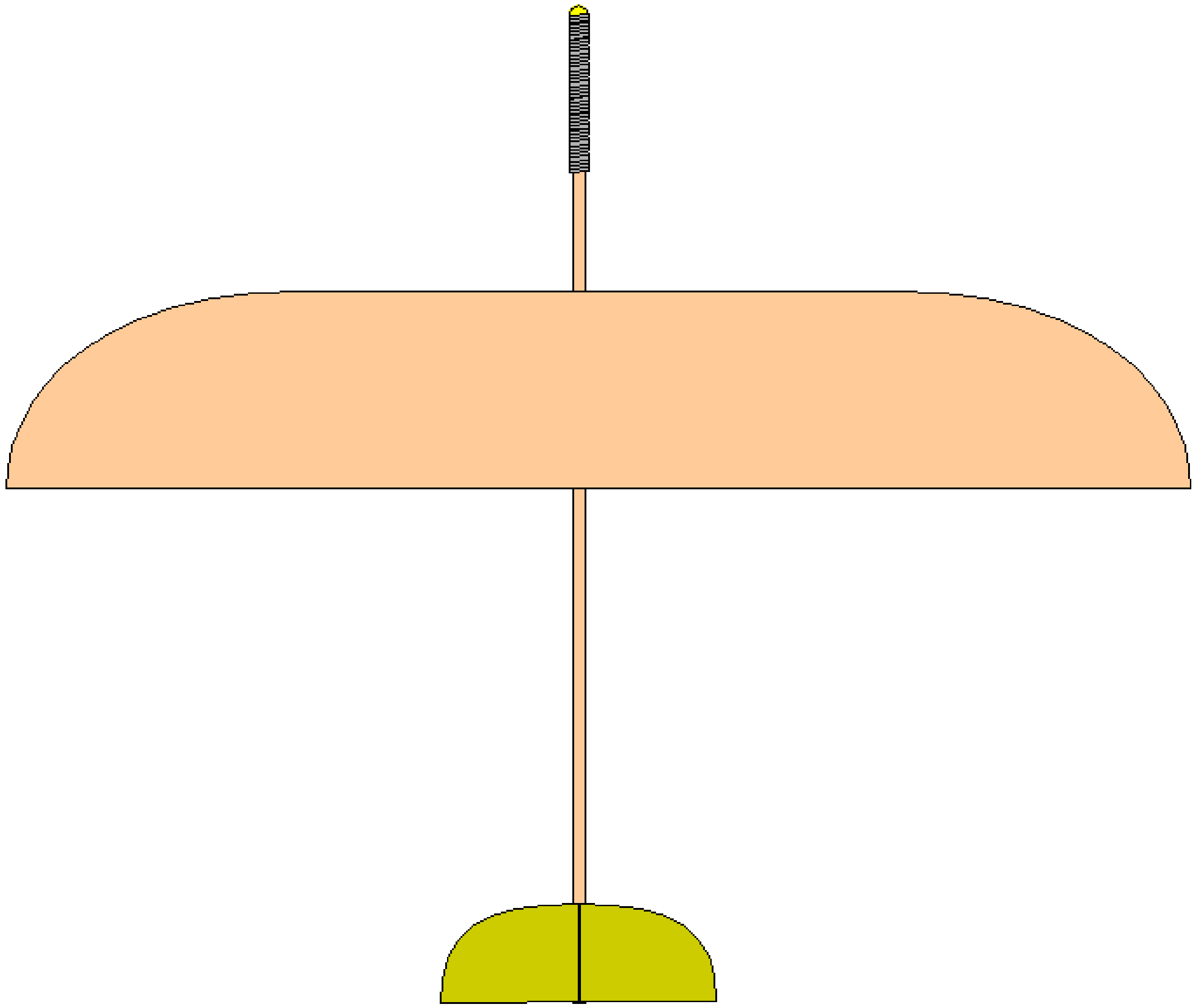
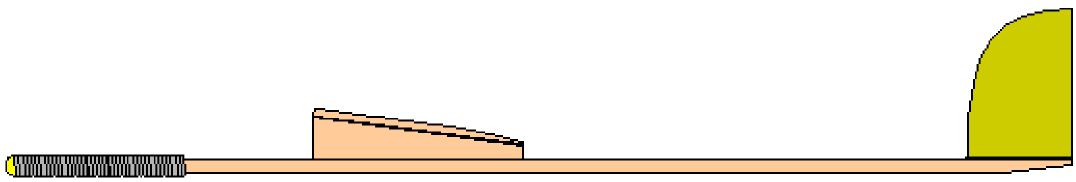
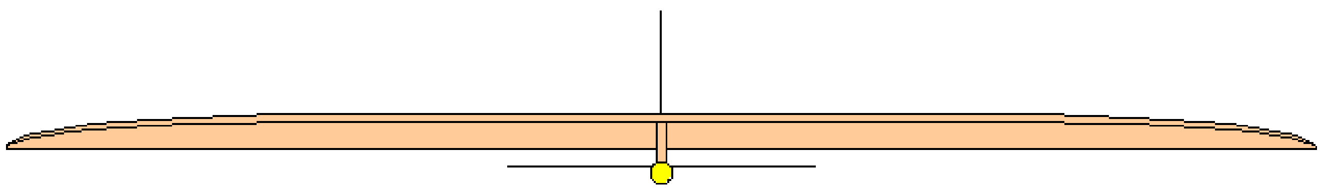
A little balsa glider with a good yield

To build a paper, cardboard or balsa glider is not difficult. Many Web pages explain the basic aerodynamic rules you have to follow. You will most often succeed to make a glider that really flies. Worst case, ask an experienced friend to tune it. But such a glider generally does not fly very far. It rather gracefully falls to the ground. Some rocket-shaped paper gliders seem to fly straight in the air but only on a short distance. They behave like an arrow; once their initial impulse is over, they will gracefully fall to the ground too. It took me years to build a little balsa glider that flies straight through my room, seemingly on a horizontal path. This page proposes the plans of that glider. I will try to explain the rules I followed to build it. The exact shape of the glider doesn't matter. What matters is to understand the rules and reasoning behind and to be able to adapt them to other shapes and purposes. The explanations assume you have an elementary knowledge of toy gliders aerodynamics. If you want some insight in flight physics then maybe try this page: Basics of toy glider physics.

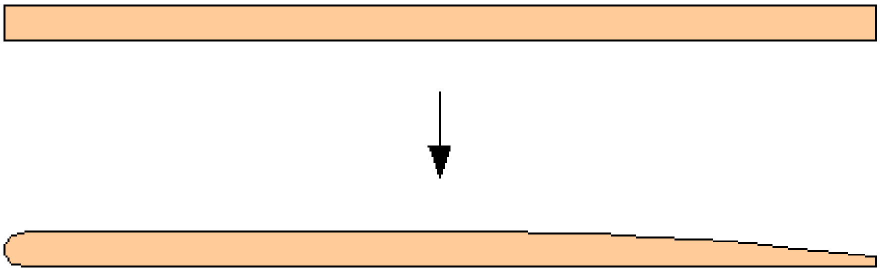
Here are drawings of the glider:





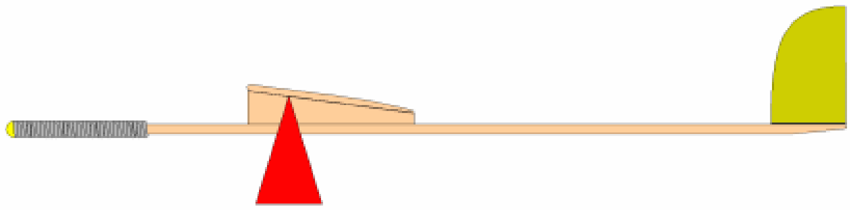


The Wing span is 300 mm. The Wing chord is 50 mm. The wing is made out of a 2 mm balsa plate (fibers parallel with the span). The wing incidence is about 7°. The leading edge of the wing is made round while the upper side of the trailing edge is sandpapered:



The front of the vertical mast has a height of 10 mm. The rear of the vertical mast has a height of 3 mm (which leads to the 7° incidence of the wing). It is made out of 2 mm balsa plate (fibers vertical). The front of the vertical mast is situated 70 mm from the front of the body. (Jeffrey Reed pointed out that these measures actually yield an incidence of 7.97°, which is 8°. You will be closer to 7° if you use a height of 4 mm instead of 3 mm at the rear of the vertical mast. The ideal height would be 3.86 mm...)

The body is a 250 mm rod of 3 x 3 mm pine wood. The front end is a little hemisphere of hot glue. The rear end has been cut out a little bit at the bottom. The front weight is made out of say 1 mm diameter solder wrapped around the rod. The exact weight doesn't matter. What matters is that the center of gravity be situated 1/4 chord behind the leading edge, that is in this case about 12 mm from the leading edge, like drawn below. The best way to get the center of gravity at the right place is to add solder carefully. Start wrapping a fair length of solder at the rod's front end. (Possibly now add the hemisphere of glue at the top.) Test the center of gravity and remove or add little lengths of solder. Till the center of gravity shows to be at the right place:



What really matters is that the glider flies well. If when you throw it, it clearly shows to need some more or some less front weight, just do that.

The rear stabilizers are made of 0.3 mm cardboard (from a pack of organic rice wafers). The vertical stabilizer has a height of 35 mm and a chord of 25 mm. The horizontal stabilizer is so to say made out of two vertical stabilizers.

The glider's weight is about 10 grams. A much heavier glider will fly perfectly yet faster (provided it is rigid enough to keep its shape). A much lighter glider may fail to fly correctly because it will fly too slowly. Indeed, a too low airspeed changes the way the air moves around the wing (Reynolds number...) Solutions for low speeds can be to use turbulators, to increase the wing chord and/or to use flatter wings. A friend was afraid to throw the glider so I made a copy of it for him, much lighter, out of very thin balsa sheets. It flies correctly but clearly I reached the limit. A lighter version would need either turbulators or a longer wing chord. Note that a heavier-and-faster version of this glider is not supposed to fly farther than a lighter-and-slower version. Speed does not imply distance. There **will** be differences in flight distance between faster and slower versions but they are not supposed to be tremendous. What will change is the duration of the flight. A light and slow glider will stay much longer in the air.

To download a printable plan of the glider, a template of the wing shape and the drawings of the glider in vector format, click here. The format is OpenOffice.org 1.x Draw. Open Office is free software, available for most computer operating systems. To get the same drawings in Open Document format, click here. To get just the plan and the wing template in standard printable Poscript format, click here.

Why a flat wing profile?

For years I heard friends sweat and dream about wing profiles. They exchange profile drawings like if they were treasures. They spend weeks, even months, assembling wings that match the chosen profile with a precision up to a tenth of a millimeter. After reading through many texts I found out that a simple flat profile was the best solution. It's far out the easiest to build. Its aerodynamic yield is close to the maximum you can expect. Just give it an angle of attack of about 7°. Apart from a good aerodynamic yield, flat profiles have a simpler behavior in the air. They are easier to cope with because they create less instability than curved/cambered profiles. They are reliable and predictable. (Don't take me wrong. An appropriate wing profile really can make a difference for an airplane. But if in doubt, use a flat profile...)

The main advantage of a cambered profile, apart from the facts that it has some more yield and can be more rigid, is that it requires far less wing surface to create an equal lift. Conversely, a flat wing will require much more chord to create the same lift than a cambered wing (for a same span). Hence, and this quite important: a flat profile can allow a glider to fly slower, because for a same span and lift a flat profile implies more chord (Reynolds number...)

Why such a thin wing profile?

A balsa plate of 2 mm is enough to get a rigid and lasting wing. So why use a thicker one? There are a few reasons not to do so. First, a thicker profile would mean a heavier glider. It would fly the same way yet faster. I prefer a slow speed, to have the time to enjoy the glider's flight. Second, at low speed and short chord, thin profiles are commonly a better choice (whether they be flat or cambered). You get more easily the air to follow the wing shape neatly.

Basically, thin profiles allow for lower flight speeds (whether they be flat or cambered). You need a higher flight speed to get the air to move correctly around a thick profile. This is why the first airplanes had very thin profiles. This too is one reason why they were biplanes; because you can't build strength into a very thin wing, so one solution is to assemble two superposed wings to get a rigid structure.

Advantages of thick wings in today airplanes is that they are more rigid for a given weight and they can contain more fuel and hardware.

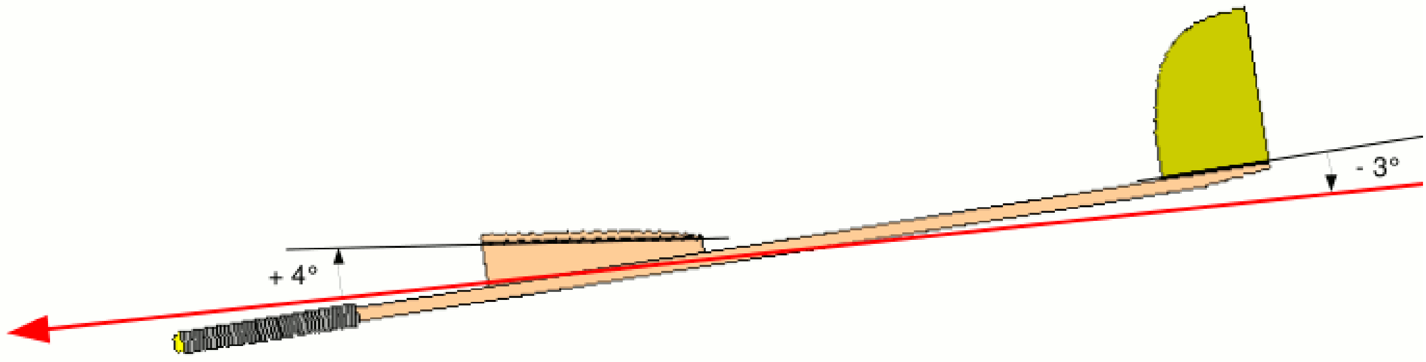
Why a wing incidence of 7°?

I read in papers that this angle provides the best aerodynamic yield for real-size airplanes. So I tried it out on my glider. Maybe another angle would be even better. Since I got the near horizontal flight path I was seeking, I did no further experiment.

Many low-cost balsa gliders have a wing incidence that seems to be 0° (compared to the rear horizontal stabilizer). This doesn't mean much since the horizontal stabilizer is not the only part of the glider that participates into imposing the angle of attack in flight. The weight at the front of the glider body matters too. Furthermore the downwash created by the wings tends to push down slightly the horizontal stabilizer, inducing an angle of attack on the wings. Such low-cost gliders won't fly far anyway. Yet they often fly correctly.

Update: look at this record-breaking glider: http://hosted.schnable.net/amaglider/assets/indoor-gliders/handlaunch-gliders/nifkin_by_bob_romash_plans.html . At first glance my glider can be seen as a simplified version. But there is at least one key difference: it has no wing incidence...

Try out the renowned FoilSim Java applet from NASA: http://www.grc.nasa.gov/WWW/K-12/airplane/foil3.html . It yields that for a flat wing profile, the optimal angle of attack is around 3°. This leads to think that, if my glider flies optimally, then its nose is pitched down say 3° during flight, so that with a built-in wing incidence of 7°, the angle of attack during flight would be say 4°, like suggested in the drawing below. The red line would be the flight path. The horizontal tail would be pitched down a few degrees, which yields stability. Then the body does not fly parallel to the airstream but this would have not too much consequences because it is quite thin. This flight attitude was not my intention and the glider would be optimal by chance.



On the contrary, maybe the Nifkin glider mentioned the paragraph above, flies with its nose pitched upwards. Indeed its aim is not to fly the furthest but to hang in the air the longest possible while. Hence it needs to get the most possible lift out of its curved wing profile, so long this causes not too much drag proportionally.

This is all why experienced model glider builders keep the incidences tunable, of both the wings and the horizontal stabilizer. You don't know in advance what the best wing angle of attack is, neither what angle you must give to the horizontal stabilizer to get that optimal angle of attack of the wings. If you also tune the front weight (to displace the center of mass), then you get a hectic three variables system.

Why such wide wings?

An airplane keeps flying because its wings are lifted by the air. According to the laws of mechanics, the huger the volume of air the wings ride on, the better the yield will be; the less energy the airplane will have to spend to stay aloft. That's one reason why gliders have very long wings; in order to span over a huge volume of air.

Why such short wings?

Wings also leave little turbulences behind them, just like a rod that you swing through the air. The swoosh noise that you can hear is generated by the turbulences. Turbulences mean drag and loss of energy. A wing is kind of a streamlined rod, that tries to generate as few turbulences as possible. This is the second reason why glider's wings are long and have a narrow chord: a longer chord would generate more turbulences. But balsa gliders have the opposite problem: their wings are so narrow (a few centimeters) and their flight speed is so slow, that the air barely manages to follow the wing profile correctly. The slower a glider flies, the more you have to increase its wing chord, so the wings can wing properly. Conversely, for a same wing surface, you get a shorter wing. (But, if you would increase the chord far too much, then you would get another problem: the wings now generate turbulences, which is the problem of big gliders.)

Why those wing tips shaped like shark fins?

While the air shears towards and along the profile of the glider wing, it will rise up, accelerate and decelerate (turn around the wing profile and pull it upwards just like a stone in a swing pulls on the cords), go into both huge and microscopic turbulences... What matters is that behind the glider the air "closes down" and stays immobile as much as possible. In other words: the air may do whatever movement around the glider, provided it's fluent and has a way to close down neatly behind the glider. The enemies to this are the aerodynamic turbulences and instabilities. One cannot avoid them but they can be lowered to a minimum.

The wing tip of a bare rectangular wing generates a strong local turbulence. The air just before and especially behind the wing tip will go on turning round in the turbulence for several seconds. That turbulence carries away a part of the energy of the glider. Hence it brakes the glider. To decrease that turbulence several solutions exist:

- Use a very wide yet narrow wing. That is a wide span and a narrow chord. That's called a "high aspect ratio wing". In such a wing, the wing tips are minute compared to the rest of the wing surface. Hence the turbulences they generate are weak compared to the glider size. Other good reasons exist to use such wings.

But I didn't, for two reasons. First of all such a wing is difficult to manufacture. You cannot cut out a narrow strip of balsa wood and expect it to be perfectly flat and rigid. Second, a problem with little and low speed gliders is that if the wing chord is too narrow, the air simply no more travels properly around the wing. You get no more "wing" effect. Thats due to the "Reynolds number". Below a given "Reynolds number" the air no more follows the wing shape. To gain back the wing effect and its lift force, you must either increase the flight speed or the wing chord. (Turbulators can help too but they add a little braking.) For my glider I was thus obliged to use a comfortable chord and hence to limit the span. (On the opposite, real gliders rely on a little chord to lower their wing profile Reynolds number, because at very high Reynolds numbers you get strong air turbulences all over the trailing surface of the wing.)

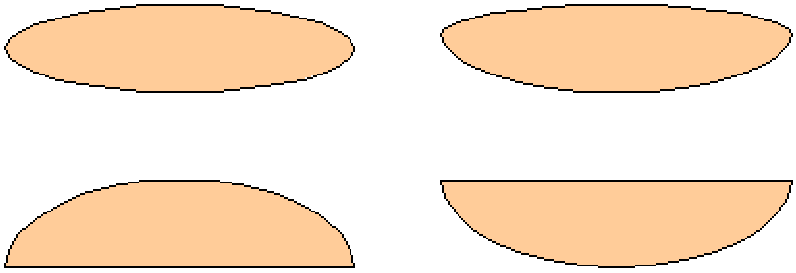
- Use winggrids. These are little wings, cleverly put at the wing tips to lower the turbulences. Some birds use this system. I heard it's a very effective system. It allows to build compact wings, with a low aspect ratio, yet with a high aerodynamic yield. I didn't choose this solutions for several reasons. First, I needed to make experiments to check out this solution. Second, on my glider the chord of the little wings would be below the Reynolds limit (turbulators would help...) Third, a winggrid on a little glider would both take a lot of time to assemble and be quite fragile, hence the lifetime of the glider would be very short.

- Use a biplane or triplane wing structure. I you intend to build a low-speed and big airplane, a biplane structure is an excellent solution. It allows to build a very lightweight, wide span and rigid wing structure. It can even have both a rather short span and a good aerodynamic yield, provided you put the lower wing behind the upper wing. That way you get sort of a huge winggrid, like in the Flying Flie. I didn't use a biplane or triplane structure because my 2 mm balsa wing was already rigid enough and because I feared some intellectual aerodynamic and structural fuss building a biplane. Besides, why try to make an even more lightweight wing? To allow the glider to fly slower? I'm already close to the lower speed limit...

- Use a trapezoidal wing shape. So the wing has a strong chord at the middle and a little chord at the tips. Hence the turbulences generated at the tips are lower. This solution is used on quite a lot of big airplanes. I didn't use it because The angle of the trapeze has to be under 10°. On a wing with a short span like that of my glider, this does not allow for a much shorter chord at the tips. So the benefit would be real yet not extraordinary.

- Use wing tips salmons. This wing tip shape is known to be quite effective to lower the turbulence. It is widely used on RC planes and gliders, often associated to a trapezoidal wing shape. I didn't use standard salmons because I believed their effect would not be sufficient for my aims. Though we are coming close to the solution I finally choose. The wing tips of my glider can be seen as "some sort of huge salmons" or "a short and fluent transition between trapezoïdal wings and salmons".

- Use an elliptical wing shape. That is the wing shape of the legendary WW II Spitfire fighter plane. It is seen as sort of "optimized to the extreme": the air pressure and angle of attack is the same all over the wing span, the air streams follow quite parallel paths all over the wing span, the wing tips turbulences are kept to the minimum, the wing span is short enough to get a swiftly maneuverable aircraft... it is smooth, homogeneous and optimal. Yet it has one big disadvantage: when the aircraft makes steep turns the lift force may disappear suddenly all over the wing inside the turn path. (The wing profile was actually slightly changed so the pilot got warning vibrations before the real stall would occur.) (Critics say the wing of the Messerchmitt BF-109 were as effective as that of the Spitfire but it had a more conventional shape and it was far easier to build.) Now my glider is not meant to make steep turns. It's not even meant to turn at all. So why not use this ideal shape? Well, the shape I choose is quite close to the ellipse. You may argue it's closer to an ellipse cut in two. Actually what matters is the chord length. The chord length over the span has to obey the formula of the ellipse. No matter those chords are pushed backwards to align with a straight trailing edge or pushed forwards to align with a straight leading edge. In the Spitfire wing, the chords are put just a little bit forwards (this has some structural and aerodynamic justifications). The four shapes beneath would all be called elliptical wings. The upper left one is a mathematical ellipse. The upper right one approaches the wing of the Spitfire. The lower left one approaches the wing of my glider (so I was quite confident in its qualities). The lower right one feels to me to be an aerodynamic nightmare. I managed to make some little balsa gliders fly correctly with that wing shape. Anyway it was clear this is not an optimal shape (see the end of the text for counterexamples).



- Copy a bird. That's what I did (go to the end of this text to read why I actually didn't) (I left the rest of this paragraph intact so you get a good example of a wrong reasoning, though the last part, about the vibrations, is excellent). I used the shape of a seagull wing, just a little shorter (lower aspect ratio). A seagull wing is a very complicated structure made of bones, muscles, tendons, articulations, skin and feathers. So simply using its rough main shape on a flat wing is not guaranteed to yield an optimal result. But I was sure I wouldn't get a bad result either, since the seagull wing shape was close to the elliptical wing shape of the Spitfire and to the trapezoid + wingtip salmon shape of good RC planes and gliders. The main difference is that the central part of the wing has parallel borders. I inclined for such parallel borders because I read a page from a top balsa glider builder who explains that he simply hates the elliptical shape. He prefers parallel borders and wide rounded wing tips. Like the Westerner 2 RC model near the bottom of this page. Furthermore I thought this was a mathematical best choice in order to keep the wing chord to a maximum nearly all over the span (remember at low speeds the chord needs to be as wide as possible). Next, why stick to the seagull shape even for the shark fin-shaped wing tips? For three reasons. The first one is not very important: because it is the closest one to the successful salmon wing tip shape. The second reason is that I read in books that this shark fin shape generates the least braking and turbulences. It's the shape that most suits a fluent air circulation. The third reason is really and excellent one: I tried out and checked that this shape really yields the least turbulence. I made two wings, nearly identical: one with the shark fin tip shape and the other with rounded tip shape (close to the Westerner 2 wing shape mentioned above). I hold them in my hand and sheared them in the air around me. The wing with the rounded wing tips produced weak vibrations I could feel in my hand. The wing with the shark fin-shaped tips produced no vibrations at all. It did glide through the air like if there was no air at all except for the lift force. So the seagull wing shape was adopted.

- Use winglets. I didn't even consider using winglets. That aerodynamic device is difficult to design. A random design, even an aesthetic one, is said to brake the plane more than using no winglets. Besides, winglets are usually meant for the tip of narrow ending wings, which is not my case. I once saw a prey bird gliding. The tip of his wings was round shaped, with no winggrids. The tip of his outermost feather made an upwards bend to form a quite little yet beautiful winglet. So maybe little winglets can enhance a little bit the yield of this glider. Maybe I should give it a try but I know their effect will be negligible. I've no way to verify their usefulness. I won't add to my glider something that I cannot check to be worth the effort.

Why pretend that the wing profile is flat though only the upper side of the trailing edge was sandpapered, which creates a very slightly curved profile?

Well right, the profile is not perfectly flat. But I'm quite sure this doesn't change much of the glider's flight characteristics. Such a thin wing with the upper and downside trailing edge sandpapered symmetrically won't change much to the glider's behavior. Sandpapering only the upper side makes the manufacture easier.

Note that if you sandpaper the downside of the trailing edge, you no more need a tail horizontal stabilizer. This is a "flying wing" shape. (Such a flying wing may benefit from a very little tail horizontal stabilizer anyway, just to avoid pitch oscillations.)

Why such a little horizontal stabilizer?

This is a key feature. Many beginners (like me) boldly believe the rear stabilizers of an airplane behave like the stabilizers of an arrow. So the bigger the stabilizers, the more stable the glider's flight will be... That's wrong.

In first approximation, a glider with a flat wing profile almost does not need a horizontal stabilizer. I made such a tail-less glider and it flies quite correctly (the build tip is to sandpaper only the downside of the trailing edge; see data about flying wings to know why).

The pitch stability of the glider arises first of all from the interaction between the weight in front of the glider and the tendency of the wing to flip upwards. It's sort of a battle between the two forces. While in flight, the wing experiences an aerodynamic torque that tends to make the glider pitch upwards. But the center of gravity of the glider has been placed slightly frontwards, which tends to make the plane pitch downwards. The two forces equilibrate and the aircraft flights straight. Why such a fragile equilibrium between two forces of different natures? Well because it is not fragile at all. It's quite stable and the speed regulation of the glider relies upon it. Indeed the weight in front of the glider is constant. It doesn't change when the speed changes. It always tends to make the glider pitch downwards with the same force. On the contrary, the aerodynamic upwards torque on the wings depends on the glider's speed. The faster, the more torque. The slower, the less torque. So, should the glider fly too slowly, the upwards aerodynamic torque decreases and the front weight makes the glider tend to dive, which makes it gain speed. Should the glider fly too fast, the aerodynamic torque will supersede the front weight, the glider will pitch upwards and tend to climb, so it will loose speed. The result is that the glider flies at a nearly constant speed. A huge rear horizontal stabilizer would supersede this phenomenon and make the glider less stable.

Then, why put a little horizontal stabilizer anyway? For two reasons. First, The regulation phenomenon explained above tends to make the glider oscillate. That's often a problem you get, when two forces battle and the system has some inertia. The tail-less glider I made flies that way: oscillating. It's cute to see but I bet it participates in the low yield of that glider. The horizontal rear stabilizer tends to prevent the oscillation. It wears away the energy of the oscillation, like the dampers of a car suspension. Second, when I said this speed regulation system is stable I was boasting a little bit. On a plane with a standard curved (cambered) wing profile there is a clear instability. Indeed when the plane pitches a little upwards, the upwards aerodynamic torque will increase a little bit. So, if the plane pitches upwards it will tend to pitch even more upwards. And if it pitches downwards it will tend to pitch even more downwards. It diverges. The forces implied are not very strong yet they make the plane unstable, unable to fly straight. The purpose of the rear horizontal stabilizer is to dominate this phenomenon and make the plane fly straight. But only a quite little horizontal stabilizer is necessary for this... (As written above, airplanes with a flat wing profile are quite neutral in regard of this phenomenon. They don't tend to increase an upwards or downwards pitch. They don't tend to stabilize it either. Only special wing profiles intended for flying wings do.) Third, I have few confidence in the wing to willingly adopt the 7° angle of attack I choose. The horizontal stabilizer helps it conform to my wishes. I'm quite sure the wing actually does not fly with an exact angle of attack of 7°. Conversely I doubt the horizontal stabilizer flies with an angle of attack of exactly 0° through the air. Anyway the system seems to come globally rather close to my wishes.

So, the purpose of the horizontal stabilizer is not to impose the flight attitude of the glider. It is rather to compensate for some weak and secondary disorders and instabilities. Therefore it does not need to have a huge surface. Actually it **must not** have a huge surface, in order not to dominate the main speed regulation phenomenon.

Why such a little vertical stabilizer?

The reasoning is quite close to that for the horizontal stabilizer. But I don't master it. Specifically, with a huge vertical stabilizer the glider gets two problems. First, it will tend to oscillate sideways; it has a yaw instability. Perhaps because the vertical stabilizer is caught alternatively by the left and right main wing vortexes. Second, it makes the glider gradually go in a spiral dive; the much hated phenomenon that killed many pilots.

The first prototype of this glider had a quite bigger vertical stabilizer and it didn't have a beautiful flight. The instabilities made the glider loose a lot of energy while flying. It was falling fast while flying. But I knew about the problem and I made a haircut to it. Once the vertical stabilizer got little, the glider's flight became wonderful. So smooth and straight. Especially, it flew much more horizontally, like I wished it to.

I was told about an even better place to put the vertical stabilizer and avoid the instabilities: below the plane body. A few airplanes and drones have such an inverted tail. The problem is that this makes the aircraft more fragile or even dangerous during take-off and landing. Even on a little balsa glider this can yield problems since a downwards vertical stabilizer will be hit more often and hence be damaged. I would have adopted this layout anyway if it had been necessary. But I got what I wanted just by using a little vertical stabilizer.

Then again, why not simply remove the vertical stabilizer? I tried it out and got the glider fly sideways, with obviously a lower yield. A vertical stabilizer is needed.

I believe the seagull wing shape itself offers some stability to avoid a sideways flight, anyway not enough.

Why not use a dihedral?

Because I didn't understand the dihedral. I did read the explanation available in popular books but I felt it was wrong. So I preferred to use no dihedral and that was OK.

There are two ways to stabilize the roll of a glider / keep the wings horizontal:

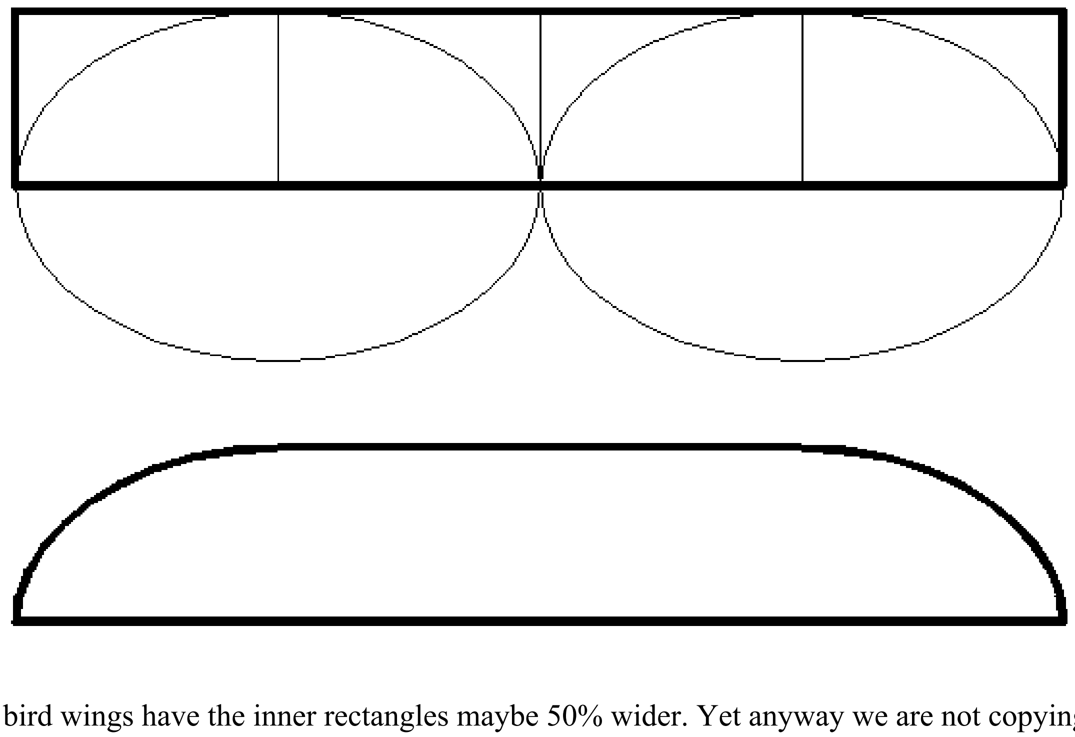
- Use a dihedral.
- Put the center of mass below the wings.

Obviously my glider relies on the second method.

The lower the wings are implanted on the airplane body (hence the higher the center of mass is situated above them), the more a dihedral will be necessary to keep the airplane stable in flight. Conversely, airplanes with wings implanted very high may be too stable (or oscillate), then a slight anhedral will be necessary to compensate (an anhedral is a reversed dihedral; the wings pointing downwards).

I want to adopt the seagull wing shape for my own gliders, with different aspect ratios. What's the build seed?

Consider that the wing is made out of four equal parts. Then cut out the two outer parts in the shape of a quarter of an ellipse:



Actually, sea bird wings have the inner rectangles maybe 50% wider. Yet anyway we are not copying a seabird wing, since their wings have a strong curvature in the inner part. (See further at the bottom of this text.)

Why use such a thin body?

The thinner, the less aerodynamic drag. Though this is not the most optimized shape. I should have bend the body so that it follows the upwards and downwards movement of the air around the wings. Maybe on a next glider.

A lot of little balsa gliders use a plate of balsa wood to be the body. Clearly those gliders do fly. But I would have been afraid to use that design. Because to me such a body is sort of a giant vertical stabilizer smeared all along the plane body. A conceptual nightmare.

Can I build a more lightweight exemplary anyway?

Yes. I build one two times more lightweight, using 1 mm balsa plate for the wing and stabilizers and a 4 x 4 mm balsa rod for the body. But this is the limit. I made one even a little more lightweight and it simply fell to the ground. I had to increase its weight to get it flying properly.

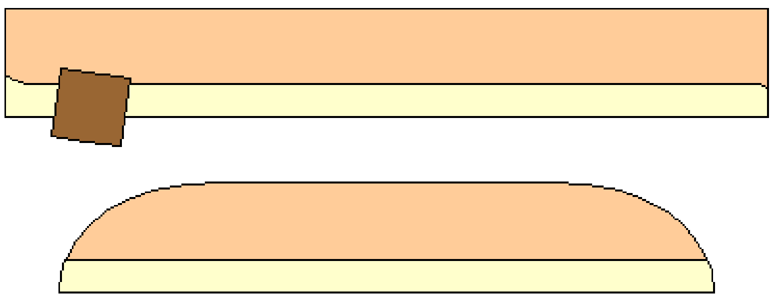
If you want to build an even more lightweight glider, so it can fly slower, then you must build a bigger one so the wing chord increases, decrease the wing ratio (again to get more chord), or use turbulators.

Some build tips and data?

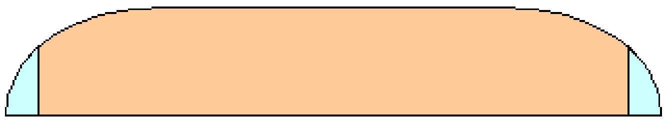
I used standard hobby water-based white glue.

For some assemblings I put one or two loose drops of hot glue to latch the two parts. During the few seconds the glue cools down I hold the pieces in their correct positions. Then I smear a little quantity of white glue all along between the two pieces. Hours later, when the white glue is dry, I remove the hot glue drops.

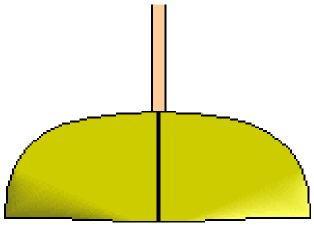
Maybe best cut out a wider wing, sandpaper the trailing edge, then cut out the wing shape:



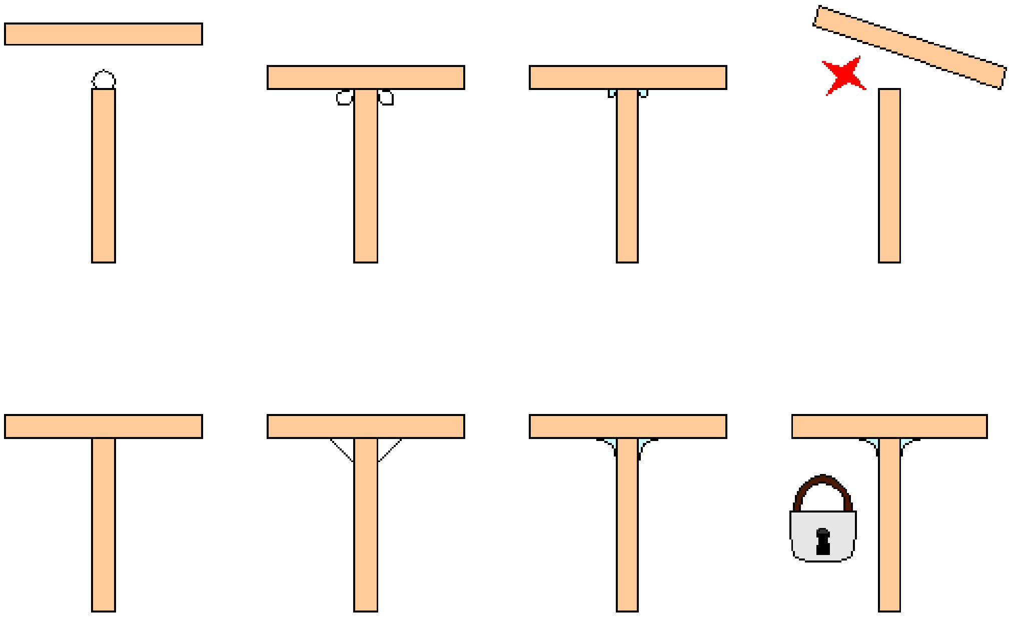
The wing tips are fragile. So I "painted" them with a thin layer of white glue:



If the glider assembly lacks symmetry it will turn in flight. Canonically the way to compensate for this is to make the outer rear parts of the wings go a little bit upwards and downwards. This will create a roll force to compensate the asymmetry. But tuning the balsa wings may be difficult and produce an ugly result. So if the asymmetry is not too important and the tendency to turn is quite weak, best is to create a roll force using the rear horizontal stabilizer. Bend it a little bit so the outer rear part of one half goes a little bit upwards and the outer rear part of the other half goes a little bit downwards. Give it a smooth gradual curved bend. Do not bend the vertical stabilizer.



When assembling two perpendicular pieces of balsa, a common practice is to spread a little glue on the edge of one of the pieces and press the two together. This yields a fragile link. You get a far better result by smearing a thick little joint of white glue along the interface between the pieces. Say 2 up to 3 mm thick. This takes at least half a day to dry up but you get a really strong result. Of course to put glue on the edge of the piece is a good practice, this will add to the resistance. But the main resistance will come from the joints on the sides.



Did you invent this glider shape?

My pride is that I managed to understand most choices and aerodynamic reasoning when conceiving this glider. Yet the result is quite identical to the canonical airplane shape. This simply means I got some understanding of this wonderful invention that took centuries to grow in the successive brains of hundreds of inventors and scientists. The fact that the glider flies quite well is the ultimate and necessary proof.

This page shows the "Feather Shooter", a glider that resembles: http://xoomee.com/feather.htm

This page shows the "Epsilon 2M" glider: http://www.nesail.com/detail.php?productID=3066

A plane shape depends on its purpose. This page: http://www.richard-seaman.com/Aircraft/AirShows/index.html shows quite a lot of different airplane shapes. All are near optimal choices in regard of the plane's operational needs.

So your glider is optimal?

Reasonably. Yet this does not mean that a better glider cannot be build. Of course it can. I've got some ideas to do that.

Part of my reasoning was inaccurate. Globally it was good since the glider glides. For sure the reasoning behind the building of the glider can be enhanced.

Roughly halfway the present text I compare four elliptical wing shapes and explain that the one with the straight leading edge is the worst. Well my friend Didier Bizzarri build a successful very low speed indoor glider that approximately uses that kind of wing shape. To view it click here. Also, flying fishes use nearly exactly the same wing shape as my glider but reversed; with the longest edge forward. (If you check for photographs of flying fishes on the Web, be careful to get pictures of flying fishes in flight. Or at least pictures that show the wings fully deployed. If a dead flying fish lays on a table or is lousily held by hands, its wings show quite a different shape.) I don't know if the "reversed" wing feels stable to the flying fish. As the fish "pilots" its flight, a less stable wing is not a problem. It is quite probable that the straight leading edge's purpose is to resist impacts. The wings of the Wright Flyer tend to end in this shape too.

Most prominent error till now is that I thought that I shaped a bird's wing. That is totally wrong:

- While the shape viewed from above does match that of a sea bird, a real sea bird wing is cambered at its root and the camber decreases towards the tip. To get the same lift at the root as such a cambered bird wing, my flat wing should have had a much longer chord, maybe two times longer. Halfway the bird wing, the camber is milder. So, to have a chance to mimic the lift of a bird wing (with my flat wing) I should have used kind of a delta wing or a trapezoidal wing. Actually, real delta wings on military airplanes are quite flat... I suppose this is not a coincidence. (Some of the best WWII fighters use a strong camber at the root, down to flat wing tips.)

  This condor on the other hand, does appear to have a wing with a constant camber:
  https://en.wikipedia.org/wiki/File:Condor_flying_over_the_Colca_canyon_in_Peru.jpg

- The incidence of a bird wing changes along the span. Maybe to adapt to the changes in airflow, maybe simply because a change in curvature also changes the optimal angle of attack.

- The bird's tail adds itself to the chord of the bird's wing.

Eric Brasseur - November 17 2003 till September 9 2015