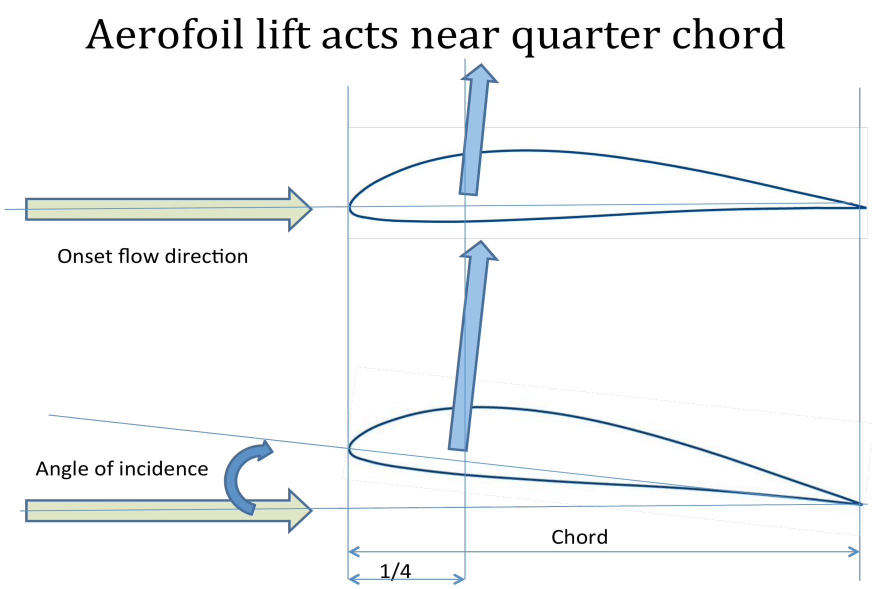
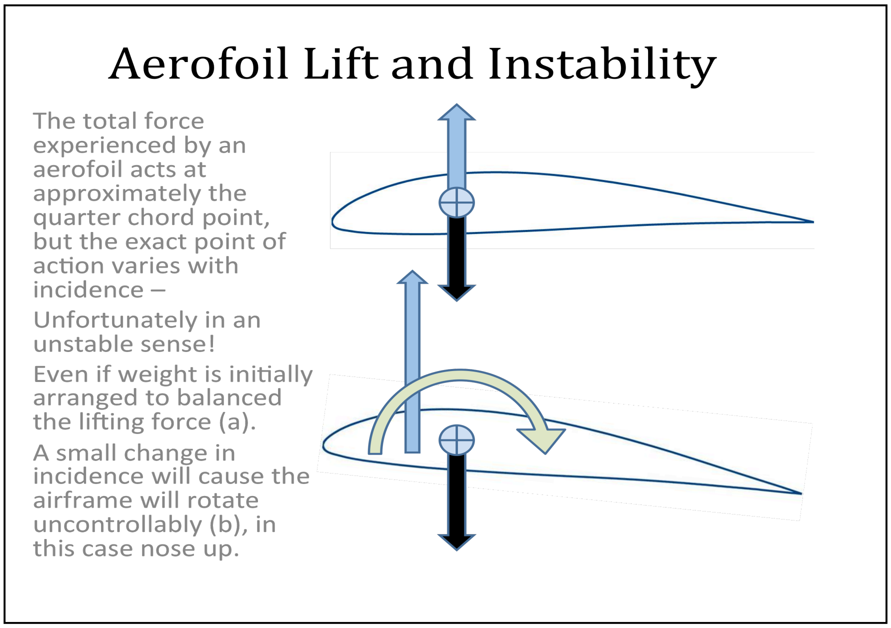
HOW AND WHY DO GLIDERS FLY - WHAT SHAPE SHOULD THEY BE?

What is flight? We all understand that air is a fluid, not dissimilar to, if lighter than, water, and we can all appreciate that an immerse body feels external force when it is pulled through the fluid. But to 'fly' in a steady and predictable way, the vehicle must be stable and be amenable to control. So the challenge is to create the lift necessary for flight in a stable and controllable way. First of all, we need a mechanism to create a force to counter that of gravity. The key feature of an aerofoil sectioned wing is its ability to create a significant force largely at right angles to its direction of motion. This force is directly proportion to the angle at which the aerofoil meets the airstream, provided this angle is not too large, there are limits!



The flow over a single isolated aerofoil generates a largely lifting force, which acts substantially at its quarter chord position: that is, one quarter of the length of the aerofoil behind the leading edge. This point of action is sometimes referred to as the 'centre of pressure' (CP). If by chance or design, an airframe with its centre of gravity (CG) at the same point would, momentarily, be in balance. Unfortunately, the point of action of the aerodynamic force (CP) moves about, such that as incidence, and lift is increased, there is no restoring force to oppose and stabilise the rotation. Worse still, the typical characteristic of a cambered aerofoil is that the point of action of the lift force(CP) moves forward as incidence and lift increases. Unchecked, this would cause the airframe to topple over backwards! This 'pitch stability' is as important as the generation of lift if the aircraft is to 'fly'.



SOLUTIONS: To guarantee stability, it is important that both:

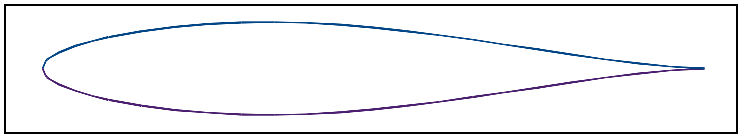
- the centre of gravity is ahead of the point where the overall lift of the aircraft acts, AND
- there exists a mechanism to provide balance (or trim) and control of the aircraft, over the full range of incidence, speed and centre of gravity position.

There are basically two approached to creating a stable airframe:

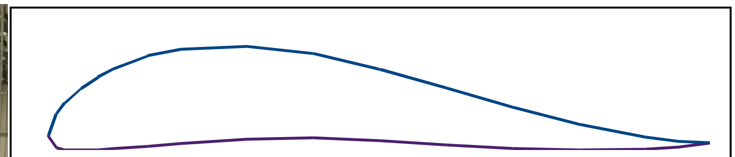
- One could modify the design of a single wing surface design to compensate for the shortcomings (the 'flying wing', see 2 and 3)OR
- One can arrange an airframe between two wing surfaces operating either side of the centre of gravity such that one stabilises the other (see 4 and 5)

SOLUTION 1: MAKE THE LIFT GENERATION PROCESS INHERENTLY STABLE

Some aerofoil sections can be designed to generate lift in a stable way. Indeed pure thickness forms, without any camber or arch are, in fact, neutrally stable, with their lift always acting at the quarter chord position, regardless of incidence angle. This will already lead to poor control characteristics.



The trouble is, they do not have good, efficient lifting capabilities at low speed. Somewhat better are is a class of shapes known as ‘reflex sections’, with an ‘S’ shaped camber line which will actually provide a limited restoring pitch behaviour providing some stability.



These have been used on several straight, or near straight wing tailless gliders affectionately known as ‘pure planks’. As sailplane pilots do not seek a lot of stability, this just about works, but the design is driven by this demand, leaving the designer with few options for creating efficient lift and low drag, so performance is limited.

ADVANTAGES: Compact design. No form drag from a tailplane or long fuselage.

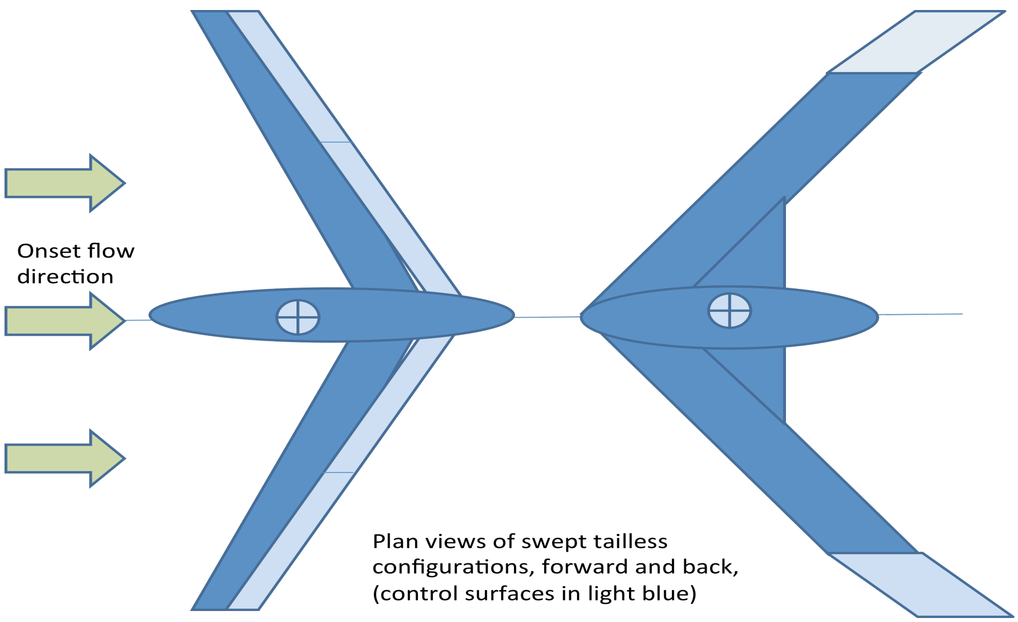
DISADVANTAGES: Poor control authority with close coupled elevator and rudder(s). Centre of Gravity range has to be well forward of 25% and will be narrow in width. Trim drag remains significant, even increased. The design needs big vertical fins for adequate directional stability. Odd, and unpredictable pitch/heave behaviour close to the ground. Basic aerodynamic design efficiency is compromised by the need for an auto-stable wing section characteristic.

EXAMPLES Weltensegler (1921 unsuccessful), Fauvel AV36, AV361 and AV222 (FR above), BKB-1 (Canadian), Backstrom ‘Plank’, Marske Pioneer and Monarch(US)and Stuttgart FS26

FEASIBILITY SCORE: 2/10

SOLUTION 2: SINGLE SWEPT 'FLYING WING'

A swept wing, particularly a long span wing such as a glider, can be designed so that those areas furthest away from the cg can be locally designed to provide the stable restoring properties usually provided by a tail. For pitch stability, sweep forward or back works equally well, but sweep back is generally preferred (see below).   The basic wing section near the CG can largely be designed for lift generation with low drag, but the tip section may to be twisted to provide a contrasting characteristic to the main section. Any twist over the wing span degrades the overall lift efficiency of the wing which, unless very cleverly designed, will have a much lower effective aspect ratio compared to its actual physical aspect ratio. (Aspect ratio, the ratio of span to mean chord is a key parameter when considering lift generation efficiency).



Plan views of swept tailless configurations, forward and back, (control surfaces in light blue)

Genesis II, with tiny elevator only

Braunschweig SB 13 Arcus

Another effect of sweep back is to improve the lateral stability of the aircraft. Swept forward has the reverse degrading effect, and also complex structural stability, so is not generally favoured. Swept back wings rarely need dihedral (as sweep has a similar effect), and also, the trailing tips are convenient places to mount effective fins (or winglets) and rudders.


German Horton IV, all wing sailplane under test in Mississippi State University 1954

ADVANTAGES: Compact design, with no fuselage or tailplane form drag. Some favourable effects on lateral/directional stability (cf planks), but fuselage design can detract from this.

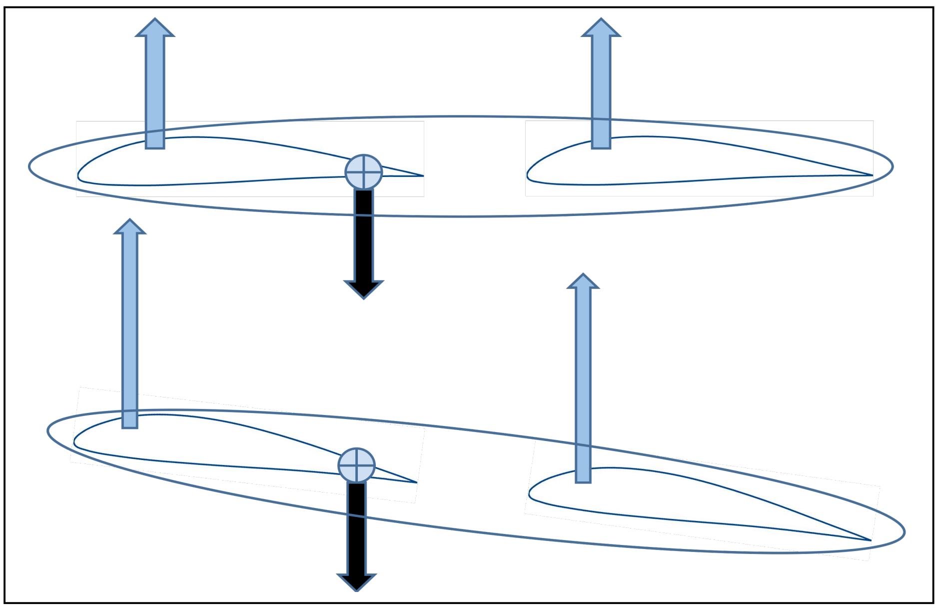
DISADVANTAGES: Structural complexities due to sweep. Stability remains limited by the need to keep sweep angles modest (less than 20 degrees). Poor pitch damping and response. There is significant penalty to lift dependent drag, particularly with twist. With wing tips occupied with fins, rudders and ailerons, elevators are drawn inboard, becoming short couples and complicated in pitch/heave response (idem planks).   Combined ‘elevons’ at the tip are an attractive solution here.

EXAMPLES: Rhon Geist, Storch VIII Marabu, Horton IV and VI (ANY Horton design is interesting, inc Horton XV), Short SB-1, GAL/56 (Military glider with Kronfeld connections), SZD6X Nietoperz, SZD20X Wampyr, Braunschweig SB13, Genesis II.

FEASIBILITY SCORE: 4/10

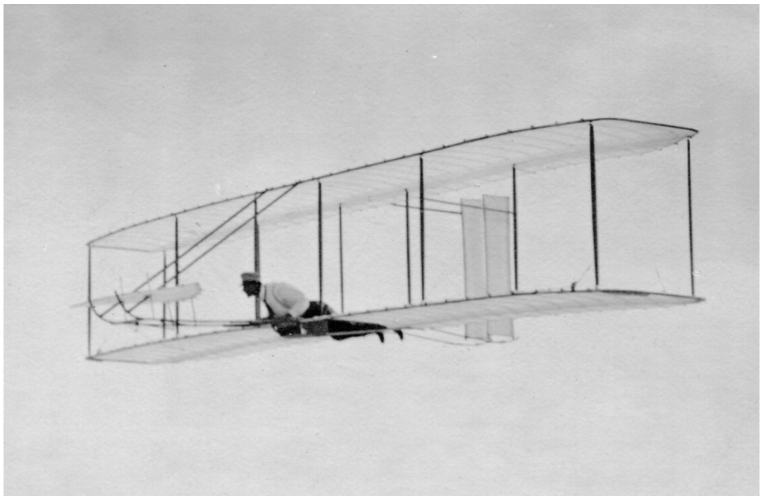
SOLUTION 3: THE TWO SURFACE APPROACH, AND THE CANARD LAYOUT

Two identical planar wing surfaces joined together in tandem, one behind the other, will ensure stability, provided that the centre of gravity is forward of the mid-point between them. The small movements of each surface's centre of lift can easily be overcome by the 'leverage' provided by the second wing (like a see-saw balance analogy). When incidence and lift increase it does so in a 'balanced' way, and small shift is points of action (centres of pressure) are easily accommodated (see below). The long distance of the rear wing from the CG also allows powerful controls to be incorporated to guarantee the necessary pitch power, and a wider range of centre of gravity positions appears to be available.



All that remains is to work out how to scale and position each surface to maximum benefit. It makes sense to arrange for one of the wings to be configured to create the majority of the lift in an efficient design, leaving the second surface smaller and lighter loaded one, in a position to provide leverage for balance, damping and control. BUT WHICH WAY ROUND?

Consider first the ‘tail first’ option, famously favoured by the Wright Brothers, the so-called CANARD configuration. The Wrights tested this approach with gliders during 1902, before successfully fitting an engine.



Wright glider of 1902 using canard layout

This looks good, because as the main (rear) wing increases its incidence and lift, and its centre of pressure move forward, the foreplane will also increase its lift to maintain balance and contributes positively to the overall lift. The total weight, including the pilot, can be placed between the two wing surfaces.

Speed Canard

Rutan Solitaire

The difficulties start when we realise that the foreplane cannot be left lightly loaded under all conditions, and that it is most highly loaded at slow speed. At low speed, it is vital that the foreplane lifts strongly, but it must also stall first the aircraft is to be controllable. Equally, at take off, strong foreplane lift is required to leave the ground. It emerges that the range of CG limits is actually rather more limited than might have been expected. Also, if one requires greater control power, this would logically be done by increasing the foreplane size, but this also has the effect of decreasing the airframe's stability. The canard configuration can commit the designer to quite sensitive trade-offs to achieve a successful all-round design.

For sailplanes in particular, a further disadvantage emerges in that the main (rear) wing is always operating in the turbulent wake of the foreplane. This prevents smooth, clean air from flowing over the main wing and reduces its overall efficiency in lift generation.

Further, there is not much structure behind the CG on which to mount the fin necessary for directional control. If a fin is added behind the rear then the fuselage extends both sides of the main wing, canard at front, fin at rear, which combined with high aspect ratio wing(s), leads to a very unwieldy airframe and negates any parasitic drag advantage.

ADVANTAGES: Combining surfaces ensure that both lift together means that all lift generated is used effectively. The canard design can offer a compact, pilot friendly layout, particularly for a pusher engine installation and/or a swept rear wing, but these are less attractive for sailplanes.

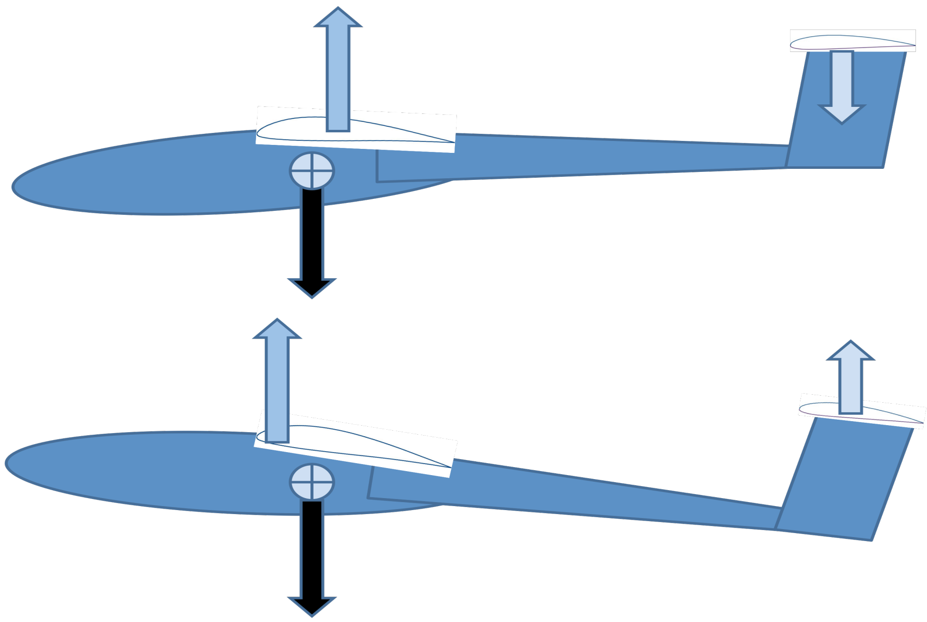
DISADVANTAGES: Foreplane design is sensitive and critical of overall success. Once designed and built, configuration changes can be complicated by conflicting trade-offs. Efficient main wing design is compromised by wake flows from the foreplane. Lateral directional stability is compromised by lack of suitable sites for vertical tail surface with adequate moment arms. Forward vision can be compromised by the foreplane.

EXAMPLES: Wright Bros gliders and Peyret Tandem (both historical), IS-5X Kaczka, Speed Canard, Rutan Solitaire.

FEASIBILITY SCORE 3/10 (for sailplanes, for other aircraft, say 5)

SOLUTION 4: CONVENTIONAL AFT TAIL

So finally we come to the tried and tested option. Place the pilot (and engine) ahead of the main, efficient lifting wing bringing the CG to about 30% chord and mount a tail group (fin and tailplane) on the end of the fuselage boom, solving both longitudinal and directional stability.



In many flight conditions, particularly at high speed, the tailplane will be generating a down force which of course means the main wing has to make extra lift to compensate. Nevertheless this only becomes significant at high speed, when the tailplane can easily and efficiently create such a force and wing efficiency is also unaffected. The tailplane and elevator can be scaled to provide all of balance and trim, pitch damping and control. If any of these are lacking, then a larger tail will improve any or all of the above. Overall efficiency is preserved by having a small tail on a long fuselage boom for maximum leverage.

The ‘T’ tail of a ASW-27 sailplane Schempp Hirth SHK with ‘V’ tail

Current designs favour the ‘T’ tail, mainly for practical reasons, combined with good tailplane effectiveness and low parasitic drag. The ‘V’ configuration (see below) brings complex engineering in the control mix, albeit it is theoretically best for parasitic drag.

DISADVANTAGES: Tailplane and fuselage wetted area, and its structure weight, are additional to basic needs of lift generation and load capacity. Tail is generally operating with a download which demands an additional lift of the main wing, but this element of trim drag can readily be minimised with good design. Maximum control authority demand is a landing round out.

ADVANTAGES: Main wing can operate in full flow of oncoming air in the most efficient manner. Wide CG ranges can be accommodated by scaling the tail size. Design can be optimised easily to minimise additional lift demand which only occurs at high speed when it can be generated easily. The pilot can be situated at front of airframe with a clear view.

EXAMPLES: Just about any sailplane, apart from those listed in other sections above. Probably over 95% of sailplanes types ever designed have this layout. Interesting interpretations are: Darmstadt D-30 Cirrus, Morelli M300 and SZD 56 Diana (very small tailplanes). Fafnir and Slingsby T51 Dart, (‘all flying’tails) and Schempp Hirth Austria SHK (V tail, above)

FEASIBILITY SCORE: 9/10

CONCLUSION

While novelty and variety are always spurs to discussion and speculation, the overwhelming majority of sailplane designs have consistently adopted the now classical small rear tail on a long moment arm solution. This combines a clear well trodden route to design for stability with other measures that enable any potential compromises on performance to be totally minimise. That is not to say that the revolutionists will not stop trying! If, in future, the use of computer automated stabilisation and control comes to be applied to sport aircraft this may allow designers to reconsider other approaches. Even so, active control only adds value provided sufficient control power is provided through well placed control surfaces. Who knows, the tip controlled, twist resistant flying wing may yet make a come back.