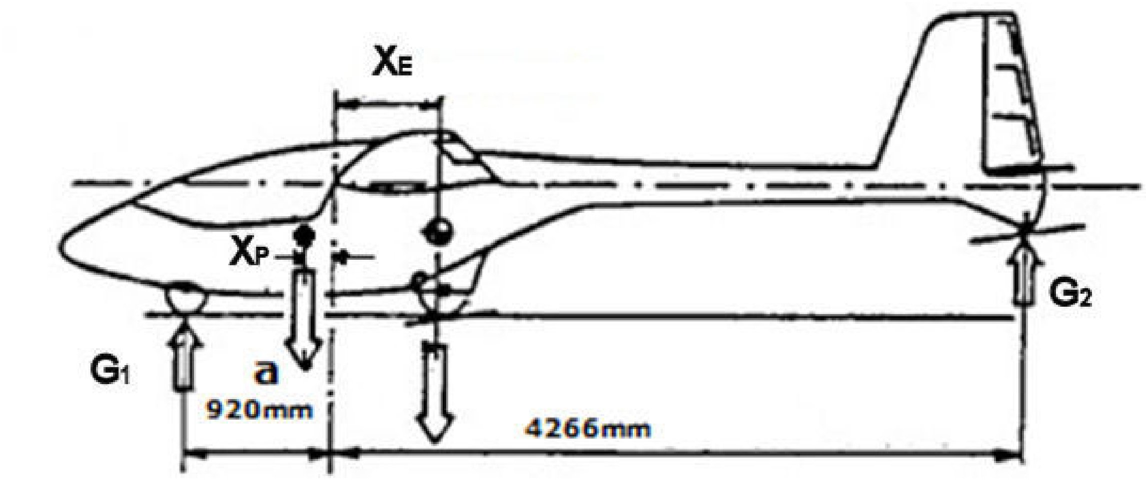

FIGURE 18 EXAMPLE PILOT ARM CALCULATION

A sailplane shown in Figure 18 above was weighed to determine a pilot arm with the seat in the fully aft position.

Nose wheel arm a = -920 mm

Tail wheel arm =4266 mm

Distance between nose and tail wheel b = 4266 – (-920) = 5186 mm

Empty weight G_E = 184.0 kg

Empty tail weight G_{2E} = 54.5 kg

Empty CG X_E = 616.1 mm

Pilot + chute weight P = 88.0 kg

New tail weight G_{2N} = 64 kg

$$X_P = \frac{b \times (G_{2N} - G_{2E})}{P} + a$$

$$= \frac{5186 \times (64 - 54.5)}{88} - 920$$

$$= -360.1 \text{ mm}$$

7.2. ESTIMATING ARMS OF FLUID TANKS

The position of the centre of gravity of fluid tanks can be determined with reasonable accuracy by estimating the centre of gravity of the item at various fluid levels. This can apply to water ballast, fuel, oil and coolant tanks.

With fuel tanks in motor gliders, particularly touring motor gliders, the question can be relevant to the problem where the cockpit loading limit is somewhat restricted and less than full fuel is proposed to be carried so that a higher weight of occupant(s), and potentially baggage, can be carried, provided of course that adequate fuel including required reserves is carried for the intended mission.

NOTE
Fuel is a consumable load. Fuel in a powered sailplane is never to be used as ballast to ensure that the centre of gravity remains within limits.

7.2.1. SYMMETRICAL TANKS

If the tank shape is symmetrical about the vertical axis ie the forward half is the mirror of the aft half when looking at the tank from the side, then the tank arm will be in the middle of the tank and will not vary with fluid level

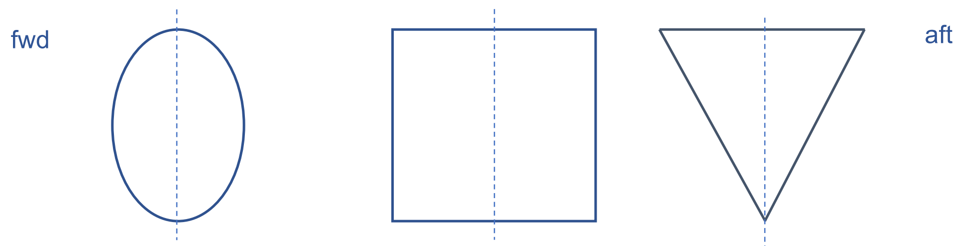

FIGURE 19 EXAMPLES OF TANKS THAT ARE FORE-AFT SYMMETRICAL

7.2.2. ASYMMETRICAL TANKS

If the tank shape is asymmetrical about the vertical axis, ie the forward half is not the mirror of the aft half when looking at the tank from the side, then the tank arm will vary with fluid level. However, many manufacturers will only provide one value for the tank arm. This will be either when the tank is full, or a linear best fit arm depending on how it varies with volume.

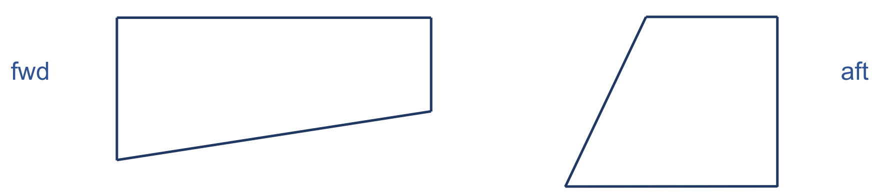

FIGURE 20 EXAMPLES OF TANKS THAT ARE FORE-AFT ASYMMETRICAL

The approach requires the tank shape to be broken down into simple geometric shapes that have simple solutions for their centre of area (centroid). Equations for areas and centroids are easily found online or in engineering textbooks.

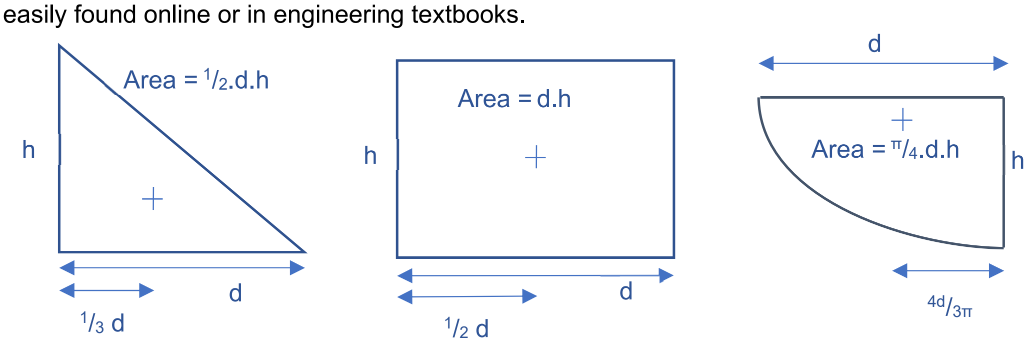

FIGURE 21 EXAMPLES OF CENTRES OF AREA OF SIMPLE SHAPES

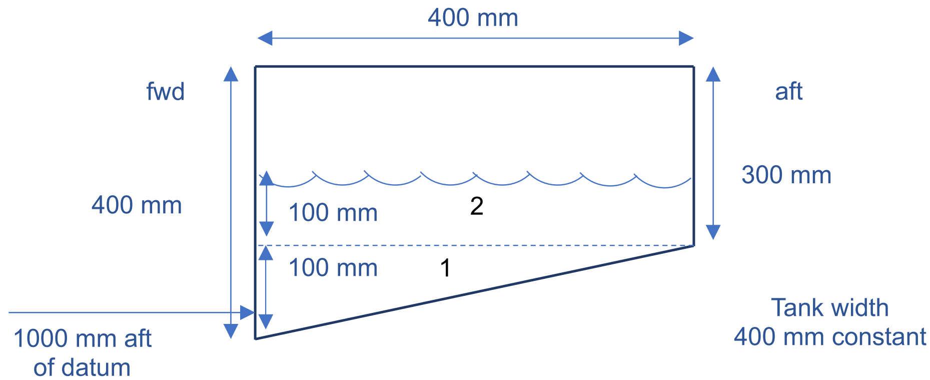

FIGURE 22 EXAMPLE OF 56 LITRE FUSELAGE FUEL TANK

In the example above, the fuel tank can be broken down into a triangle, Volume 1, at the bottom portion and a rectangle on the upper portion, Volume 2. If the tank is 200 mm deep at the deepest part (ie the forward edge) the centroid can be calculated as follows:

$$Volume\ 1 = \frac{1}{2} \times width \times length \times height$$

$$= \frac{1}{2} \times 400 \times 400 \times 100$$

$$= 8{,}000{,}000\ mm^3 = 8\ litres$$

$$Volume\ 2 = width \times length \times height$$

$$= 400 \times 400 \times 100$$

$$= 16{,}000{,}000\ mm^3 = 16\ litres$$

$$Total\ Volume = 16 + 8 = 24\ litres$$

The arms for the individual volumes are calculated as follows:

$$Arm\ 1 = 1000 + \frac{1}{3} \times length$$

$$= 1000 + \tfrac{1}{3} \times 400$$

$$= 1133.3\ mm$$

$$Arm\ 2 = 1000 + \frac{1}{2} \times length$$

$$= 1000 + \tfrac{1}{2} \times 400$$

$$= 1200\ mm$$

The overall arm is found by the sum of the moments. In this example the volume is exchanged for the weight, however either weight or volume can be used:

$$Moment\ 1 = Volume\ 1\ \times Arm\ 1$$
$$= 8\ \times 1133.3$$
$$= 9{,}066.4\ mm.L$$

$$Moment\ 2 = Volume\ 2\ \times Arm\ 2$$
$$= 16 \times 1200$$
$$= 19{,}200\ mm.L$$

$$Total\ Moment = 9{,}066.4 + 19{,}200 = 28{,}266.3\ mm.L$$

$$Arm = \frac{Total\ Moment}{Total\ Volume}$$
$$= \frac{28{,}266.3}{24}$$
$$= 1{,}177.8\ mm$$

This method can be repeated for several depths to reveal how the tank arm varies with volume.

Depth	Vol 1 (L)	Vol 2(L)	Total Vol (L)	Arm 1 (mm)	Arm 2 (mm)	Moment 1	Moment 2	Total Moment	Arm
400	8	48	56	1133.3	1200	9066.4	57600	66666.4	1190.5
350	8	40	48	1133.3	1200	9066.4	48000	57066.4	1188.9
300	8	32	40	1133.3	1200	9066.4	38400	47466.4	1186.7
250	8	24	32	1133.3	1200	9066.4	28800	37866.4	1183.3
200	8	16	24	1133.3	1200	9066.4	19200	28266.4	1177.8
150	8	8	16	1133.3	1200	9066.4	9600	18666.4	1166.7
100	8	0	8	1133.3	0	9066.7	0	9066.7	1133.3
50	2	0	2	1066.7	0	2133.3	0	2133.3	1066.7
0	0	0	0	1000	0	0	0	0	1000.0

TABLE 2 ARM ESTIMATION VERSUS DEPTH

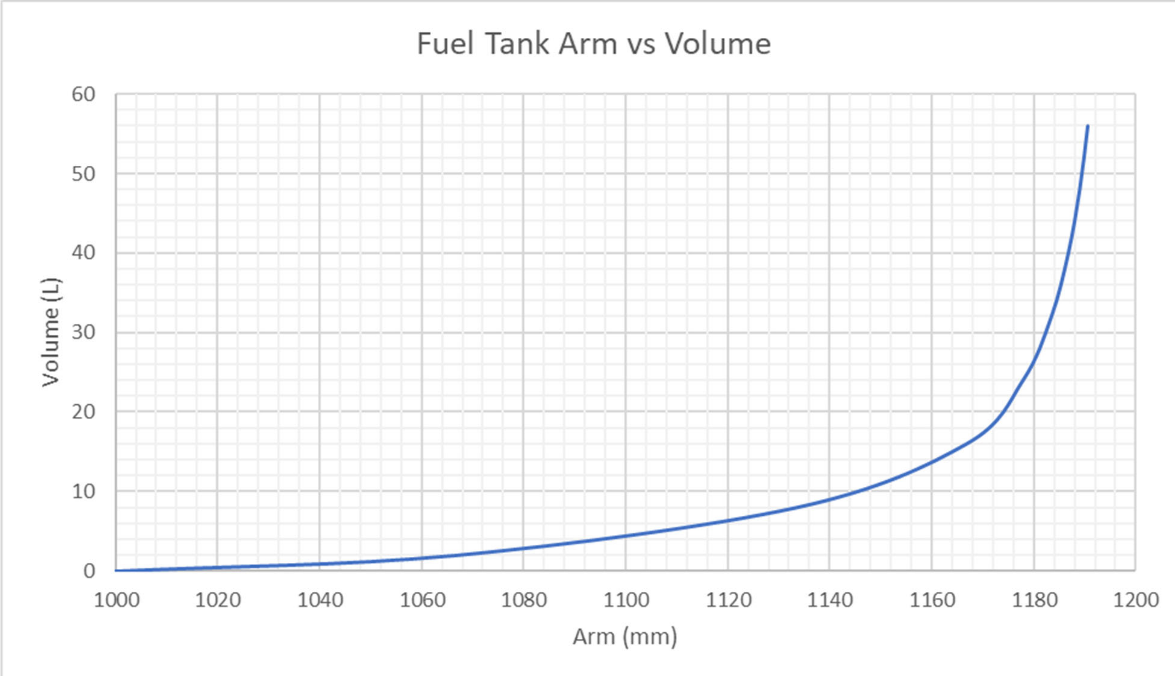

FIGURE 23: EXAMPLE FUEL TANK ARM VS FUEL VOLUME

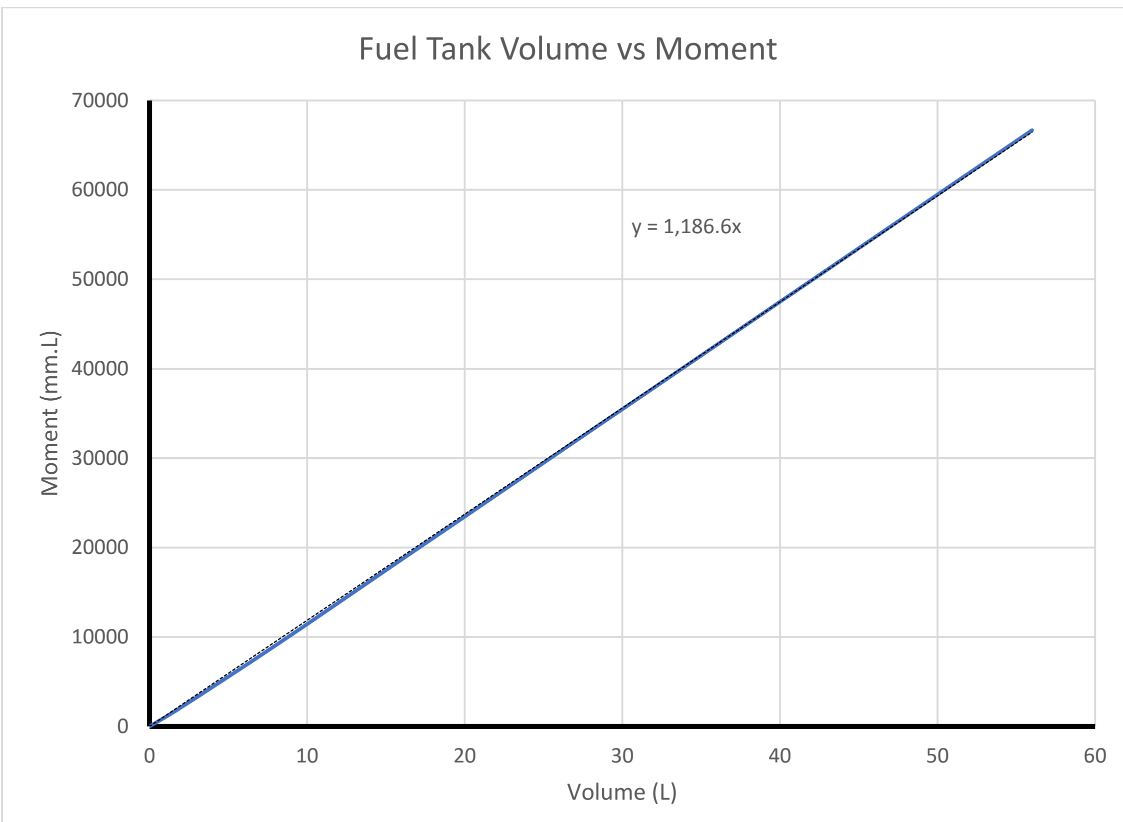

FIGURE 24: EXAMPLE FUEL TANK VOLUME VS MOMENT

Figure 23 plots the Table 1Table 2 data for the volume vs the arm. It shows that the arm starts at the forward edge of the tank and rapidly moves aft as the tank is filled.

Figure 24 plots the Table 2 data for the volume vs the moment (if weight is used to calculate the moment, plot the weight vs the moment instead). Whilst the curve is very straight, it is still a curve. A line of best fit shows the fuel tank arm from the Flight Manual is likely to be 1187 mm. If the pilot is limiting the fuel to 30 litres, to enable the cockpit weight to be increased by 14 kg, then the fuel arm is approximately 1182 mm. The difference with the Flight Manual value is small, less than 0.5%, but the difference gets worse as fuel is consumed. As a general rule, the longer the tank is and the more asymmetric the tank is, the more extreme the change in arm will be with fluid level.

The above example is relatively straight forward as the tank width is assumed to be constant. Where the tank width varies with height, the average width for that depth of each section can be used as an estimate.

This approach works well for tanks that can be broken down into simple shapes. Very complicated tank shapes will be time consuming to estimate and are best calculated by a model on a computer.

An alternative approach is similar to that of determining the pilot arm. Level and weigh the sailplane on scales in the empty weighing configuration and conduct a number of weighs with progressively more fuel / fluid volume added. Ideally fuel will always be located relatively close to the flight CG so that fuel consumption minimises balance influences. Accordingly the weight increase will appear mostly on the main wheel scales, and very high accuracy front scales will be needed to derive fuel arm data from the sequence of weighs. This method can also be used for wing ballast tanks and tail ballast tanks. For tail ballast tanks, the change in weight will be predominantly on the tail wheel scales.

7.3. DETERMINING OTHER ARMS

The position of the centre of gravity of most items of equipment 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 or on an upturned angle extrusion on a flat table.

Sometimes when an item of equipment of component has an irregular shape, or is in an awkward location, or a very precise measurement is required, the arm must be determined by consecutively weighing the sailplane with and without the item as the only change. This process parallels the pilot moment arm determination above.

As long as the weight B of the equipment or component part is known, its arm may be determined using the same equations as for the pilot arm except that the weight of the item is substituted for the pilot weight.

Models 1, 1a and 3:

$$X_B = \frac{b \times (G_{2N} - G_{2E})}{B} + a \qquad \text{(Equation 24.a)}$$

Equation 24.a is also valid for model 2. However greater accuracy may be achieved by using the longer distance from the datum to the nose wheel / skid:

$$X_B = \frac{-b \times (G_{1N} - G_{1E})}{B} + a + b \qquad \text{(Equation 25.a)}$$

Any Model

$$X_B = \frac{G_N \times X_N - G_E \times X_E}{B} \qquad \text{(Equation 26.a)}$$

If the item is in front of the datum the arm is negative. If the item is removed from the sailplane when it was weighed empty, the weight B needs to be entered as a negative number.

Equations 24a and 25a only apply with a rigid undercarriage. If the sailplane has a soft suspension undercarriage, equation 26a has to be used. However, with light objects and a relatively stiff undercarriage suspension there will be very little movement of the mainwheel axle such that equation 24.a or 25.a may be used.

For light weight items installed in or removed from the fuselage, the process can be made more accurate by only weighing the fuselage before and after. Care is needed to ensure that the fuselage is levelled and kept balanced with minimal force applied. Alternatively use the fuselage cradle from the trailer and determine the distance of the cradle axle centre at the mid-point (ie half way between the wheels) to the datum as dimension ‘a’ and the distance of the cradle axle centre at the mid-point to the tail wheel as dimension ‘b’.

8. SPECIAL CASES

The above equations and considerations apply to all sailplanes provided special care is taken with the sign of the numbers (negative for arms in front of datum and also for 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 weight and balance theory to allow for these situations.

8.1. WEIGHING THE IS-28 / IS-29 / IS-30 / IS-32 SERIES

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

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

8.2. FLYING WINGS

Flying wings are relatively rare amongst sailplanes 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 have very short lengths, which puts emphasis on scale calibration, scale levelling and measurement accuracy.

b. The CG range may be short (eg 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.

8.3. CANARD SAILPLANES

Canard sailplanes are also relatively rare amongst sailplanes however some exist. Inspectors who weigh them should already have considerable weight and balance experience as the CG ranges are typically very short and flight outside the CG range becomes rapidly unstable.

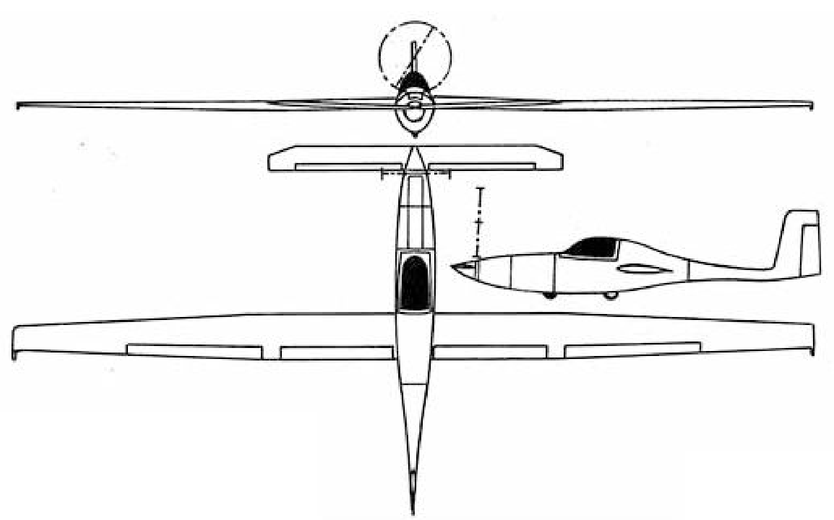

FIGURE 25 RUTAN SOLITAIRE CANARD MOTOR GLIDER

9. 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 from takeoff right through to landing. 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 always 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 or use the sum of moments method. Where an inspector is unsure the CTO must be contacted.

9.1. 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 emptied down to either unusable fuel or completely empty as required. Other fluids eg oil, coolant, and hydraulics may need to be full.

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

SAMPLE ONLY

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

FIGURE 26 EXAMPLE OF POWERED SAILPLANE PLACARD

9.2. 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. Fuel location 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 with water ballast.

c. In some cases fuel use needs to be considered. Some sailplanes may be able to operate with two heavy pilots if less fuel is carried. The arm of the fuel may change with fuel level depending on the tank shape.

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

9.3. 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. In some cases fuel use needs to be considered. Some powered sailplanes may be able to operate with two heavy pilots if less fuel is carried. The arm of the fuel may change with fuel level depending on the tank shape.

d. 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.

10. CHECKING

All weight and balance records, calculations and placards must be independently reviewed and checked. Weighs of simple sailplanes should be reviewed and checked by a second inspector with at least a Basic Weight and Balance Authority. Weighs of complex sailplanes should be reviewed and checked by a second inspector with at an Advanced Weight and Balance Authority. For assistance in finding a suitable reviewer, contact the RTOA of your region or the CTO.

The review and calculation checks shall take place before the log book entries and placard or flight manual page changes are made.

11. COMPUTER SPREADSHEET USAGE

A computer spreadsheet can aid significantly with all of the above calculations, particularly as a check, but much care must be exercised in ensuring that the formulae entered into the spreadsheet are correct. It does make much of the work easier. However, it is very easy to make mistakes that are hidden and a weight and balance spreadsheet containing errors is a serious threat to safety.

Rather than trying to solve all the required equations is one large, complex spreadsheet, it can be easier to employ small spreadsheets covering limited parts of the calculations, for example some trim weight calculation. Small purpose constructed spreadsheets can assist with calculations involving iterative solutions.

In every case, any spreadsheet used for weight and balance MUST be validated to ensure that it is giving the correct answers. The only real way to do this is to do some of the calculations by hand or use known sets of correct data and make sure that these and the spreadsheet agree! Further independent checking is essential, as it can be very difficult to find your own errors in a complex spreadsheet.

11.1. SUM OF MOMENTS METHOD FOR WEIGHT AND BALANCE

This is a very powerful method of calculation for weight and balance purposes and it does not involve complex formulae. As such it is a good way to check your calculations performed by using the equations in the earlier sections.

NOTE

There is a fundamental difference between the Sum of Moments method and the derivation of the equations in Section 6. The Sum of Moments method always uses moment arms relative to the datum. The equations in Section 6 derive moments about the selected pivot point eg the aft CG limit.

The sum of moments method uses a table of the weights, arms and moments for the sailplane. The table works by multiplying the weights by the arms to get the moment for each row. At the bottom of the spreadsheet add up all the weights and all the moments. To get the final CG position, simply divide the total moment by the total weight.

The simplest version is to create a table with at least 5 columns. The fifth column is for comments and similar information. Have a least five rows as shown below, two rows for headings, one each for the front and rear scale weights and arms. The last row is for the totals.

CAUTION

Be careful with dimension ‘b’. It is not the arm to the rear scale.
The arm for the rear scale = a + b. Take care if a is negative.

VH-UVW Weight and Balance				
Item	**Weight (kg)**	**Arm (mm)**	**Moment**	**Comments**
Front Scale	339.9	66	22433	
Rear Scale	46.1	4550	209755	
Total Weight & CG	**384.0**	**601.5**	**232188**	

TABLE 3 EXAMPLE EMPTY SAILPLANE

Add to get the totals in both the weight column and the moment column.

The resultant Arm = Total Moment / Total Weight

For a more complex version, create a table with at least 5 columns as before. Include sufficient rows for the sailplane empty weight, any added or removed equipment, the pilots and their baggage, ballast and anything else to be loaded into the sailplane (including fuel, oil, oxygen systems, etc).

VH-XYZ Weight and Balance				
Item	**Weight (kg)**	**Arm (mm)**	**Moment**	**Comments**
Empty Weight	386	601.5	232179	
Front Pilot	110	-1339.0	-147290	Heavy Solo Pilot
Rear Pilot	0	-247.0	0	
Removable Ballast	0	-1745.0	0	
Total Weight & CG	**496.0**	**171.1**	**84889**	

TABLE 4 EXAMPLE SAILPLANE WITH ONE PILOT

This sailplane, a two seater, has the following limitations:

- CG Range is 92 to 333 mm aft of the datum,
- The Maximum Take Off Weight (MTOW) is 570 kg, and
- There are two 6 kg removable ballast weights which can be installed 1745 mm forward of the datum.

In the example above, the addition of a 110kg solo pilot increases the total weight to 496kg (well below MTOW) and moves the CG to 171.1mm aft of the datum, which is well within the allowable CG range.

To add an instructor to the rear seat, simply enter the instructor’s weight in the appropriate cell. In the example below it can easily be seen that with a 110kg pilot in the front seat, the instructor must be limited to 74kg to keep the sailplane below MTOW. CG is not an issue, at 116.9mm aft of the datum, it is still well within the allowable CG Range.

VH-XYZ Weight and Balance				
Item	**Weight (kg)**	**Arm (mm)**	**Moment**	**Comments**
Empty Weight	386	601.5	232179	
Front Pilot	110	-1339.0	-147290	Heavy Front Pilot
Rear Pilot	74	-247.0	-18278	Medium Rear Pilot
Removable Ballast	0	-1745.0	0	
Total Weight and CG	**570.0**	**116.9**	**66611**	Right on MTOW

TABLE 5 EXAMPLE SAILPLANE WITH TWO PILOTS

A similar approach can be used for a minimum weight solo pilot. The table below clearly shows that a 48 kg solo pilot needs both removable ballast bars to remain within the allowable CG range. A 47 kg pilot will push the sailplane past the rear CG limit.

VH-XYZ Weight and Balance				
Item	**Weight (kg)**	**Arm (mm)**	**Moment**	**Comments**
Empty Weight	386	601.5	232179	
Front Pilot	48	-1339.0	-64272	Light Solo Pilot
Rear Pilot	0	-247.0	0	
Removable Ballast	12	-1745.0	-20940	with ballast
Total Weight and CG	**446.0**	**329.5**	**146967**	Aft CG Limit Approached

TABLE 6 EXAMPLE SAILPLANE WITH A MINIMUM WEIGHT PILOT

This method can also be used to update a sailplane's weight and balance after a modification. In this case an oxygen system has been installed, mounted 375mm aft of the datum. The table is used to calculate the new Empty Weight and CG position.

VH-XYZ Weight and Balance				
Item	**Weight (kg)**	**Arm (mm)**	**Moment**	**Comments**
Empty Weight	386	601.5	232179	
Front Pilot	0	-1339.0	0	
Rear Pilot	0	-247.0	0	
Removable Ballast	0	-1745.0	0	
Oxygen Cylinder	5.3	375.0	1987.5	Oxy system installed
Total Weight and CG	**391.3**	**598.4**	**234166.5**	New EWCG

TABLE 7 EXAMPLE SAILPLANE AFTER MODIFICATION

Once the new figures have been entered into the table in the top row, the table can be used to generate the changed placards. The table below now shows that, with the oxygen system installed, the allowable instructor weight has reduced when there is a large pilot in the front seat (was 74 kg, now 68 kg).

VH-XYZ Weight and Balance				
Item	**Weight (kg)**	**Arm (mm)**	**Moment**	**Comments**
Empty Weight	391.3	598.4	234153.92	with Oxy system installed
Front Pilot	110	-1339.0	-147290	
Rear Pilot	68	-247.0	-16796	
Removable Ballast	0	-1745.0	0	
Total Weight and CG	**569.3**	**123.1**	**70068**	

TABLE 8 EXAMPLE SAILPLANE MAX WEIGHT AFTER MODIFICATION

For a more complex sailplane, lines can be added for tail ballast, water ballast, fuel, oil, etc., and the approach is identical.

For generation of placards, an iterative approach can be used. For instance, to calculate the minimum and maximum rear seat pilot weights for each front seat pilot weight, simply enter the particular front seat weight and experiment with rear seat weights to find the max. and min. figures which keep the sailplane within its design limits. The table above is an example of that approach. With 110kg in the front seat, no more than 68kg can be carried in the back seat if the MTOW is to stay within limits. The process is repeated with front pilot weights, 100 kg, 90 kg, etc, to populate the table placarding allowable P_1 and P_2 weight combinations.

As stated at the beginning of this section, spreadsheets must be validated to ensure that they are correct. In using an iterative approach, it is very easy to enter data into the wrong cells, thereby ensuring a wrong result. These errors can then flow into the following calculations. For that reason, it is important to 'protect' all cells (refer to the help section of the spreadsheet you are using for guidance on protecting cells) that you do not need to enter data into. This will help prevent data entry into the wrong cells.

In the example above the only cells that you should be able to enter data into are the weights below the empty weight line. Those are the weight cells for the front pilot, the rear pilot, and the removable ballast.

The data entry cells may be highlighted in yellow background fill to make them stand out whilst leaving the text readable. An alternative is the locked cells may be differentiated by applying a light grey background fill colour, again selected so the text is readable.

11.2. VALIDATION OF A WEIGHT AND BALANCE SPREADSHEET OR PROGRAM

Validation of a spreadsheet or program is the process of ensuring that the spreadsheet or program is working correctly by demonstrating that it produces the correct output results for the given correct input data. This is done by duplicating the computer's work using different methods to check that the computer's results are consistent and correct.

Minor and difficult to detect errors in a spreadsheet or program will likely cause serious errors in the results. In weight and balance calculations these are a serious threat to flight safety. Each Weight and Balance Authority holder must pay attention to the validation as it is the mitigator for this risk.

Methods available to check spreadsheets and programs include:

a. Hand calculation, including use of a calculator;

b. An independent spreadsheet or program; and

c. Using previous known weight and balance input data and output results with the spreadsheet or program to check that the computer results match the previous results.

CAUTION

Apparent errors may not be solely from errors in the spreadsheet or program being validated. Errors in previous weight and balance calculations have been found.

In this context "independent" means that the method used does not depend on the output of the spreadsheet or program being validated. If more than one method of calculation is available, the duplicate calculations should use a different method to that used by the spreadsheet.

For example, if the spreadsheet to be validated is based on the equations in the earlier chapters of this manual, the "Sum of Moments" method may be used to validate it as long as the sheet used for the "Sum of Moments" does not contain links to the sheets being checked. In the case of hand calculations, they should be based on the original measurements and scale readings, not output from the program or spreadsheet being validated.

In duplicating calculations, all elements of the spreadsheet that affect the result must be checked. This means that if the spreadsheet or program extends, for example, to cover wing and tail water ballast options then the inputs need to include some wing and/or tail ballast loading cases so that the broad capability of the program to generate correct outputs is tested. It is insufficient to just test using the limited input data and output results from a simple sailplane.

Generating a number of validated sets of input data with the corresponding output results is essential to using and maintaining the spreadsheet or program used by the Weight and Balance authority holder now and into the future.

Records of the validation calculations must be retained with the Form W1 and may be used by the Weight and Balance Authority holder conducting the independent check.

Validation may be conducted by the person who developed the spreadsheet or program, although for complex systems an independent check by another Weight and Balance Authority holder would be a wise precaution.

12. PLACARDING

12.1. PLACARDS

Cockpit placards aim to give the pilot a simple but sufficient set of rules, within which the pilot can safely fly the sailplane keeping within weight and CG limits. The placards enable the pilot to avoid having to do an actual weight and balance calculation out on the flying field prior to flight.

The minimum placarding requirements are advised in the Manual of Standard Procedures Part 3 at section 8.3.7 to 8.3.9.

Placards must meet the needs of the pilot-in-command (PIC) when walking up to the sailplane to decide the disposable load status for the forthcoming flight. The flight may range across one or two pilots, wing water ballast or no wing water ballast, utility or aerobatic category operations, wing extensions fitted or removed etc. Emphasis must be made on keeping the placard simple and remove extraneous information.

For complex placards, it is worth validating them with a range of pilots for that sailplane to ensure the placard is able to be understood correctly.

12.2. 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 is not required 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 kg to 102 kg) and round up for minimum weights (70.2 kg to 71 kg).

12.3. MANUFACTURER'S PLACARDS

Many manufacturers prepare a set of standard placards which assume a standard (or average) sailplane ie all sailplanes of that type have identical empty weight and empty CG positions. Assuming all aircraft of a batch or type are identical has several flaws. As there are always weight and balance differences between individual sailplanes due to manufacture variation, the standard placard may be unnecessarily restrictive and prevent the individual sailplane using its full loading potential. Alternatively, the standard placard may permit operation outside the weight and balance limits for the individual sailplane.

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

13. LOGBOOK ENTRIES

A weight and balance is incomplete until records are finalised, and the appropriate logbook entries have been made. Reporting to the GFA and the Registered Operator is involved. In certain circumstances reporting may involve the sailplane manufacturer.

13.1. SAILPLANE LOGBOOK

In the green pages at the rear of the sailplane logbook enter the empty weight, CG arm and moment empty from the W1 weighing record together with the date and W&B authority holder certification.

Secure the W1 weighing record page and the Record of Sailplane Configuration pages to the logbook white pages with a suitable durable adhesive or staples. As per MOSP 3, in case the page(s) is/are inadvertently detached, include a written certified endorsement in the logbook stating:

a. An entry is attached,

b. The type of maintenance carried out,

c. The name of the organisation performing the maintenance, and

d. The date the work was certified.

Where $X_{SAFEAFT}$ is used to work out loading limits, the value of $X_{SAFEAFT}$ shall be recorded in the sailplane logbook with the weigh results. Refer to Section 6.2.

Where a measured pilot arm is determined from weighs and then used to calculate minimum and maximum pilot weights, the pilot arm and its determination shall be recorded in the sailplane logbook. Refer to Section 7.1.

13.2. RECORDS TO BE SENT TO GFA

The W1 weighing record (page 2) and pilot weight determination (page 3) shall be emailed to GFA via returns@gfa.org.au for placing in the sailplane file kept by GFA.

13.3. RECORDS TO BE SENT TO REGISTERED OPERATOR

The following must be sent to the Registered Operator of the sailplane:

a. Sailplane Logbook including the Form W1 Weighing record (one page), pilot weight determination (one page) and Record of Sailplane Configuration (two pages).

b. Records of placards new or revised, or loading system changes.

c. Records of any further weight and balance calculations, relevant pilot arm and/or relevant fuel arm determinations supporting the resulting weight and balance outcomes.

13.4. RECORDS TO BE SENT TO TYPE CERTIFICATE HOLDER / MANUFACTURER

A life extension inspection specified by the manufacturer / type certificate holder may require that a post inspection weight and balance report be included as part of the life extension survey report required to be submitted to the manufacturer / type certificate holder. The life extension may be conditional on receiving back from the manufacturer / type certificate holder written agreement to the life extension. This is becoming more common with current production sailplanes.

If a sailplane is maintained in accordance with a logbook statement to follow the manufacturers maintenance schedule, it may be a requirement to regularly reweigh the sailplane. As part of these requirements the results of the weight and balance may need to be sent to the manufacturer.

13.5. RECORDS TO BE KEPT BY THE WEIGHT AND BALANCE AUTHORITY HOLDER

A copy of all of the above should be kept for each sailplane weighed.

At the minimum a log of weighs performed by the authority holder must be kept including which sailplane, the date, and the scales used.

Such records are of great benefit to the authority holder when they are being considered for renewal of their Weight and Balance Authority, and essential when applying for consideration for upgrade to the Advanced W&B Authority.