Plank vs. Swept

We are often asked to comment on the relationships between planform and performance potential. Our response nearly always focuses on the task (thermal duration, casual slope flying, dynamic soaring, etc.) and the design and building abilities of the person making the inquiry. Because of the positive and negative aspects of plank and swept wing aerodynamics, structure, and construction methodologies, that response can become quite involved.

We’ve made a list of the advantages and disadvantages of the plank and swept wing configurations and created a Table which outlines the major points involved. This month’s column is devoted to expanding on the listed items.

The plank planform impresses would-be designers with its simplicity. Because there is no sweep, the wing can be built using standard construction methods. A spar which is strong in bending supports the wing. Torsional loads, which are quite small, can be carried by the spar, but are better handled with a D-tube structure at the leading edge or through a thin skin which covers the entire wing. The plank wing, if properly designed, requires no twist.

The swept wing, on the other hand, impresses would-be designers with its grace in the air. The internal structure of the swept wing must take into account both a longer effective span and substantial torsional loads. The supporting spar must be strong enough to minimize wing bending under load. (Bending a swept wing in the spanwise direction changes the incidence angle of the wing tip.) Because of weight considerations, the torsional loads are better handled with an engineered skin, usually fiberglass or carbon fiber with the grain running at 45 degrees to the spar rather than a torsionally rigid spar.

The swept wing structure is also complicated by use of winglets. While winglets can improve performance by contouring the air flow near the wing tips, numerous studies have shown the performance improvement falls off dramatically as flight parameters move away from the design point. While there may be some advantages to using winglets rather than a single vertical fin on a thermal duration machine, the spar must accommodate the winglet junction and the various aerodynamic loads the winglet creates as the aircraft moves through various flight regimes.

Planks with taper and small amounts of forward sweep (as typified by a straight leading edge from tip to tip) may be harmed by winglets. Use of winglets or Cessna-type downturned wing tips prevents the outer portion of the wing from stalling with the rest of the wing, and their generated lift is far enough forward to generate a nose up moment. This is quite dangerous and makes recovery from a stall more difficult. If properly set up, a plank of this type should be very nearly stall proof, even with full up elevator. This is because pitch authority decreases as the turbulent flow off the wing blankets the elevator.

From an aerodynamic standpoint, the plank once again offers simplicity. Airfoil design is not complicated, but poses some challenges due to the positive pitching moment required for stability in pitch. The positive pitching moment is almost entirely controlled by the trailing edge angle, mandating some sort of reflex in the mean camber line. While early reflexed sections had relatively large positive pitching moments, the trend toward values closer to zero is now several decades old. Reducing the reflex lowers drag and increases the maximum coefficient of lift. Because the wing is not swept, the air flow tends to remain parallel to the aircraft centerline.

Swept wings obtain their stability through aerodynamic wing twist. Depending on the airfoil(s) used, some amount of geometric twist may be required. As can be easily imagined, twisting the wing is a necessary evil — it's needed for pitch stability, but increases drag during most flight regimes.

Aerodynamic twist is related directly to some design coefficient of lift. As an example, if the wing twist is set up to provide the stability and coefficient of lift required for thermal flight, high speed flight will suffer. Large amounts of down elevator will be required to overcome the effects of the built in washout. This cannot in any way be considered to be aerodynamically "clean." Drag thus tends to be minimal around some single predetermined design point.

Airfoil design for swept wings is challenging as well. While the pitching moment constraint is removed, an airfoil for use on a swept wing must be able to handle some amount of cross-span flow. Airfoils designed using two dimensional flow often fail to meet expectations once sweep is applied. The three-dimensional flow induced by sweep is very much different than the two-dimensional flow which is assumed by the designer and the computer software used.

Swept wings may also be able to take advantage of "induced thrust." Briefly stated, sweep tends to progressively increase the effective angle of attack of outer portions of the wing. Near the wing tips, where the induced upwash is greatest, the lift and drag vectors are rotated forward in relation to the flight path. To maintain a constant effective angle of attack across the span, some amount of washout is needed. and it is possible to produce some small amount of thrust in the outer region of the wing.

But flight is more than simply going forward in a straight line. We want to make sure we can control the aircraft in all three axes — pitch, roll, and yaw — so that we can take off, travel from one area of lift to another, core any thermals we run into, and land safely.

In a conventional tailed aircraft, pitch is handled by the elevator which is mounted on a long arm (the fuselage) well behind the CG. A similar arm is easily applied to a swept wing design by making sure the sweep is sufficient to place the elevator some distance behind the CG. The plank planform is somewhat more limited when it comes to achieving an adequate elevator arm.

There are two generalized means of obtaining the required arm within the plank planform: If the planform is of relatively low aspect ratio, obtaining the arm is not too difficult. The elevators may be placed outboard where they can influence the effective angle of attack of the outer portion of the wing. With the elevators deflected upward, the wing has some amount of effective washout, inhibiting tip stall. Dave Jones' Blackbird 2M serves as an example of this design methodology. As the planform tends to higher aspect ratios, this simple trailing edge placement becomes less effective. The usual way of handling this difficulty is to enlarge the local chord near the wing root so the elevator can be moved inboard and thus further aft.

It should be noted that elevator deflection on a plank planform always works against the desired coefficient of lift. That is, as the elevator is deflected upward to force the wing to a greater angle of attack, it produces a downforce which to some extent counteracts the generated lift. Similarly, it acts as a flap and produces an increase in lift as it is deflected downward to force the wing to a lower angle of attack.

Aileron function is a bit more problematic for swept wing aircraft than for planks, but there are also some tantalizing possibilities. Adverse yaw is the major problem involved in use of ailerons. In conventional aircraft, adverse yaw is compensated for by aileron differential — the aileron moves further upward than downward — and judicious use of rudder. This is not possible on the swept wing because of the aft location of the aileron on the wing. The upward moving aileron, with greater deflection, will always tend to pitch the aircraft upward. There are some rather complicated ways of overcoming this tendency, but these involve either some sort of auxiliary control surface actuated through a mixing function or a special twist and lift distributions.

For a plank with a high aspect ratio tapered planform and a central elevator acting through a large local chord, like the PN9f or Pioneer II, the outboard ailerons are so close to the CG that any differential has no effect on pitch at all. Some method of inhibiting adverse yaw, such as Frise-type control surfaces, may be necessary on a plank with a lower aspect ratio.

A single central vertical fin and rudder can be used quite effectively on a plank planform. Proper contouring of the wing-fuselage junction will normally provide a protrusion behind the wing on which this flying surface can be mounted. If there is no fuselage at all, a lightweight boom can be used. It's important to get a sufficient arm for the fin and rudder to work through. Sweeping the surface rearward can be used to move the aerodynamic center of the flight surface further aft, but it should be noted that a swept hinge line will affect the aircraft in pitch. Some amount of downward lift will be generated each time the rudder is deflected. A swept back vertical fin alone can be used very effectively on designs which do not require a rudder. The statements above hold true for swept wings as well.

Flaps are always an interesting proposition on tailless aircraft. Conventional tailed aircraft can readily handle all sorts of flap deflection. That's because the elevator is mounted on a generous arm, and as long as it's out of the wing wake, it has a lot of control over the aircraft pitch angle and hence the wing angle of attack. Tailless aircraft, whether swept wing or plank, have a shorter elevator arm. This limits the amount of control over pitch that the elevator has, but control problems usually do not arise because of the inherent low moment of inertia. As flaps are deflected, however, large moments can be generated which cannot be acceptably controlled. It's important to formulate the flap size, shape and placement such that deflection does not produce adverse pitching moments.

For a plank, flaps of about five percent of the total wing area can usually be mounted such that their hinge is at 40% of the local chord. Such a placement minimizes any pitching tendency as the flaps are deflected. Deflection angles of 45 degrees are sufficient. It should be noted that flaps of this type are not to be used to improve thermal performance, as the increased lift is far outweighed by the tremendous amounts of drag produced. Such flaps can, however, be used to increase the height achieved on a winch launch and to effectively control the glide path during landing approaches.

Flaps on swept wings can be used as a means of glide path control and to improve both thermal and high speed performance. Again, placement is an issue, as pitch control should not be adversely affected. Flaps for swept wings should be placed at the trailing edge, but their placement along the span is not easily determined. Too far inward and the wing will tend to pitch upward. Too far outboard and flap deflection will force the nose down. Overall size and local chord have an influence as well. Ideally, inner flaps should be deflected downward some small amount while thermalling. The outboard elevons should also be deflected downward to compensate, thus increasing the generated lift across the entire span. If the root section has a negative (nose down) pitching moment, deflecting the flaps upward by a very few degrees will remove the camber at the rear of the wing, reducing the local coefficient of lift and increasing the flight speed.

Inertia in pitch is the one characteristic which we have difficulties evaluating. Our thoughts at this time are that inertia in pitch is one of those “eye of the beholder” items. Pilots used to flying conventional tailed aircraft, which have a large amount of inertia in pitch, are initially uncomfortable with the relative lack of inertia demonstrated by well designed planks and some swept wing planforms. For full size aircraft, like Jim Marske’s Pioneer II and Monarch, lack of inertia in pitch gives a more comfortable ride in turbulence. The aircraft reacts quickly to differences in angle of attack and tends to fly through turbulence by aligning itself with the movement of the local air mass. Tailed aircraft in similar situations tend to bounce up and down. Swept wings tend to react in a way which is somewhere between the two.

Some of those who contemplate flying a plank are quite concerned about the lack of overall length and are worried that they will not be able to see the changes in pitch which allow them to monitor the performance of their tailed aircraft. After a few flights with a plank, however, they don’t miss that piece of feedback at all. It becomes “normal” to let the aircraft seek its own attitude and to control its speed using elevator stick position rather than reacting to perceived fuselage alignment. The same flying method becomes second nature when steering a swept wing around the sky.

From all of the above, it appears a plank would be the choice of the designer looking for an airframe which can be relatively easily formulated and constructed without resorting to composites. Plank performance can be exceptional, particularly within thermal duration tasks, and control systems are essentially similar to those of conventional tailed aircraft.

A swept wing, while it does pose several unique problems so far as design and construction, certainly has the potential for greater performance in all flight regimes. Although control systems for swept wings can be quite complicated, with numerous control surface mixes being the norm, it is possible to tailor the lift distribution across the entire span, greatly increasing efficiency while maneuvering. Additionally, the effective dihedral of swept wings varies in direct proportion to the coefficient of lift, making them very stable in thermals.

In the end, it would seem that the designer who is performance driven may be more willing to expend large amounts of design time for the potential significant performance improvements available from a swept wing. The question as to whether that time and effort is worthwhile, however, is never known until the aircraft is flown.

While we most likely haven’t solved any problems, or defined the specific direction a designer should take in producing an airframe, we hope this treatise has provided some useful information and perhaps initiated some new lines of thought within the minds of readers.

Future “On the ’Wing...” columns will cover two topics related specifically to swept wings — wing twist distribution schemes and “induced thrust.” Perhaps an exploration of these topics will entice a few fence sitters to more intensely investigate the rather unique potential of swept wing planforms.

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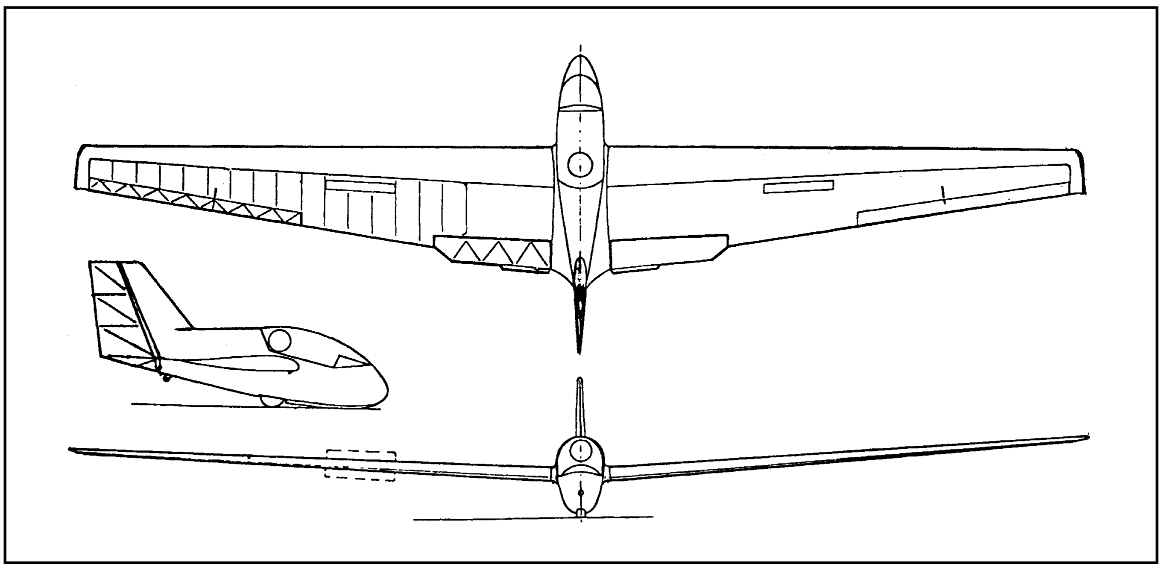
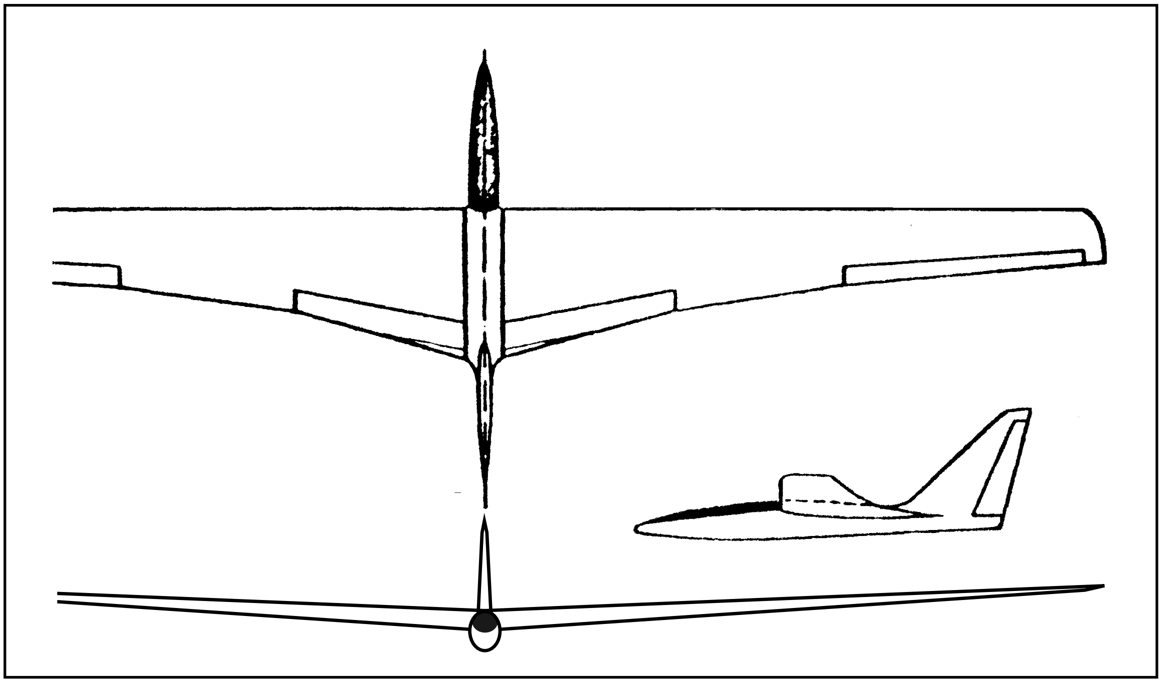
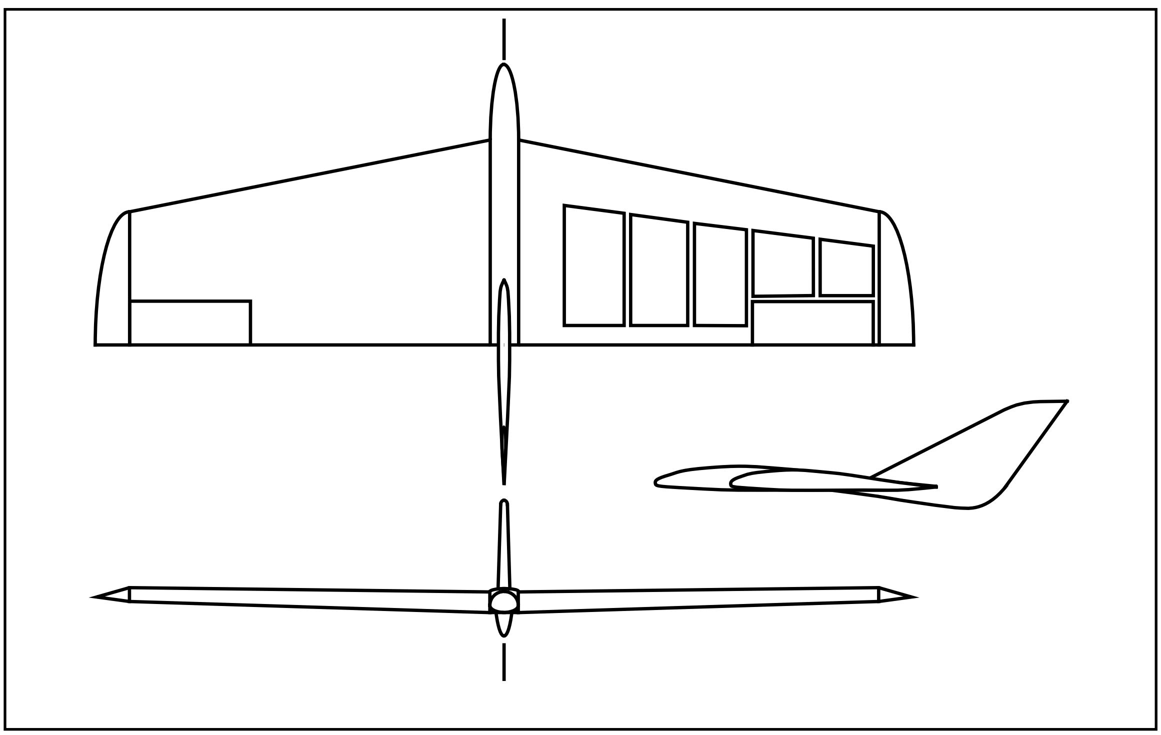
	Plank	Swept
+	• no twist • basic structure • aileron differential possible • airflow remains parallel to centerline • conventional control system • flaps possible, but see below	• airfoil design has few constraints • substantial elevator arm • winglets improve tip flow • fuselage behind wing leading edge • flaps possible, but see below • can take advantage of “induced thrust”
neutral	• low inertia in pitch	• higher inertia in pitch
–	• airfoil design limited by C_m • increased drag due to reflex • elevator arm relatively short • elevator deflection works against C_L • flap effects are limited • fuselage forward of wing leading edge • winglets may harm stall characteristics	• required twist increases drag • complicated structure • aileron differential affects pitch • cross-span airflow • winglets work best at one speed • non-conventional control system • flaps difficult to size and position



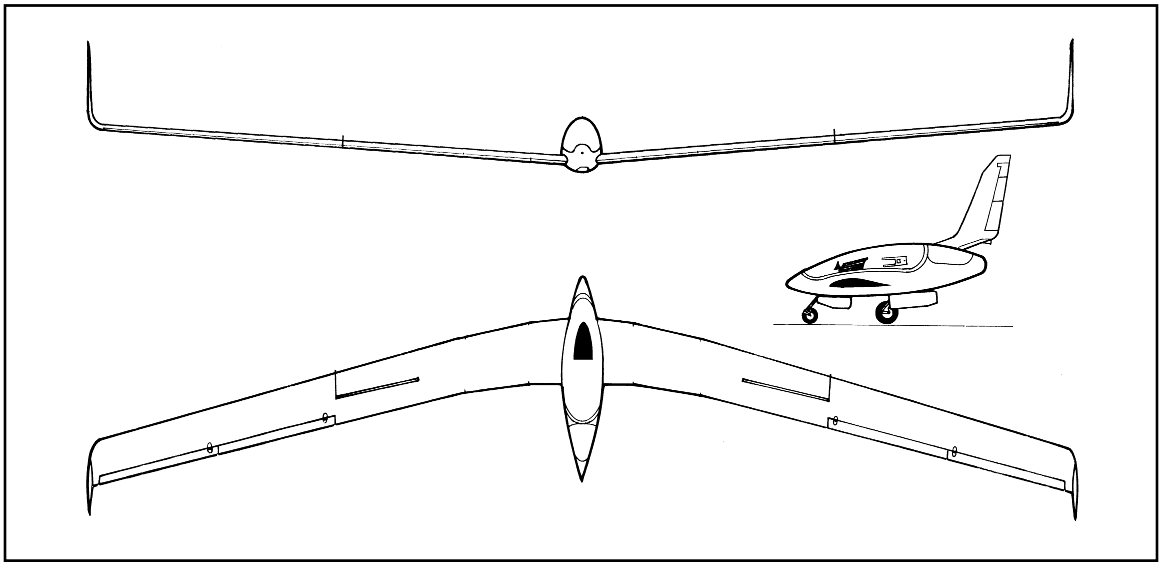
Jim Marske’s Pioneer II-D. An example of a full size plank with taper and an enlarged wing root chord which allows the elevator to be placed more rearward. Note also the swept back vertical fin and rudder which gives a slightly longer arm. Span is 13 meters.



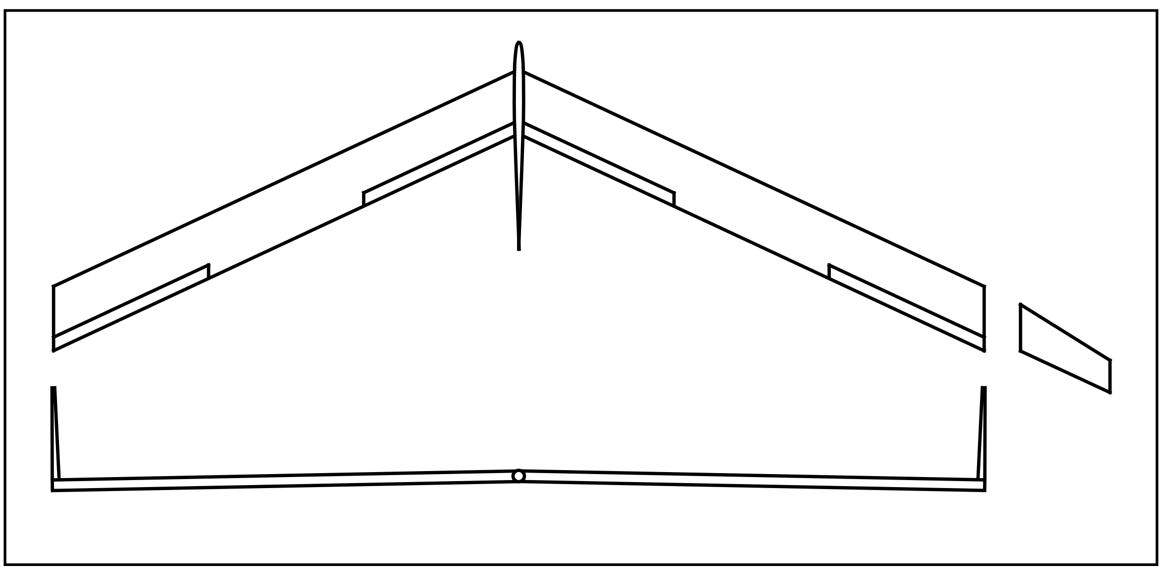
Dieter Paff's PN9f. This is an RC model based on a preliminary design for a full size sailplane. The wing span is just over three meters.



Dave Jones' Blackbird 2M. The Blackbird 2M is a low aspect ratio plank which uses elevons only. The outboard elevons put effective washout in the wing tips during thermalling. Flaps hinged at 40% chord have been used successfully on this model.



Akaflieg Braunschweig's SB 13 *Arcus*. Constructed by a group of students in Germany, the *Arcus* follows the Standard Class rules — 15 meter span, no flaps. Air brakes are used for glide path control. Note there are two elevon surfaces per side. The spars meet at the fuselage center perpendicular to the centerline, then curve back roughly following the wing sweep and continuing up the winglet. The spars are monolithic structures of carbon fiber. This airplane was a real handful to fly until wing fences were installed.



Hans-Jürgen Unverferth's CO8. This is one of the latter in a series of tailless aircraft designed by a German team headed by Hans-Jürgen Unverferth. CO8 uses elevons and flaps on a relatively high aspect ratio wing having a span of 2.6 meters.