Minimum v2 Building Instructions (revision v2-e)

By Jochen K.

Minimum v2 specifications:
DC rotor, **three-bladed**, 2" Aerobalsa RotorBlade Airfoils™
rotor diameter: 930 mm / 36.6"
AUW: 520 g / 18.4 oz.
RC functions: roll (aileron), pitch (elevator) and throttle
battery: 3s/910 mAh
motor: Plettenberg Freestyle 24, 75 g / 2.7 oz., turning a 9x4.7 APC Slow prop at 8650 /min while drawing 12.5 A
servos: 28 g / 1 oz., metal gears

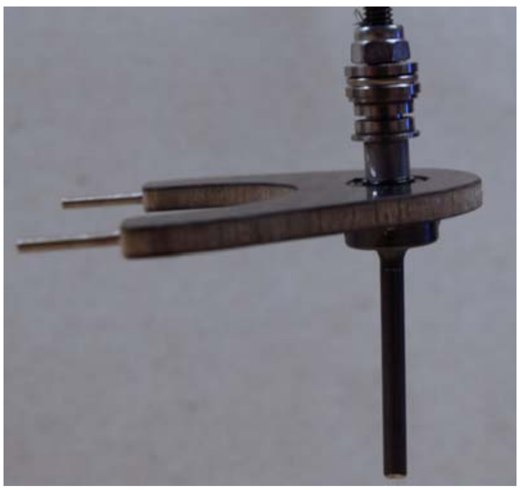
There are two versions of the Minimum plans, a jpg-version for looking at and a pdf-version for printing. ***If you print the pdf-files without any size adjustment, they should print to scale.*** Some printouts will have bits missing because of the model's size, but what you need will be printed.

The Pivot Hinge

Let's start off with the pivot hinge. I'm using a drive shaft - wheel axle combination from a model car as a pivot hinge, and I've picked a part that seems to be available in the US as well as in Europe. Go to
http://www.cenracing.com/cars/ff/fftuningparts.html
and look for item no. FFS004, the universal swing shaft for Buggy/Rally. As the name of this item is a bit long, I'll refer to it as the CV joint from now on.

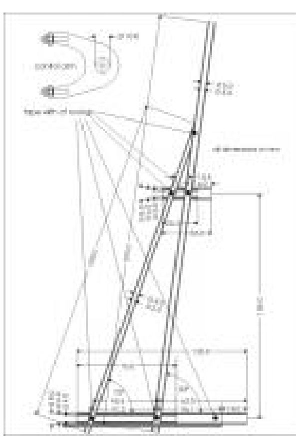
You have to do two things to convert the CV joint to a pivot joint: cut off the drive shaft part 30 mm from the ball in the actual joint and sand off the black paint from the 5 mm O.D. part of the wheel axle. This is where the ball bearings go, and without removing the paint it's a rather tight fit.

Now make yourself a control arm as shown in the upper left corner of the ‘airframe’ drawing. I've used my favourite cf-balsa-cf sandwich combination for this part, but if you don't have access to such an exotic material use 3 mm PVC or something similar instead. Epoxy the control arm to the CV joint.



Slip an aluminum or brass or plastic tube of 8 mm length with an I.D. of 5 mm over the wheel axle, followed by the two ball bearings of the rotor. I've used ball bearings with an I.D. of 5 mm, an O.D. of 8 mm and a thickness of 2.5 mm. My ball bearings have a little rim to hold them in place, but that is not really necessary. In an earlier version of this rotor head I used a needle bearing instead of two ball bearings. Well, I've had my needle bearing lock up two times in mid-flight and what happened then was rather spectacular. No need to have this experience again. On top of the upper ball bearing goes a 5 mm thrust bearing and then a self-locking nut.

The Airframe (‘Airframe-v2-e.pdf’ drawing)



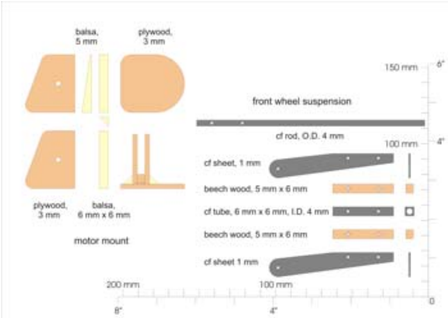
For the airframe you'll need
- one piece of CF tube, O.D. 8 mm, I.D. 6 mm, length 170 mm
- one piece of cg tube, O.D. 6 mm, I.D. 4 mm, length 120 mm
- one piece of CF tube, O.D. 5 mm, I.D. 3 mm, length 290 mm
- one piece of CF tube, O.D. 5 mm, I.D. 3 mm, length 230 mm
- one piece of square CF tube, 6 x 6 mm, I.D. 4 mm, length 80 mm
- one piece of aluminum or brass tube, O.D.6 mm, I.D. 5 mm, length 30 mm
- one wheel collar, I.D. 6 mm
- two wheel collars, I.D. 8 mm

Epoxy the 6 mm cf tube into the front end of the 8 mm cf tube. Now comes the only tricky part in building the Minimum: you have to drill two 5 mm holes at angles of 82° and 70° into the reinforced 8 mm cf tubes. For the location of the holes have a look at the plan. I've gone over to using a flat 4 mm mill to pre-drill these holes and then I enlarge them with a round file to the desired angle and diameter. Now print out the airframe plan and loosely assemble the cf parts on the plan. Use a round file to sand off the top of the support strut so that it fits onto the rotor mast. You may have to enlarge the slanting holes to make everything fit, but that doesn't really matter. Once everything is aligned, take the airframe parts apart, apply epoxy at the relevant positions and reassemble. Put some 1.5 mm balsa pieces under the rotor mast and the support strut and hold everything down while the epoxy is curing. Then slip the 30 mm aluminium tube over the top of the rotor mast and epoxy in place. This tube is for keeping the end of the rotor mast from splitting under strain.

The wheel collars are used to keep the pivot joint, the front wheel assembly and the taiil boom in their positions. For the 6 mm wheel collar holding the pivot joint I suggest a version with two grub screws opposite each other. If you can't find one, make one yourself. Drill a 2.5 mm hole opposite the original one and cut a M3 thread into it. Slip this wheel collar over the top of the rotor mast and epoxy it in place, about 5 mm from the top of the mast. Now, using the wheel collar holes as a guide, drill 2.5 mm holes through the CF of the mast and extend the wheel collar's M3 threads right through the CF.
If you follow this procedure, you'll take a minimum of material out of the wall of the mast and leave it as strong as possible. Epoxy the two 8 mm wheel collars over the ends of the main boom and repeat the thread-cutting procedure.

There's one part left in the bill of materials we haven't yet used. That's the square cf tube with the round hole down the length of it. If you can't find this type of tube, use a round cf tube with an O.D. of 6 mm and an I.D. of 4 mm instead. Epoxy this tube to the bottom of the main boom, about 2 mm behind the bottom end of the rotor mast, rectangular to the main boom and to the rotor mast (see ‘BottomView’ drawing). This part will take the axle of the main landing gear later on. To give the airframe the stability needed, take epoxy drenched cf rovings and tape the joint of the rotor mast with the support strut, the joint of the support strut with the main boom and the joints of the rotor mast and landing gear support with the main boom with those rovings. Make sure that the landing gear support is well fixed to the main boom. Also wrap some rovings around the ends of the square tube to reinforce them.

The Front Wheel Assembly (‘MotorMount&FrontWheel.pdf’ drawing)



For the front wheel suspension you'll need:
- one piece of cf rod, O.D. 4 mm, length 150 mm
- one piece of cf tube, 6 x 6 mm, I.D. 4 mm, length 40 mm
- two pieces of beech wood, 6 mm x 5 mm, length 40 mm
- one piece of cf sheet, 1.5 mm thick, 25 mm x 85 mm

Here's that odd bit of square cf rod again. To replace this part, epoxy a cf tube with an O.D. of 6 mm and an I.D. of 4 mm into a cf tube with an I.D. of 6 mm. Then sand the top and sides - if there are such things - of the outer tube down to the inner tube, and you've got something which, while not being exactly square, will do.

Cut the 1.5 mm cf sheet into two parts of roughly the size of the wheel supports and fix them together with some double-sided adhesive tape. For this kind of operation I'm using the type of tape which is normally used for sticking photographs into albums, it's thin, just strong enough and easily removable. Now print out the shape of one support on a sticky label of the right size and stick it onto the CF. Then cut the supports down to the correct size and drill the 2 mm holes for the axle and the two 2 mm screws. Take those two supports apart again. Use the same method to stick the two beech wood pieces together and stick one of the wheel supports onto the side of this pack, correctly aligned, of course. Use the holes in the support as a template for drilling the two screw holes into the wood. Remove one piece of beech wood, replace it with the 'square' cf tube and drill again. Take everything apart again and stick the 4 mm cf rod into the round hole of the square tube. The front ends of both parts should be flush. First drill one hole through the round cf rod, put an O.D. 2 mm piece of anything through this hole and drill the other one. To keep the ends of the 'square' tube from splitting up under stress, tape them lightly with epoxy drenched cf rovings. Then sand some cut-outs in the wood pieces to allow for the tapings and reassemble everything, using 2 mm screws of 20 mm length.

The suspension just described will take the usual 65 mm slow-fly wheels, which have a width of just below 14 mm. If you are using thicker wheels, you'll have to increase the thickness of the beech wood parts to the size of your tires.

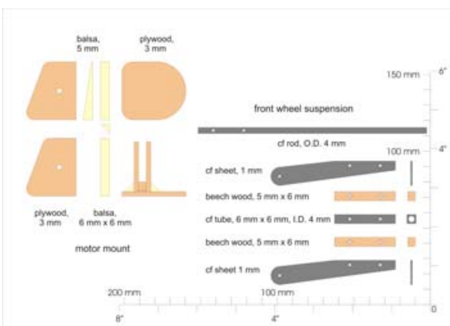
The axle for the front wheel is a short cf rod with 2 mm diameter, held in place by wheel collars at both ends. For the main landing gear use a 3 mm cf rod with a length of about 330 mm. Slip a piece heat-shrink tube with an I.D. of 3 mm and a length of 90 mm over the cf rod and center it - no need to shrink it. This will protect the cf rod from breaking all too easily at the edges of its suspension. Then thread the axle into the 4 mm hole of the square cf tube below the main boom. Tape some textile adhesive tape around the axle and the heat-shrink tube on both sides of the square cf tube to keep the axle centered. To keep the wheels of the main landing gear in their proper positions, I use heat-shrink tube on the insides – shrunk this time - and wheel collars on the outside.

I've enlarged the original holes in all the three wheels to a diameter of 3.2 mm. This gives you a good fit for the main landing gear. Into the hole of the front wheel I've pressed a 15 mm long piece of my ever-present outer bowden cable tube. This has an O.D. of 3.2 mm and an I.D. of just over 2 mm and gives you the perfect fit for the 2 mm axle.

The Battery Tray

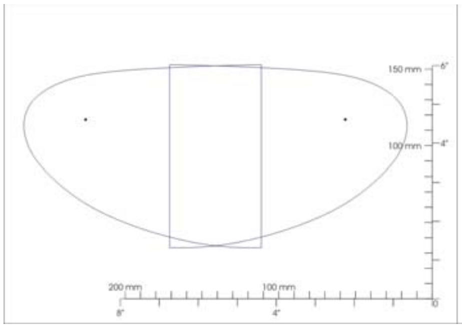
From a 3 mm piece of ply cut out a rectangular piece of the size of the battery you are going to use and stick it on the top of the front wheel suspension with some good double-sided adhesive tape. Use a rubber band to hold the battery in place.

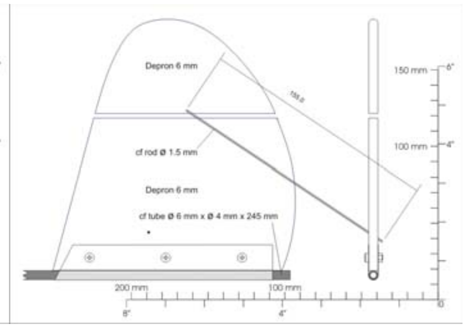
The Motor Mount (‘MotorMount&FrontWheel.pdf’ drawing)



Cut the main parts of the motor mount from 3 mm ply and drill the two 3 mm holes in the flanges as shown. I suggest that you make the mounting plate that will hold the motor about 10 mm longer on the right side and cut off what you don't need later. Glue one of the parts that affix the motor mount to the airframe to the mounting plate. Wrap a layer of cling wrap around the airframe, put your glued-together parts on the cling wrap and glue the remaining part to the motor mount. Insert the wedge that ensures a horizontal motor position into the U of the motor mount. Stabilize everything with the triangular moldings. If you want some extra strength in the motor mount, you'll have to make those moldings yourself. Take a 6 mm balsa plank and cut out a triangular part by sawing perpendicular to the grain at an angle of 45° to the surface. This way the balsa fibers will run from one piece of ply to the other one, providing a very strong connection. Use a 3 mm screw to fix the motor mount to the airframe, in the position shown in the plans.

The Tail Unit (‘ElevatorFin-v2-e.pdf’ and ‘RudderFin-v2-e.pdf’ drawings)



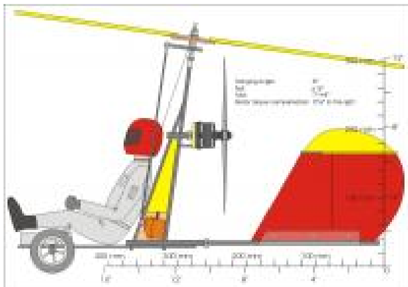


For the tail unit you need a cf tube, O.D. 6 mm, I.D. 4 mm with a length of 245 mm. And you need to build a support for the rudder. Take any sort of rod with 6 mm diameter and a minimum length of 150 mm and glue it flush to the side of a 6 mm piece of balsa. Cover this with a bit of non-sticking cling wrap and put it in a vice, the rod on the upper side. Take two strips of 50 mm wide gf tape and laminate them over the rod. Put another layer of cling wrap on top and smooth down the tape on the sides of the balsa. Use two flat rods and some clamps on the sides of the balsa to hold the gf tape in place. Cut the cured holder into the shape shown in the plan. The holder may look rather flexible, but once you've glued it to the end of the tail boom it's strong enough to hold the rudder. I've used silicon for that connection, this way you can take it apart again. Now drill three 3 mm holes for nylon screws into the rudder holder as shown in the plan.

Cut the rudder fin out of 6 mm Depron and put it in the rudder support. Make 3 mm holes in the Depron and fix the rudder with nylon screws. Dismantle again.

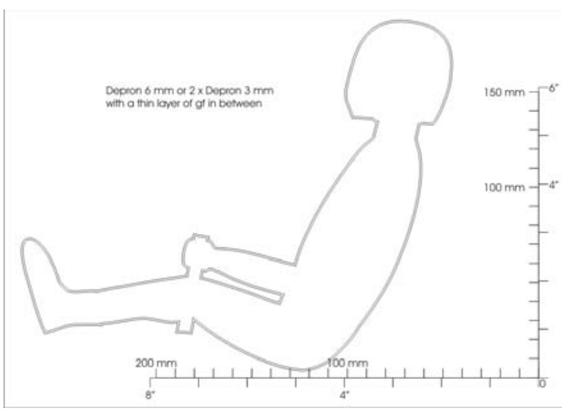
Print the plan of the elevator fin out two times, cut out a right and a left side, glue the papers together and use as a template for cutting the elevator fin out of 3 mm Depron. If you want to paint the tail unit, do it now before assembling. Glue a flat cf rod (3 mm x 0.1 mm) with a length of about 750 mm all around the edge of the elevator fin for stability. Glue the elevator fin to the lower rudder fin and use two cf rods with 1.5 mm diameter and a length of 155 mm to stabilize the tail unit. The places where the cf rods go into the Depron are marked in the plans. Glue the top of the rudder fin onto the elevator fin and bolt the tail unit into the rudder holder. Stick the tail boom into the main boom, align everything and fix with the grub screw of the wheel collar.

RC Installation ('SideView-v2-A4e.pdf' drawing)



Cut a 40 mm wide piece of 3 mm plywood to fit into the bottom of the clearance between the rotor mast and support strut. This is where your servos will go. If you are using bigger servos, make this strip a little wider. Fill the upper part of the clearance up to the motor mount with 3 mm Depron. Paint those parts before epoxying them to the airframe. Use silicon to glue the servos to the plywood or use any other method you like. The bottoms of the servos should be in parallel with the rotor mast and the servo arms at the top. Put the pivot hinge into the top of the rotor mast, align and fix with the grub screws. Make yourself some push rods out of 2 mm cf rods using ball links for the connection to the control arm. The top of the pivot hinge should be in line with the rotor mast when the servos are in neutral position. Use some Velcro strips to fix the Rx and the ESC to the Depron part above the servos. Try to maintain a little distance between those two devices to minimize possible interference.

The Pilot ('Pilot-v2-e.pdf' drawing)



You can cut the pilot figure out of a 6 mm sheet of Depron, but I prefer to use two pilot figures cut from 3 mm Depron with a thin gf sheet in between. This makes the figure a little sturdier. Paint the pilot. Place your battery in the position shown in the plans. Then use Velcro strips at the back and bottom of the pilot to fix him to the airframe. Hold the pilot's feet in place with a rubber band slung around the front wheel assembly.

Adjusting the Motor Position

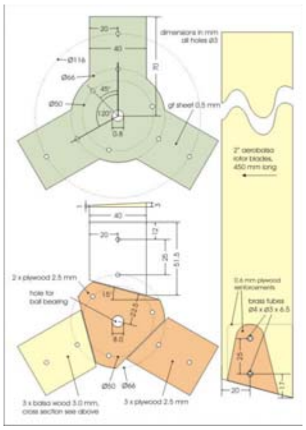
Have a look at this video: http://www.rcgroups.com/forums/showthread.php?t=656493#post7087583.
You can see that the gyro is wildly rotating when the motor position is in line with the airframe. When the motor offset to the right – seen from behind - by the correct amount, the rotations will stop. This is a compensation of the effect the prop wash has on the rudder and the offset is depending on the motor and prop you use. If you want to find out the correct offset for the combination you are using, use some good double-sided adhesive tape to mount your motor provisionally and repeat the test, adjusting the motor position until the gyro stops rotating. The offset for the motor/prop combination I'm using is shown in the plans. When you've found the

suitable motor position, drill the appropriate holes, cut off the unneeded parts of the mount and fix your motor.

Adjusting the Hang Angle

Now, with all the parts in position, you can adjust the hang angle of the gyro by fixing a piece of string to the rotor shaft and hanging up the gyro. Adjust the battery position so that the rotor mast is slanting backwards by about 8°.

The Rotor (‘RotorHub.pdf’ drawing)



Cut the flapping hinge out of 0.5 mm gf using the pdf-printout as a template. Mark the holes for the rotor shaft (8 mm) and rotor blades (3 mm) and drill them. Do not drill the three holes that hold the hub together. Cut the upper rotor hub out of some strong 2.5 mm plywood, again using the printout as a template. Mark the position of the central hole (8 mm) and the three outer holes (3 mm) and drill them. Sand the straight sides of the hub where the flapping hinge goes so that the sides are leaning inwards at the upper edge by about 30°. Now cut out the bottom rotor hub and drill its central hole. Take a short piece of 8 mm O.D. rod and slip the bottom rotor hub, the flapping hinge and the top rotor hub on this rod. Align everything and use the holes in the top rotor hub as a template for drilling holes in the flapping hinge and the bottom rotor hub. Put a 3 mm screw in each newly drilled hole to hold the parts in place. Put marks on the three parts so you can reassemble them in the same position. Dismantle, bolt the upper and lower hub together and sand the lower hub to the shape of the upper hub, keeping the straight sides vertical this time. Take the two ball bearings and carefully epoxy them into the central holes of the upper and lower rotor hubs. Dismantle again. Make some counterbores in the top rotor hub for countersunk M3 screws, then put the flapping hinge between the hub parts and bolt together using those screws. This way you'll get a flat upper hub surface, which will protect the rear ends of your blades in crashes. You’ll protect the ends even more if you glue a ring of sponge rubber – some 5 mm high – on the upper rotor hub around the rotor shaft.

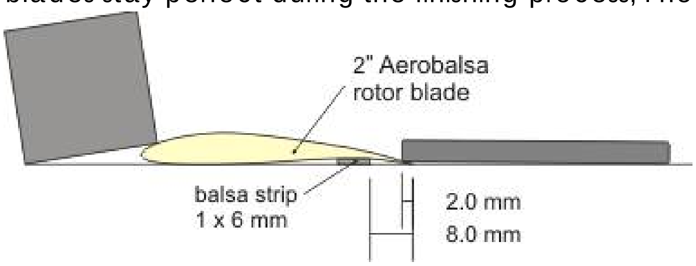
Cut three blade holders out of 2.5 mm plywood and three shims out of 3 mm balsa. These parts have the identical dimensions. Drill the holes for the blade-holding screws and sand down the balsa shims until the leading edge is 1 mm high while the trailing edge remains untouched (see cross section in drawing ‘RotorHub’).

Take three 2" Aerobalsa rotor blades of 450 mm length. Cover the inner end of the blades with pieces of 0.6 mm plywood as shown in the plan and drill 4 mm holes at the appropriate places. Epoxy small pieces of brass tube (O.D. 4 mm, I.D. 3 mm, length about 7 mm) into the 4 mm holes and sand them down until they are flush with the surface of the plywood. Cut off the inner ends of the blades according to the plan. Paint the blades with filler several times and sand them smooth after each painting. Cover the blades with some self-sticking film or paint them in bright colors.

Put Nylon screws into the holes of the rotor blades, slip the shims on these screws and stick the screws through the holes in the flapping hinge. Then put the blade holders at the bottom of the flapping hinge and bolt everything together. Put the rotor on the shaft, tilt the gyro on its side and balance the rotor by sticking some pieces of textile adhesive tape onto the ends of the lighter blades. Check the balance again when the rotor has really spun for the first time.

Bade Finish

You can finish the blades a described in the section above, but to be sure that the blades stay perfect during the finishing process, I now use some Scotch tape to stick



a 1 x 6 mm / .04 x .24" wide strip of relatively hard balsa to my building board and cover it with cling wrap. The blade is then placed over this strip, with its trailing edge 8 mm / .3" distant from the 'trailing edge' of the balsa. I use a heavy ruler - also covered in cling wrap - to hold down the last 2 mm / .08" of the blade's trailing edge and then bend the blade's leading edge down to the building board with some weights (see attachment). Now I soak the last 10 to 15 mm / about 1/2" of the top side of the blade with thin ca and wait 'til the glue is thoroughly cured. After removing the blade from the board, I soak the bottom side in the same way.

Now you can apply the plywood blade holders and continue with the usual finishing process.
Blades treated like this will give you a uniform and very good performance.

RC Set-up

Use a delta mixer in your Tx to control the rotor head. Set up the throws of your servos to give you a maximum roll motion of the rotor of ± 15° and a maximum pitch motion of about ± 8°. If your Tx allows this, mix throttle onto the roll signal so that the rotor tilts a further 6° to the right (seen from behind) at full speed to compensate the motor torque. This value is dependent on your motor and prop, you may have to adjust this to your own needs. I’m using 50% exponential on roll and pitch.

Your First Launch

If this is your first gyro, I suggest that you take some preliminary steps before you do any sort of launching. For these, choose a day with a bit of wind, moderate to good. Turn on your equipment and check that everything is working correctly. Then hold the gyro into the wind with the rotor about vertical and give it a flip. While the rotor is spinning up, turn on your motor and set it to idle, just turning over a bit. Then walk into the wind at a moderate step. Rotor spin-up is more a function of time than travelling speed. After a few meters you should hear a swishing sound from the rotor and feel some drag. If the wind is good enough, this may already have happened before you started walking. Slowly turn the gyro nearly horizontal and adjust throttle, so that the motor thrust is just counteracting the drag of the rotor. Now you should feel a bit of lift. If not, walk a bit faster, adjusting motor speed, but do not run. If you have to run to feel lift, better wait for a day with more wind.

Try to hold the gyro as lightly as you can and watch for any tendencies to tilt to one side. Correct with roll trim if necessary. Then turn your roll stick left and right. Does the gyro react? Does it react very fast? Try to get a feeling for the reactions of the gyro. Remember, I'm using 55% exponential on roll, with the last few millimeters of stick travel reserved for emergency reactions only. Turn the roll stick to neutral again and have a look at the throttle stick to remember its position. Jog a few steps into the wind and give full speed at the same time. Get the feeling of the gyro again and then shut everything down.

Get your breath and go to a place, where you can sit down, calm your trembling hands and think about what you've just done. Did everything work alright? Was there a situation when you had doubts? What were they? Can you resolve them in the next try?

Repeat this procedure a few times, and when you feel comfortable with the situation, then it's time for a real launch. For this, choose a day with blue skies. Do not make your first flights on an overcast day, you'll most surely lose orientation and crash your gyro. Don't ask me how I know. For a hand launch the wind should be strong enough to keep your rotor turning once you've given it a flip, but not much more. For a ROG the wind should be a bit stronger, this will keep the ground speed down.

If you're hand launching, repeat all the steps mentioned above, but shove - don't throw - the gyro more or less horizontally into the wind while you're giving full speed. Here are two good examples of hand launching:
http://www.rcgroups.com/forums/show...182#post6392648
http://www.rcgroups.com/forums/show...149#post7559451

For a ROG, set your gyro into the wind and give the rotor a spin. Set your motor to idle and tilt back the rotor. Wait for it to spin up. Then apply a little power and move the gyro forward at walking speed, slightly releasing the rotor back tilt at the same time. Increase power and decrease rotor back tilt a bit more, but try to keep the rotor speed up. Do this slowly, time is more important than speed. If there's any tendency of the gyro to tilt to the side of the retreating blade, at once release the rotor back tilt. When the rotor is in its normal position and it's still spinning nicely, it's time to apply full power gradually. And, eventually, it should take off.

If, after hand launch or ROG, the gyro shoots into the sky, throttle back - do not use forward pitch in this situation. Otherwise fly it as straight as you can until you are well above the horizon and can see her clearly against the sky, then throttle down to a more or less horizontal flight. If you have any difficulties to get the gyro flying straight, or if she's too far away by now to be seen clearly, set the motor to idle and get her down, anywhere. Shut off the motor before touching down.

Flying the Minimum

There are some differences to flying a plane that you have to watch out for. When you want to climb or descend, you use the throttle do to this, not the elevator. As the gyro is not inherently stable, you have to end all manoeuvres you're doing by actively putting the gyro upright again. In turns the Minimum behaves like a plane with ailerons and elevator. When you want to turn, bank the gyro and then pull a bit of elevator to get it round the turn. The main difference to a plane is that you have to apply far more power in turns to keep the flight path level, otherwise the gyro will rapidly loose height and sort of slip into the turn. If that happens, put her upright again at once, apply power and pull pitch. And the response of the gyro is far more sluggish than that of a plane. When you're cruising along and the gyro starts going somewhere you don't want to go, use short, relatively hard corrections instead of small, long ones.

It's important to land straight into the wind, otherwise the gyro is likely to turn over and you'll have to replace one or two of the Nylon screws holding the blades. When you want to do a dead-stick landing, simply turn the Minimum into the wind and turn the motor off. The gyro will come in at an angle of about 60° and you just have to use elevator to pull it out of this dive at the right moment.

Sooner or later you're going to crash the Minimum. However, most of the time nothing much happens. Things that come in handy in such a case are some Nylon screws for the blades, some styro ca for the tail unit, a 3 mm cf rod to replace a broken landing gear and a predrilled 4 mm cf rod for the front wheel assembly.

Here’s a video clip of the Minimum v2 in action:
http://www.rcgroups.com/forums/showthread.php?t=741749