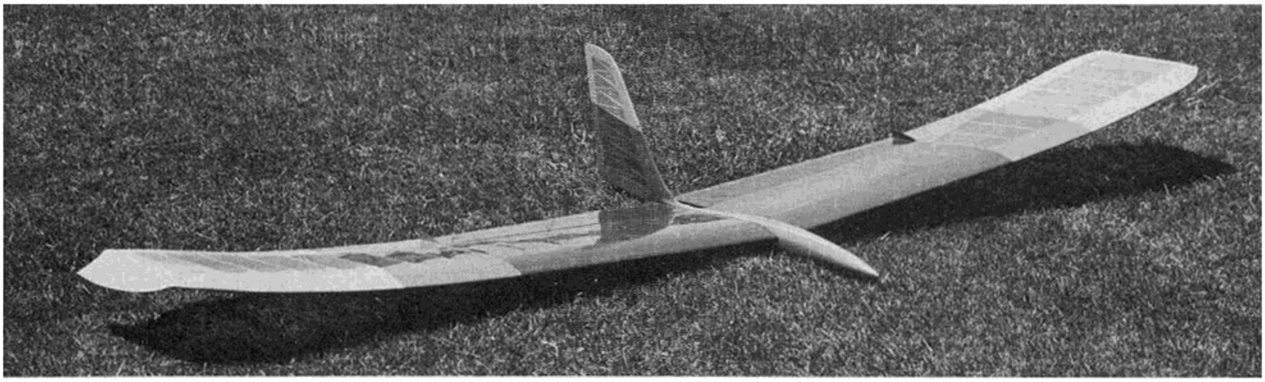


WINDFREAK

PART I

By Roger Sanders

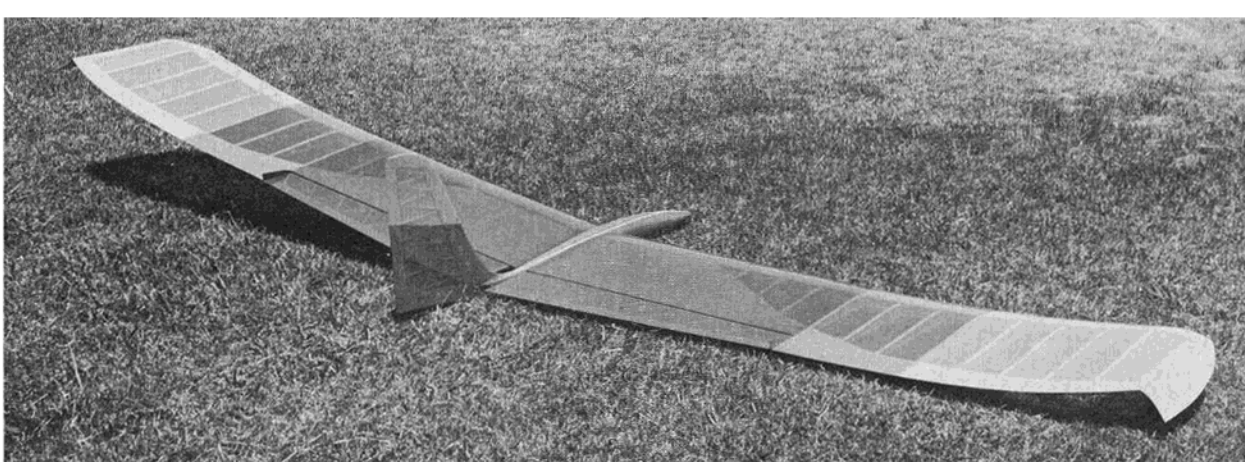
Flying wings have long intrigued me, but I have been very puzzled by their absence from the usual flying field. Furthermore, I have never seen a truly competitive design used in competition. The reason for this state of affairs becomes rather obvious when one watches the flight performance of typical flying wings. They tend to have very poor glide slopes which result in poor duration, they seem to have to fly fast, have strange control behavior, and tend to be suicidal on tow.

At the same time, it is apparent from theory that flying wings should offer magnificent maneuverability and have an outstanding glide slope. Now, greater maneuverability and glide slope sounds ideal for a sailplane . . . why aren't people flying them? The answer is that nobody has developed a flying wing that would match or exceed the performance of conventional sailplanes. I do not know why better flying wings haven't been developed, but felt that there was no good reason that one couldn't be developed. I have designed a long string of conventional sailplanes. Some of these were not good performers, but some of them were outstanding. I felt that I had determined what would produce outstanding flight performance. Since flying wings are subject to the same laws of flight as conventional gliders, I believed that I could apply my experience and knowledge to a flying wing with excellent results.

"Finally . . . an advanced flying wing sailplane design that will match the duration of the best conventional designs, while maintaining the legendary maneuverability of flying wings."

The "Windfreak" was inspired by Ken Bates' "Windlord", which it superficially resembles. (Model Aviation, March 1978). However, the Windfreak is a totally different aircraft except for the same general wing planform. The important aerodynamic parameters are quite different; the air frame is grossly stronger and, probably most important, a much different airfoil is utilized. While I obviously feel that the Windlord can be improved upon, I nevertheless feel that Mr. Bates' design was a giant step forward in the design of flying wings. The name "Windfreak" was partly derived from "Windlord" out of appreciation for Mr. Bates' design. The "freak" part of the name seemed appropriate because the ship is certainly the most unique ship one is likely to see at your local flying site.

In this article I will attempt to give some insight into how I go about designing a sailplane, some of the parameters involved, what the various parameters do, and the various compromises involved. Before we can design a sailplane, however, we must know what we want it to do. I, therefore, developed several performance goals I hoped to accomplish. These goals used Lee Renaud's "Olympic II" as a yardstick. I doff my hat to Mr. Renaud as



I feel his designs are the finest performing ones on today's soaring scene. The Olympic II has, in my opinion, the flattest glide slope, the best manners, and greatest maneuverability of the commercially available standard class gliders. I fully agree with Mr. Renaud's design theory as outlined in his article on the Olympic II in RCM, June 1976. However, I felt that a flying wing should be able to outperform it. My goals were as follows:

1) The glide slope must be as good as, or better than, an Olympic II.

2) The maneuverability must surpass an Olympic II.

3) Behavior on tow must be stable, predictable, and result in launch altitude at least equal to an Olympic II.

Obtaining the first goal, a good glide slope is deceptively easy. All that is required is to have a good lift to drag ratio (L/D). Since lift is a compromise of various factors and is fixed by the airfoil used, what we are really talking about is **reduction of drag.** Drag reduction is a very furtile hunting ground. Much can be done to reduce it. The effect that drag reduction has on flight is startling. Virtually all gliders have more drag than they might have, including the Olympic II. It was by reducing drag and improving the lift characteristics of the airfoil that I hoped to exceed the glide slope of the Olympic II.

There are three types of drag: induced, parasitic, and profile. Induced drag has been called the "price of flight". It is produced in exchange for lift, and it is determined by the aspect ratio of the wing. In short, long skinny wings have less induced drag than short wide wings. As usual, there are compromises here. It involves Reynolds Numbers, wing loading, towing characteristics, wing strength, and turning performance. Without getting into these things in detail, let me simply state that, as a general observation, it can be seen that low aspect ratio wings exhibit better Reynolds Numbers, have lower wing loadings, tow higher, have greater wing strength, and turn better than high aspect ratio wings. Therefore, one must trade off drag for some of the other desirable characteristics. Experience has shown that an aspect ratio of 11:1 is about ideal for a standard class ship, while higher ratios are better for larger ships. The Windfreak has an effective aspect ratio of 11:1 although it appears to have an aspect ratio of 7:1. This is because the lifting part of the wing is only 10" wide. The last 4" of the wing is reflexed and does not produce lift and, therefore, does not produce induced drag.

This is a good time to explain how a flying wing flies. There seems to be some mystic about "wings". It appears that they should not fly. This is because they do not appear to have a "tail". Nothing could be further from the truth. They most certainly have a "tail" (stab). A flying wing is nothing more or less than a conventional glider with the fuselage cut so short that the stab/elevator is attached to the back of the wing. Since all airfoils must have some positive angle of attack to be stable, the stab must be at a slight angle in comparison to the wing . . . therefore, flying wing airfoils are "reflexed". It is very simple, and the only question is how much reflex should be used.

An astute observer may note that although the reflexed section of the wing does not produce induced drag in the conventional sense, it does produce induced drag from negative lift. This is true. But remember that it produces overall less drag than the stab/elevator which it replaces from an induced drag standpoint, so we are still ahead.

Parasitic drag is the one that can be most controlled by the careful "modeler designer builder." Parasitic drag is that drag caused by all factors not related to induced drag or profile drag. Such things as fuselages, fins, hinge gaps, sharp fuselage corners, large cross sectional areas, poor streamlining, control horns, tow hooks, switches, blunt trailing edges, rubber bands, dowels, gaps between the wing and fuselage, skids, wheels, and surface interfaces cause parasitic drag and should be minimized as much as possible. Taken individually, each of these things is very small, but when added together, the effect is startling. It is much like the lightweight back packer who says, "Don't worry about the pounds, just take care of the ounces and the pounds will take care of themselves!" There are many ways to reduce these items of parasitic drag. To start, you should use a fuselage that is as skinny as possible, and it should be rounded. Fins, rudders, elevators, etc., should be as thin as structurally possible. Tapering these items is ideal. Streamline everything as much as possible. Hide control linkages and horns inside the various structures and, if you can't, then put them in the turbulence following another required structure. Put switches inside the fuselage and use a small wire to turn it on. Make the wire push in to turn "on" so that less wire is sticking out in flight (seriously!). Make sharp trailing edges. Don't use rubber bands or dowels. Fit the fuselage to wing joint so it is close, consider taping it (smoothly please). Don't use skids. Minimize interfaces between the stab, fin, rudder by using fully flying surfaces and fillets at the joints. Use high aspect ratios on the empennage. Use **MonoKote type hinges** and seal the hinge gap on the other side with some type of film. Always remember that it takes energy to push anything through the air. The less you have to push, the longer the energy you put into the glider by towing it to altitude will last. The longer the energy lasts, the longer you stay up. From a physics point of view, you put 1500 foot pounds of energy into a glider that weighs three pounds and is released from tow at 500 feet of altitude. If there is dead air, that glider will land at the moment it uses up 1500 foot pounds of energy overcoming **drag**. If you want to stay up, you must reduce drag. Every little bit counts. Don't poo poo a 1% drag reduction. 1% of 7 minutes is only 4.2 seconds, but that may be all you need to beat the next guy in a contest - - - why give anything away?

Profile drag has to do primarily with the airfoil. A blunt thick airfoil will have greater drag than a long thin one. However, again compromise is in order because thin airfoils have generally less lift than thick ones (of the flat bottom variety), and stall characteristics are influenced by these factors as well. Remember that it is the **ratio** of lift to drag that counts, not either one in an absolute sense. In other words, if we could make an extremely thin flat plate wing, it would have extemely low drag, but it would have even less lift. Therefore, its L/D would be terrible and it would have a poor glide slope. This leads to a discussion of airfoils but I want to mention that a short, sharp reflex greatly increases profile drag. It is much better to use a long gentle reflex.

Airfoils are at the heart of the flying wing performance problem. There is absolutely no doubt in my mind that the reason that flying wings perform so poorly is that they are using the wrong airfoils. Additionally, we are thinking about the airfoils the wrong way. A flying wing airfoil should be thought of as a conventional wing and airfoil with a stab hung on the back. Then we won't make the wrong calculations with regard to aspect ratio, wing thickness, CG location, wing high point, and L.E. radius. The typical flying wing airfoil is obtained from full scale ships and tends to be excessively thick (drag), have an excessively forward high point (profile drag), and tends to be semi-symmetrical (poor lift). In short, they have a poor L/D. No wonder they won't stay up.

Why not use a top quality coventional model glider airfoil? One of the best is the one used on (guess what) the Olympic II. I feel that it works even better if it is thinned from 10% to 8% or 9%, has a more rearward high point, and has a little bit of raised entry. These changes give better penetration and higher L/D although stall is a bit sharper and turns are not quite as tight. I chose 9% for the Windfreak. Note carefully that a 9% thickness with a 10" chord gives a wing that is only 0.9" thick. I am not counting the reflex which would give a root chord of 16". If I did, I would end up with a wing that was almost 1½" thick! If you take the 0.9" wing thickness and figure the thickness of the entire wing chord you find that we now have a percentage thickness at the root of only 5.6%, and at mid-span, only 6.4%. As indicated, this is erroneous thinking for calculating flight performance, but it is a very serious concern when talking about structural strength! All that is required to do to the airfoil at this point is to add a long, gentle reflex such that the mean chord line intersects the mean camber line at about 75% of the total chord. This results in surprisingly little reflex. The completed airfoil should now fly exactly like a conventional one, the CG should be at the same point, about 33% of the chord (not counting reflex, remember), the lift should be excellent, and the profile drag should be vastly improved over a typical flying wing airfoil.

Maneuverability refers to the basic ability of the ship to respond quickly to controls and to make tight, flat thermal turns. There are many factors that are interrelated to accomplish these desirable traits. One of the most important is dihedral. In general there are three types of dihedral: straight dihedral, polyhedral, and elliptical dihedral. Of the three, there is no doubt that elliptical dihedral is superior. However, it cannot be used in a wing that has a hinge line in it because a hinge line must be straight if built in a conventional manner. Elliptical dihedral has less drag and is overall more efficient than any other type. It is not really difficult to build, in fact, I find it easier to build than a polyhedral wing. Straight dihedral does not produce as flat a thermal turn as a polyhedral wing, and is the least efficient of the three because the lift vector of the entire wing is so far from vertical. Polyhedral is good, but it has drag around the polyhedral break, and it is very difficult to produce a truly excellent fit at the polyhedral junction. Additionally, the polyhedral joint tends to be heavy and adds mass to the wing at an undesirable area as will be explained further in this article.

The amount of dihedral/polyhedral is extremely important and is a major area of compromise in any design. To begin, the use of any dihedral is bad from a straight L/D standpoint because the lift developed is not vertical. Therefore, dihedral reduces straight line glide slope. If no dihedral is used, the rudder will only yaw the ship, no roll will result, and the ship will not turn. A small amount of dihedral will result in a ship that is slow to turn and will tend to slip off in a turn. Too much dihedral will result in quick turns, but the ship will be excessively stable and will not want to stay in a turn. It requires that you constantly lean on the rudder in a turn which gets to be a problem in prolonged thermal turns. Remember also that any control offset results in drag, so this should be avoided as much as possible. In my opinion, the ideal amount of dihedral will result in a ship that turns quickly, doesn't slip off in a turn, and will stay neutral in a turn. True neutrality is very hard to come by, and the best ships seem to tend to gradually level out from gentle turns, remain neutral in medium tight turns, and require some opposite rudder to get out of really tight turns. So what are the magic angles? There are no absolute values, but in general, I have found that on a polyhedral wing, 8 degrees at each joint is about right (that would be 4 degrees at each fuse/wing joint for a total of 8 degrees for the central wing joint). Dihedral requires 14 to 16 degrees. Polyhedral can be done in any combination, of course. In the case of the Windfreak, I chose to use elliptical polyhedral. That is to say that I used straight dihedral from the root to the end of the elevators and elliptical curve for the polyhedral section from there to the tip. I used 10 degrees of dihedral and 6 degrees of elliptical polyhedral. This results in ease of building, less drag than a polyhedral joint, and still retains the straight section required for the elevator hinge line.

The other extremely important parameter regarding maneuverability and responsiveness is inertia. Specifically I am referring to mass at the extremes of the aircraft. This means that you must keep the **wingtips light**. It is also necessary to keep the extremes of the fuselage light. However, please note carefully that it is much better from a low inertial standpoint to have a short heavy nose than a long light one. This is a very important consideration and one that can be worked with extensively when you are deciding what wing loading you are going to be using. In short, it is better to add the ballast required to reach your design wing loading to the nose of the ship which is then shortened as much as possible, than it is to add weight to the CG and leave a long light nose.

Weight at the wingtips naturally leads to a discussion of spar design since it is the spars that add the most weight to a wing. In the design of spars, I must say that most designs are very poor. There is absolutely no reason to ever break a wing on tow! None. It is so easy to design strong spars that are also light that the winch line should always break before a wing does. Furthermore, extremely stiff wing rods should be used as wing flex results in loss of altitude. Let's look at the forces on a wing spar for a moment and it will then become obvious what must be done to make strong light spars.

Imagine that the wing spar is a solid bar of material extending from the top to the bottom of the wing and that the wing is on tow. At the bottom of the spar, the forces are trying to pull it apart (tensile loads), while at the top of the spar the forces are trying to crush it together (compression loads). If you think about it a little, somewhere in the middle of the spar, the forces are changing direction and there are neither compression or tensile loads. In short, the spar material in the middle is doing nothing and is wasted weight we are hauling about. It is at the **surface** of the wing where the forces are the highest and where we should concentrate our spars. There are, however, considerable forces trying to crush the spars together. These forces must be resisted by something, therefore, we use shear webs. It should be obvious at this point that spars should be thin and flat and built right on the surface of the wing. The spars should not be placed below wing sheeting, and they should not be placed on edge so that they extend deep into the interior of the wing. Shear webs should be placed with their grain running vertical between the spars and they should be placed directly between the spars. If they are glued onto the sides of the spars then it is only the glue joint that is preventing the spars from crushing together. If the shear web is directly between the spars then the glue only keeps the shear web from slipping out of position. Furthermore, the forces on the spar tend to balance themselves on the shear web so that the spar doesn't twist to one side. It is my opinion that most wing fractures are due to shear web glue fractures. The spars can then come together and they then have virtually no strength and the spars break.

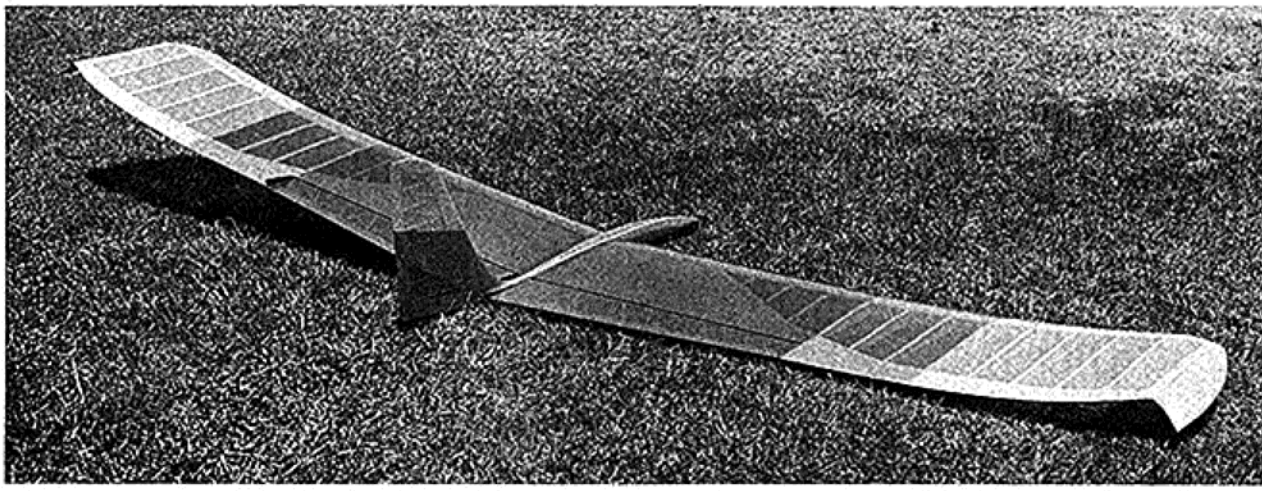
Now, isn't that interesting . . . if you draw a picture of the spar structure I have just described, you find you have the classical "I" beam! Well, now that the secret is out, I'll tell you another one: The bending loads on the wing increase dramatically as you get near the root. In other words, you do not need large, heavy spars near the wing tip. The spars must take both compression and tensile loads, so suitable materials must be used. There recently has been a great deal of interest in filamented graphite spars for example. However, although this material is excellent for handling tensile loads, it will not handle compression loads. If the graphite is potted in epoxy, then the epoxy will handle the compression loads . . . but epoxy is much heavier than other materials such as spruce. Aluminum works well, but it is difficult to work with, shape, and glue. I have found that spruce is still the best material you can use from a practical standpoint. By using thin spars and tapering them, you can have a wing that is extremely light, and virtually unbreakable from a bending load standpoint.

The other, and more difficult, area of wing strength involves torsional rigidity. In other words, how can we keep the wing from fluttering? There are a few rules, but it should be noted that at some fearful velocity any wing will flutter and destroy itself. The name of the game is to get the wing still enough so that it will not flutter in a terminal velocity vertical dive. Ships are available that will do this, but they usually use foam and plywood, fiberglass, or balsa sheeting, and have enough drag that they won't go too fast. For our purposes, all these special purpose wings are too heavy. We can do pretty well if we remember that again the forces are at the surface of the wings. In short, use "I" beam ribs (capstrips), lots of sheeting, and short wide wings. The higher the aspect ratio of the wings, the harder it is to keep them stiff. The thinner they are the harder it is to keep them stiff. As before, the most stresses are near the root, so concentrate your efforts there. Fortunately, this is the area where we can afford to add some weight.

One final consideration with regard to maneuverability is the wingtips. I have experimented with various types of wingtips. These fall into three categories: straight, swept up, and swept down. The worst are the plain tips. Swept up tips were initially used on the Windfreak, but behavior in tight turns was not as good as expected. Sweeping the tips down improved turn performance obviously and, as an added bonus, winch altitude was increased. It was also possible to remove some of the washout in the wings and still maintain tight thermal turns without tip stalling.

Wing loading is a very important consideration. I have built ships that were so light that they literally would not fly, and I have also gone to the other extreme. Let me say that, although a light ship will allow for slightly better turns, the heavier one will be more stable and, in general more versatile. It is amazing how much weight you have to add to a ship to make it truly so heavy that it will not fly well. As a general rule now, I design my ships so that I have a short nose moment and fill the first few inches with molton lead. Lead shot would also work okay, but it is not as dense. It, therefore, takes up more fuselage space and I don't have any to spare. On larger ships, the wing loading should be increased due to scale effect. I consider a wing loading of 7 oz./ft^2 to be a minimum in the Windfreak. That is really too light. Better to go to 8 or 9 oz./ft.^{2}. The problem is in getting the weight around the CG. You do not want it at the extremeties. Recall, also, that you are not really dealing with a 1400 in.^{2} wing since only about 940 in.^{2} is actually lifting. Mine came out to 48 oz. It flies well at that weight, but I think it would do better at about 55 oz. The structure is grossly strong and it should have no problem handling 80 oz. □

From RCModeler Nov. 1978



WINDFREAK

Part II

By Roger Sanders

FLIGHT PERFORMANCE

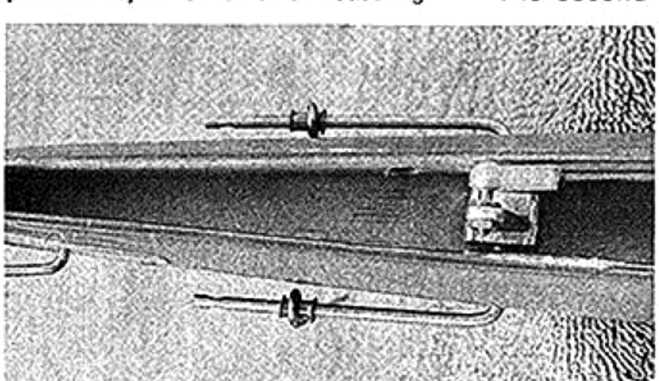
I do not feel that it is appropriate for the designer, builder, pilot to evaluate his creation because he will be biased. This view is supported by reading articles where the authors talk only in superlatives about their design. At the same time, the reader should have some idea of what to expect from a given design, and unless an impartial evaluator is available to discuss the performance of a ship, the author is required to do the evaluation. Since an impartial evaluator is not available in this case, the author will do the evaluation, hopefully in an honest manner. Since no design is perfect, the bad points will also be discussed, and the opinions of other pilots will also be mentioned.

To begin, I want to compare the performance of the ship to the original goals of the design. The first goal was to match or exceed the glide slope of an Olympic II. Since we do not have a practical objective method of measuring this, the opinions of several observers and pilots were pooled. There was general agreement that this goal was met. That is to say that at slow speeds, both an Olympic II and the Windfreak were able to stay up about equally. However, when the two ships were compared at high speed (penetration glide slope) at the same weight, there was no contest. The Windfreak could cover more ground with less altitude loss than an Olympic II.

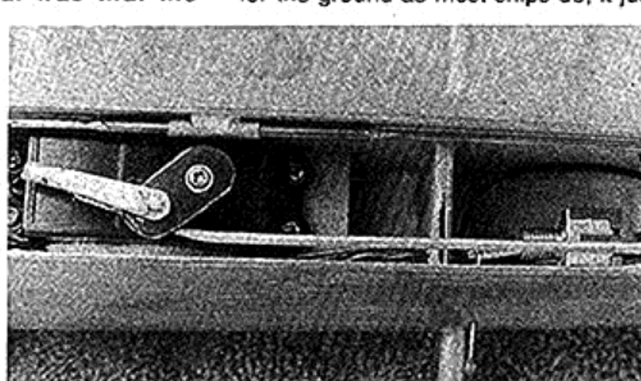
The state of the art of soaring takes a giant leap forward with the Windfreak - - - a flying wing configuration that can equal, or exceed, the performance of a conventional design under all weather conditions. When it comes to maneuverability, it is unsurpassed.

The second goal was that the Windfreak must be able to surpass an Olympic II with regard to maneuverability. This turned out to be much more difficult to evaluate because the behavior of the two ships is quite different. There was no question that the Windfreak was much more responsive than an Olympic II, but at the same time the actual diameter of a tight turning circle seemed to be about the same for both ships. The only area of maneuverability where the Windfreak was clearly superior was in pitch control. It will recover from a stall virtually instantly - - - something no conventional ship can do.

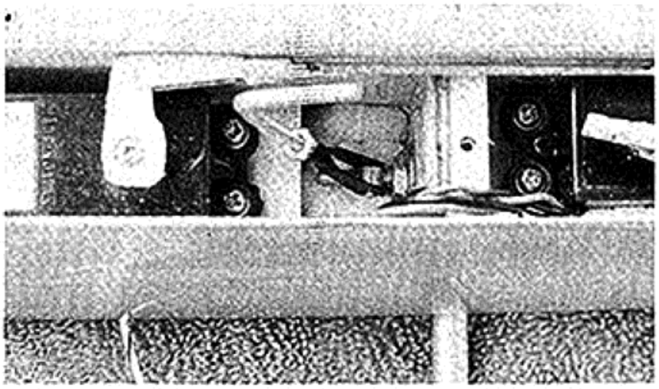
The third goal was to have a ship that towed predictably, was stable, and reached maximum launch altitude. This goal was clearly met. All were surprised to find that the Windfreak goes up on tow as though it were on rails! There is no hunting tendency. It does not tend to stall at all. When forced into a stall, rather than dropping a wing and heading for the ground as most ships do, it just



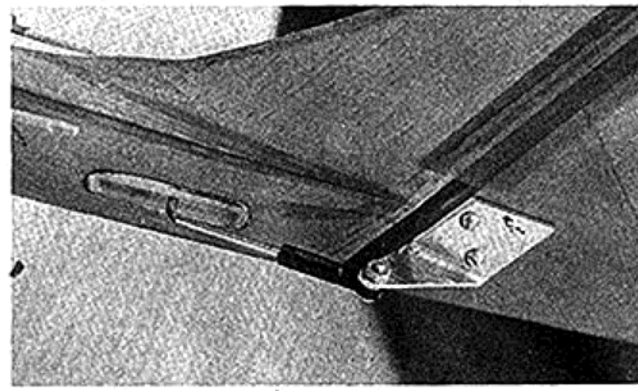
Elevator drive showing cast aluminum boat tiller – Strong!



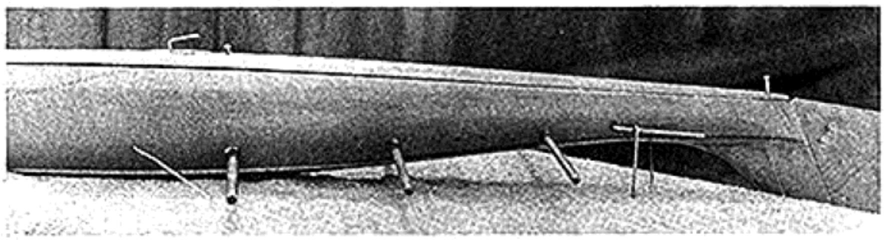
Differential elevator drive detail. Servo arm in level flight position. Note reversed clevis and bend in pushrod for clearance.



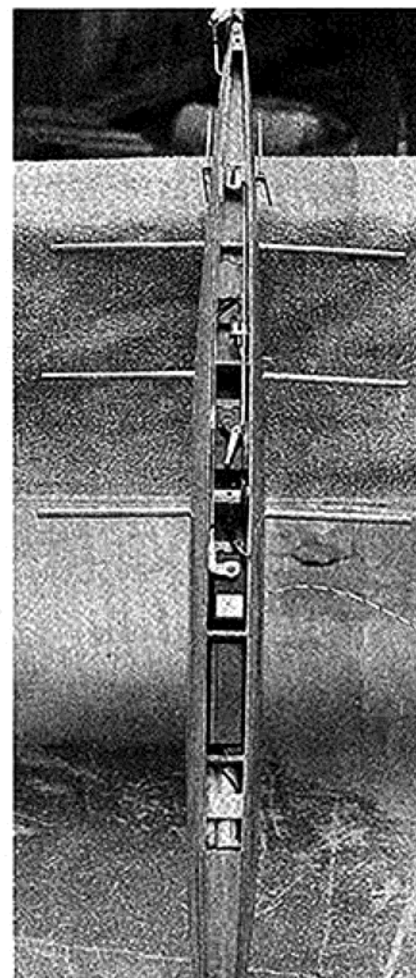
Swivelling tow hook mechanism.



Detail of control horn on rudder.



View of hatch showing tow hook and hatch hold-down bolts.



Detail of radio with bottom hatch removed.

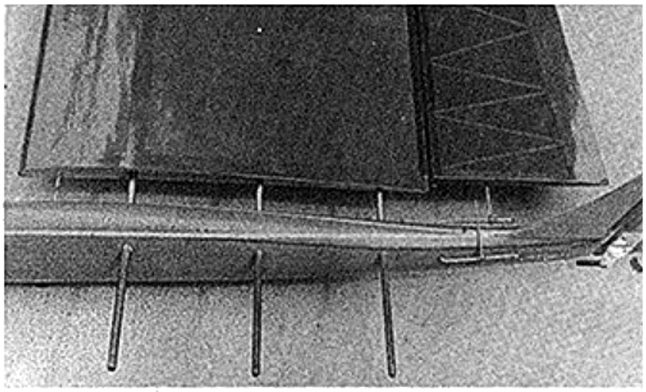
dips its nose for an instant and heads skyward again immediately. It grabs altitude with the best of them.

Flying a wing turned out to be quite a different experience, and several pilots expressed mixed feelings about the ship. All were very impressed by how quickly it could be recovered from a stall. The stall behavior and instant response to elevator results in a ship that will recover from a gentle stall in a matter of inches. A severe verticle whip stall can be recovered in a matter of just a few feet. This incredible pitch control tended to cause most pilots to have some problems with over controlling. Furthermore, most felt that they had to concentrate harder on flying the ship because of this. In short, it was not relaxing to fly. With practice, however, this control should offer advantages for the skilled pilot. When flying in the wind, this degree of control was very helpful. The turn performance was also very quick and the turns were very tight. However, tight flat turns were difficult to execute smoothly and with minimum height loss because of the quick response to pitch command. Again, this could be an advantage to a skilled pilot but it requires concentration.

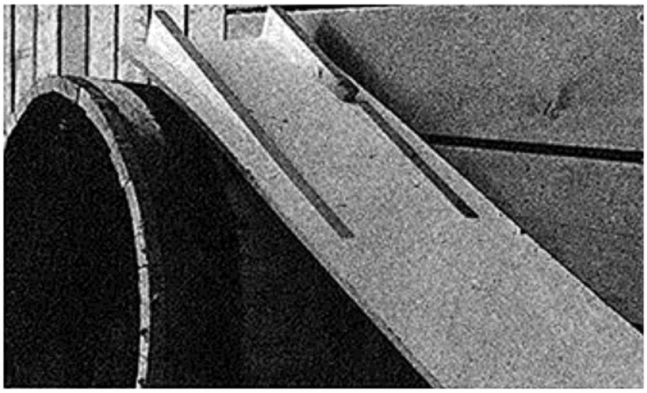
Orientation is not a problem. However, the lack of a fuselage makes it more difficult to read lift and determine the pitch attitude of the ship at a distance. Like a conventional ship that is directly overhead or so high that the fuselage can't be seen, the pitch has to be determined by the speed of the ship rather than by the fuselage attitude.

Speed is one of the Windfreak's strong points. The wings are so stiff that it is virtually impossible to flutter them, and the clean design allows truly superior wind penetration without ballast. It is my opinion that this ship would be untouchable in the FAI speed run because of its speed and instant turning ability. The combination of excellent penetration glide slope and instant response to commands results in a ship that is truly at home in gusty wind conditions. Any ship in the wind requires concentration and powerful command authority and the Windfreak offers some real advantages here. A conventional ship tends to balloon when entering a wind gust or exiting from a turn and, because of the time required to level the ship, the pilot must apply down elevator immediately to prevent a stall. The Windfreak also balloons under these conditions. However, it is so responsive to pitch control that you can allow it to continue to balloon and then apply just a touch of down at the top where it will level out without stalling. The Windfreak will gain altitude out of turn or into a gust where a conventional design will not. The result is a really uncanny ability to gain altitude in the wind. The turn response in the wind is so quick that you can correct for the effects of cross wind gusts that turn the ship before the craft actually changes course. The advantage this offers on a windy landing approach must be experienced to be appreciated. Because of the outstanding windy weather response, the ship is quite at home on the slope. Its speed is such that in the hands of a skilled pilot who can utilize both the speed and quick turning abilities of the ship, it should be unbeatable in sportsman class slope racing.

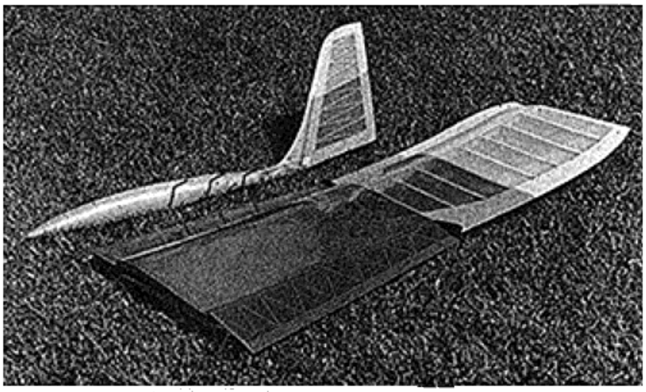
There is another characteristic of the ship that is shared by all ships that exhibit a really good L/D: They are hard to land. This is because a draggy ship will tend to slow down and settle right in for a landing, while a clean ship will tend to keep penetrating and doesn't want to stop. Don't misunderstand me, I am not saying that the ship can't be landed well . . . only that it is not quite as easy as with some ships. Once this penetrating quality is learned, the ship can be landed with the best of them . . . and better than most in the wind. The lack of a fuselage does allow it to ground loop easier than a



Detail of wing fit and elevator drive.



Curved building board.



The "Windfreak", when disassembled, makes a very easy to handle package.

The author just winding up one more perfect flight with his "Windfreak."

conventional design.

It should be apparent by now that this is not a ship for beginners. Although it is stable, its quickness allows the unskilled to get into trouble immediately. This quickness can also be used to advantage by the skilled pilot in that small lift can be centered quickly, wind can be handled well, and landing can be very precise.

In summary, if you are a skilled pilot who is looking for a highly maneuverable ship that is quick and responsive . . . a ship that instantly does what you want it to do . . . a ship that will hang up there with the best of them . . . a ship that will really move when you want it to . . . in short, a ship that you can really fly rather than just steer around the sky, then the Windfreak is for you. Let's move on and build one.

CONSTRUCTION

Just as this ship is not recommended for beginning pilots, it is also not recommended for beginning builders. However, construction can easily be modified by the individual builder to make things easier if he so desires. I shall make suggestions about this as we go along. Presumably the experienced builder is familiar with various building techniques, so only a few comments will be mentioned and special problems will be discussed in detail.

The wing has a lot of curves in it with the reflex and the elliptical dihedral, and special techniques are required to build it. You should decide if you want to build the elliptical version, since straight dihedral will work as will conventional polyhedral. Frankly, I find that elliptical polyhedral is easier to build than building separate polyhedral sections and joining them. If you make conventional polyhedral, use 8 degrees at each joint, and "break" the wing at the second rib past the elevator. The last rib should be elevated 2.5" for the 8 degree angle. The wing rods should be bent so that one end is 0.6" high (assuming a wing rod 9" long). Unfortunately, straight wing rods cannot be used because the wing is too thin to get the proper angle on the rods, the rods must be bent. If you use straight dihedral the wing rods must have a bend that leaves one end 1.1" high. If you use elliptical polyhedral you have two choices. You can use 6 degrees of polyhedral and 10 degrees of dihedral, or you can use 8 degrees of both. I chose the former because to use more curve requires that the top sheeting be curved inward when being attached to the spar because it tends to curve outward when being attached to the wing. Since I attach the spar to the sheeting before gluing the assembly to the wing, and it is much easier to glue the two if they are straight, I opted for a bit less wing curve than I really would have preferred. If you want a full 8 degrees of elliptical curve, then make your building jig 3.5" high at the tip. 6 degrees is 2.3" with wingrods that are 0.8"

I made my wing curve jig out of a 1/2" thick piece of cellotex to which I nailed on two pieces of wood with the proper curve. This assembly is quite flexible, but it works fine when placed on a flat work table (see photographs).

The spars are made from 1/2" x 1/8" x 48" spruce. Take all 4 of them and stack them together using double sided tape in several places. Draw the taper on the top spar. Note that the taper doesn't start for 14" as measured from the root. Cut the spars on a band saw or Dremel saw. Take a sanding block and sand the tapered section smooth. Split the spars apart and glue them to the balsa planking. I do this by taping the spar to the planking with masking tape so the fit is perfect, then opening up the two, using the tape as a hinge and filling the gap with glue such as Titebond. Do not use the instant adhesives for gluing spruce or plywood. Now close the "hinge", wipe off the excess glue, and let dry. You will have a perfect joint with no gaps or sanding required if you cut the balsa planking straight with a straight-edge before taping it up. If you don't have a long enough straight-edge, go to a home building supply and get a 6' length of aluminum bar about 1.25" wide and 1/8" thick.

Assemble the bottom sheeting, capstrips, and trailing edge on a flat surface. Add the ribs. I cut only the front of the spar notch when making ribs and trim each notch to match the spar taper when I install the rib. The reflex section of the rib is above the T.E. at this point, only the flat part of the rib is glued in place. After the glue has set, just bend up the T.E. sheeting to meet the ribs and glue with instant adhesive.

Build both wing panels to this point, but do not add the plywood root ribs or L.E. yet. With the wing rods not yet bent, assemble the plywood ribs, brass tubes, and wing rods. Place the partially completed wing panels in their flying position on a flat surface; be sure the alignment is right, and then glue in the ply ribs and tubes. Now you can bend the rods.

At this point the jig hasn't been used and the wings are flimsy. Now use the jig to curve the wings and add the L.E. Carve the L.E. to shape (you may do this back on a flat surface). Place the wing back on the jig and add the shear webs. Things start getting stiff now so be sure the jig is weighted so it rests firmly on the work table. Add the top sheeting/spar. You will have to soak the balsa because it will not want to follow the curve of the wing, but it can be made to do so if no more than 6 degrees of polyhedral is present. If more than that is used you will have to add the sheeting. Splice it appropriately to get it to follow the spar line, then add the spar later. When the spar is dry the wing will retain its curve forever. The L.E. is now shimmed several inches high so that the T.E. contacts the jig. The T.E. sheeting will be all wavy, but don't let that bother you, just hold it down with pins and add the shear webbing. Now laminate the top T.E. sheeting in place. The T.E. will now be perfectly stiff and true.

The elevator and rudder are built the same way. Note carefully the 1/32" plywood strip on the T.E. of these items. This is very important. It prevents the MonoKote from crushing the ribs into the very thin balsa T.E. stock, and it adds amazing stiffness to the entire structure. **Use hard balsa** for all construction except wing tip blocks.

The elevator is sanded flat on top, and the underside is curved. Ideally the top of the elevator would be concave, but it is getting awfully thin as it is and it is just this side of impossible to sand it concave anyway.

Hinge lines are made with Slik Tak (available from Airtronics for 50¢/roll - - 1 roll is 3' long and 2" wide). I don't use MonoKote hinges anymore because I have had trouble with them fracturing and they are excessively stiff. When placing the Slik Tak on the inside of the hinge, do not use one piece. Use about 3 or 4 pieces and leave some gaps. This will prevent binding. The surface piece is of course solid. The hinge gap is sealed with photographic film. Get a roll of C-120 in black and white. Drop it into fixer and all the emulsion will come off leaving a violet tint only. This can be cut and held in place with double sided tape. Clean the MonoKote with acetone before applying tape so that it is really clean and you will never have to worry about it coming off.

I use a sheet of 1/4" plate glass for sanding structures like elevators and rudders. These small parts are hard to hold, so I stick them to the glass with double sided tape and then I can sand them. The T.E. can be sanded with great precision if it is placed about 1/4" from the edge of the glass. Sand with a sanding block all the way to the glass and you will have a perfectly uniform and thin T.E.

WINDFREAK
Designed By : Roger Sanders

TYPE AIRCRAFT
R/C Flying Wing Sailplane
WINGSPAN
100 Inches
WING CHORD
14" (Avg.)
TOTAL WING AREA
1400 Sq. In. Total
940 Sq. In. Effective Area
WING LOCATION
Shoulder Wing
AIRFOIL
Flat Bottom Reflexed
6.4% Total Thickness
9% Effective Thickness
WING PLANFORM
Constant Chord
POLYHEDRAL
See Text
OVERALL FUSELAGE LENGTH
36" (included rudder)
RADIO COMPARTMENT AREA
(L) 15" x (W) 7/8" x (H) 2"
VERTICAL FIN HEIGHT
12 Inches
VERTICAL FIN WIDTH (incl. rudder)
7" (Avg.)
REC. NO. OF CHANNELS
2
CONTROL FUNCTIONS
Rudder and Elevator
BASIC MATERIALS USED IN CONSTRUCTION

Fuselage	Balsa, Ply & Oak
Wing	Balsa, Ply & Spruce
Empennage	Balsa & Ply
Wt. Ready-To-Fly	48 Ounces
Wing Loading	4.9 Oz/Sq. Ft. (7.3 Oz./Sq. Ft. Effective Loading)

I recommend that the ship be covered with MonoKote. The other coverings are not as stiff and the MonoKote is very important in preventing wing flutter. The colors are up to you. I have tried all the colors and find that no one color is best for all conditions. Therefore, you see my ship "giftwrapped". It may be odd looking, but I can assure you that it is the most visible craft in the sky!

The wing fillets to the fuselage are made with micro-balloons and resin. Assemble the wing to the fuselage, but be sure to rub Vaseline on the wing rods and the side of the fuselage so the resin won't stick. I do this after the fuselage is covered or painted. Masking tape is then placed along the bottom of the wing/fuselage joint and brought up the T.E. and L.E. so that no liquid can spill over. About one ounce of resin is mixed with micro-balloons until it will just flow slowly. This is then poured into the gap and allowed to get firm, but not hard. The wing is then flexed up and down on the rods a little to break the resin's bond to the Vaseline and the wing is gently worked off the rods and set aside to harden. Sanding is done by wrapping masking tape around the wing just beyond the fillet and the fillet is sanded with a block to the level of the tape. The tape is then peeled off and the final sanding is done. This prevents ruining the sheeting when coarse sanding the fillets.

The fuselage may require a bit of modification to fit your radio. The idea is to make everything **just** fit. The problem is in putting the extra wires somewhere, switches, and linkages. Furthermore, it has to be done in such a way that things can be placed in order so that everything will fit. It is not impossible to do, but it does take some thought and planning. If you don't feel up to it, make the fuselage bigger. You will lose some glide slope, however. The plans show just the plywood box. You can choose to leave the fuselage that way if you want, but if you do, you should make the entire thing out of 1/8" plywood . . . aircraft ply, not light ply. Remember that you want as much weight around the C.G. as you can get. To round the fuselage, just laminate 3/8" balsa and start carving. Make the nose block out of oak or at least use pine, but don't use balsa. Small nose blocks get mashed. Once the basic fuselage is constructed, assemble the ship and try to determine about how much weight you can add to the nose. Pour molten lead or lead shot into the nose, and resin it in place. If you add too much, you can drill some of it out later or add lead to the tail.

The tow hook pivots on a clevis from a Du-Bro Swiv-Link. The hook itself is made from just ordinary pushrod wire. A lock nut is used to prevent the wire from turning. A nylon elevator exit guide is used in the floor to allow motion of the hook. It looks flimsy, but it's not. The elevator linkage is a modified flap linkage made by Dodgson Designs (2904 so., West Camano Drive, Camano Island, Wash. 98292 — about $5.00). This is cut apart and the two ends are filed so that they fit together snugly inside a brass tube. A cast aluminum boat tiller has a couple of pieces of brass tubing telescoped inside of it so that it fits around this joint snugly. The brass tubing is drilled so that the set screw can extend through them. The piece of brass that is around the linkage is not drilled, however. The set screw then is placed solidly against the inner brass tubing after the two linkages are set into place.

You will have to make up a control horn for the rudder because no commercial horns extend far enough forward to come up to the hinge line. If you do not have the connection at the hinge line, you will have differential rudder throw.

You really must have differential in your elevator, however. I make up my own servo arms from blank discs since the servo arm offset really should be about 60 degrees, not just 45 degrees as is typical standard aileron differential servo arms. Use ball links where indicated. The linkages to your servo **must not have lash** in them when dealing with large surfaces that are fully flying in responsive aircraft! Under absolutely no circumstances should plastic tubing pushrods be used! It is advisable to put in new gear trains in your servos and replace the upper servo case as well so the servo will be as tight as possible. Always clean the servo pots before installing them in a new aircraft. If a servo turns the wrong way, take it apart, reverse the wires to the motor and to the ends of the servo pot, re-center the servo by rotating the pot as needed, and clean it. You should then be able to use it for a long time with good reliability.

I always install new nicads in each plane I build. It is cheap insurance. In addition, I have to take the battery pack apart to make it fit and the installation is semi-permanent. Most of today's radios simply run on 4 cells in series, and there is no magic to wiring them up. I also like to be able to charge the batteries without removing the hatch since I often fast charge on the field after an hour or so of flight time. Since the wall of the rounded fuselage is thick, no conventional jack will mount into it, therefore, I use a couple of pieces of brass tubing for contacts and stick telescoping sized brass tubing inside of them for charging. When the ship is assembled the wings cover the charging tube holes (drag, remember?). I refuse to use slide switches in my radios. They are unreliable. They are cheap, and they are too big. Have you ever seen a slide switch in a full scale aircraft or in medical instrumentation? Of course not, they are too unreliable. Use miniature toggle switches. If you drill a small hole in the end you can operate it with a wire that sticks through the side of the ship (low drag). The switch can be epoxied in place, no need to mount it with a nut.

The wing rods may all be 3/16" music wire. I used a 7/32" one in the front for increased strength, but it certainly isn't necessary. You may get the 7/32" rod from Airtronics, it is the same one used in the Grand Esprit.

When hooking up the differential elevator control, you will find that a standard clevis will bind against the servo shaft. To get around this, a different linkage must be used. Although there are drive pins that are threaded and snap into the top of a servo arm, I don't like these because they are only driving the rod on one side of the servo arm. I prefer to take a Du-Bro Solder Link and simply solder the pushrod to the side of the clevis and turn the clevis around backwards. With some careful positioning and wire bending, you can get the necessary clearance (see photos). This is a very rigid attachment.

For pushrods, I use the best quality double butted bicycle spokes because they are tapered so that standard brass tubing can be run over them. The brass can be used as a guide or bearing. The hard chrome plating on these spokes will wear a very long time against the brass. A tiny drop of oil is desirable. Guides must be used for rigid linkages. A similar tapered rod is now available from hobby dealers, but the price is absurb compared to a spoke. When soldering anything to these spokes, be sure to sand through all the plating. There is three layers: Chrome, nickel, and copper. You must solder to bare steel for a solid joint.

A problem can sometimes appear when thick wing fillets made of resin and micro-balloons are used - - - the wing rods can crack the fillet. To avoid this, drill out the wing rod holes in the fillet so the rods do not fit tightly. Finally, spoilers will make the ship much easier to land. Feel free to use them, but do not use them on the top of the wing alone. Either put them only on the bottom, or top and bottom, but not the top alone. The reason for this is that top spoilers will cause the ship to sharply pitch down when they are actuated. This is true with any ship, but conventional designs with their long leverage arm prevent things from getting out of hand. In my opinion, bottom spoilers are superior to top ones, but top and bottom are the best yet. The ship will simply slow down and sink without changing pitch when top and bottom are used together.

The radio antenna is run down the inner section of a NyRod which is mounted in the wing. When using this type of antenna system, you will probably find it necessary to have a Teflon insulated antenna wire, since vinyl insulation is reluctant to be slipped down 3' of plastic tubing without grabbing and crimping. Teflon wire is much stiffer and slicker. If your present antenna wire is not suitable (try it first), then simply cut some Teflon wire to the identical length and change the wire. If the length is the same, it will not change your radio tune. Be sure to put a few inches of Teflon wire into the antenna hole between the wing and fuselage when making the wing fillet so that the holes stay open. The resin will not stick to the Teflon. When the resin is cured, simply remove the short piece of wire and a perfect fit between the fuselage and wing will be available for your receiver's antenna.

TRIMMING AND FLYING

Trimming is very important in this design as its crispness will show up trim errors in exciting fashion! The C.G. is critical. The correct point will be found to range across the width of the spar. Unlike conventional ships, you cannot fly this one nose heavy since there is not enough elevator force to overcome the nose heavy condition and very high speeds will result. Therefore, do not allow the C.G. to range ahead of the spar. The ship will be completely pitch unstable if the C.G. is much behind the spar. While conventional ships can be flown (with great difficulty) when the C.G. is too far aft, this design has such rapid pitch response that it will be unflyable in this condition. I like a rearward C.G. position and find that about 1/8" ahead of the rear edge of the spar to be ideal. For initial testing, the center of the spar would be a good place to start.

The wings **absolutely** must be free from warps! If you built the wings flat or with polyhedral, then simply lay the various sections on a flat surface (I use the 1/4" plate glass) and look closely. If you built the elliptical version, the situation becomes more difficult. The technique I use is to lay the wings together with the trailing edges facing each other on a flat surface. I weight the wings at about mid-span where they start to curve upward. A book works well for weight, place it on the spar. I then examine the root to see that the flat section is parallel with the flat surface. It almost surely will be if you build the wings true to begin with because the inner section of the wing is extremely stiff. If it is not, work over the MonoKote until it is true. The wing is so stiff that you will have a tough time warping it much with MonoKote, but slight corrections can be made. To set up the tips, you will need a yardstick with a **straight** edge. The wings should have identical curves in them so all that is necessary is to lay the yardstick across the bottoms of both wings and observe the non-reflexed sections. The flat parts of both wings should be parallel to the yardstick if the wings are perfectly true. I initially left the wings in this form and did not add washout since Ken Bates indicated that washout would destabilize the wing. However, I found I had marked tip stall problems in tight turns. This was a bit unusual in its character, in that the ship would tighten up and spiral dive when large amounts of up elevator was added. It would not produce nice tight flat turns. I then added about 3/16" of washout to each wing tip. The results of the washout were amazing. It is hard to believe what a little bit of the right kind of warp will do. Turns were then extremely tight and flat. No adverse affect was noted on stability, therefore, I consider 3/16" of washout to be essential. Note that the 3/16" is measured at the 10" chord point, not at the end of the reflex. It is, of course, measured between the yardstick and the wing. Both wings must be identical. I washed out about the last 20" of the wing. If you built the wings identically and de-warped them correctly, the trailing edges should very closely follow each other along the full length of the wing curvature. Don't forget to de-warp the elevators. The tops of these should be flat. Remember to de-warp the rudder as well. Re-check all structures after testing and also again in one month.

Assemble the ship and adjust the radio and linkages so that you have about 30 degrees of rudder throw. Actually 20 degrees is plenty but you never know when you might want a little extra. The elevator should be adjusted so that the outboard tip matches the fixed re-curve on the outer section of wing. If your C.G. is right, this setting will produce a slow, flat glide and probably ideal stability and pitch response. However, I realize that seasoned pilots may prefer the C.G. at a different location. If the C.G. is further forward, excessive up elevator will result in increased drag which should be avoided. More aft positions are okay, but the margin of stability and trim control range gets very narrow.

There is a way to safely test glide a glider without ever letting go of it, and I highly recommend it. Simply run with the ship and carefully note whether it wants to lift from your hand, sink, or stay neutral. You should not exceed its normal airspeed when doing this, of course, but since normal airspeed is probably in the range of 15 to 20 mph, this should not be problem unless the wind is blowing hard. What you are looking for is a ship that tends to remain neutral in your hand. If it tends to lift, I can guarantee you it will balloon up and try to stall. It is a bit more difficult to determine if the ship is trying to sink, and you may find that you can run and release it for just a moment to see if it wants to stay where you left it or if it wants to dive. This is really easier to do than it sounds. Once you have got the ship so it is neutral by moving the C.G. or elevator or both, you can go ahead and toss it with confidence. You must have airspeed, so give it a good shove! Be ready on the controls as it will tend to climb a bit and you will want to prevent a stall. However, that is far preferable than having the trim off so that it won't fly slowly and it immediately hits the ground. Always maintain adequate airspeed.

Winching is easy. The only way to get into trouble is if you do not use enough up elevator! If you launch it at middle trim, it will go extremely fast and not climb and it gets a bit hairy. It works much better to launch at full up trim and even add a bit of up stick partially up the line. It is nice and stable on tow and presents no problems. Be sure that the tow hook is bent enough so that it is slightly more than 90 degrees so that the tow ring will not slip off!

Landings tend to bend the hook because it hangs out quite a bit, and rather than straightening it, it works better to leave it bent. It will settle in one position and won't bend any more and all you have to do is make sure the hook is slightly more than 90 degrees so the tow ring won't slip off. No further adjustment will be necessary.

When flying in wind, I suggest that you do not ballast until you have tried the performance of the ship without ballast. It really will go quite fast with a little down trim. If you do want to ballast, you have a genuine problem as to where to put it since there is no room inside. There are a couple of ways around this. First, you can build in some ballast boxes made of 1/8" ply at the C.G. in the fuselage. This box should be sealed with resin or epoxy on the inside, and it should be closed with a large nylon wing hold-down bolt. This box can then be filled with liquid mercury. Mercury is heavier than lead. In fact, two tablespoons of mercury weigh over a pound, therefore, only very small ballast boxes are needed. Mercury eats most other metals, so be sure that your wing rods are coated with resin if any of them extend through the ballast box.

Ballast boxes can be built into the wings that will accept the usual lead rods or lead shot. I really don't like that much because the weight can burst through a wing in really rough landings. Furthermore, there really isn't much room in the wings because they are so thin. Probably the best way to add ballast is to take 1/4" sheet lead about 2" wide and 4" long and tape it to the top of the wing with some masking tape. It looks ugly, but the tape streamlines it somewhat and the lead will fly free in a bad landing. The lead should be curved to the contour of the wing and be placed at, or just slightly ahead of, the C.G. This type of lead can be obtained from X-ray supply houses. They are commonly used to counterbalance X-ray tubes.

When landing, you will find that coming in high and hot is not very satisfactory because the ship just keeps going and is hard to get slowed down and stopped. I find that it works better to come in at medium speed and then do one or two quick stalls to slow the ship just before landing. The stall lasts such a short time and you can recover so quickly that you can still maintain excellent directional control, but the stall causes gross amounts of drag which brings the ship's speed down in a hurry. The ship does not have to be flown as fast on landing approach as a conventional ship, because you do not need as high an airspeed to control it. You can get through ground turbulence very nicely at medium speeds.

When coming down from killer thermals, you may find that spinning the ship doesn't result in altitude loss as rapidly as you might wish. Inverted flight is probably the best way, but this is difficult to do if you are only a speck in the sky. I have come down in 20 to 30 degree terminal velocity dives, but the speeds obtained under these conditions can only be described as awesome. There is simply no question that you can lose in excess of 2000 feet per minute under these conditions, however.

For those of you who think I might be exaggerating about the abilities of this ship to hang together under extremely high speed conditions, I have a story to relate: One time I was in very strong lift at extremely high altitude and was rapidly losing sight of the ship. I attempted to go inverted, but as the ship came around, I lost sight of it. I asked one of the observers to tell me what it was doing, and he reported that the ship was doing large outside loops at very high speed. As I had neutralized the controls when I lost sight of it, I added some up elevator at this point and again neutralized when I thought I should have leveled out. Apparently the ship must have been at the bottom of an outside loop and inverted when I added the up, because when the ship was again spotted several seconds later, it was in a vertical dive and going at incredible speed. I finally spotted the ship myself a few seconds later, and by this time everybody was yelling to pull up. All the while the ship continued to accelerate at fearsome velocity. I had the sense to very gently pull up elevator to recover from this dive, but that ate up several more seconds, and about the time I had pulled up 45 degrees, I heard, "You lost something!" Expecting to see the ship blow apart at any moment I continued my gentle pull out, and finally got it slowed down and flying under control again. I had come down from nearly out of sight to about usual launch height in a matter of a few seconds. One of the observers was a power pattern flyer, and he flatly stated that he had had his .60 powered pattern ship in full power terminal velocity dives and that the Windfreak would have smoked right by it at the speed it had been going.

It wasn't until I tried to turn that I discovered that the entire rudder had blown off the ship in the dive. We were all amazed that it was still flying. I still needed to get it down and I tried to get it to tumble and spin by stalling it and making it flop around, but each time I tried it would recover nicely and continue flying just as before. Who says flying wings are unstable? I gave up trying to get it to spin, and concentrated on getting it to pull out when it was headed in my direction. When it did, I dived it at about 20 degrees, then pulled out near the ground and managed to land it within 30' of me with no more than a ground loop.

After we all picked our jaws up off the ground, we went over and found the ship to be undamaged except for the missing rudder.

A couple of the flyers mumbled something under their breath about my unbelievable luck (this wasn't the first time that I had deserved a total wipe-out but came through virtually untouched). I had to build another rudder as the original was never found. Probably the most amazing thing of all was that throughout the entire incident the wings never fluttered! □