The Jarvis Illustrated Guide to Carbon Fiber Construction

Jim Jarvis of Austin, Texas shares his method of building carbon fiber rockets.

Tech Tips Series by Jim Jarvis
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Over the last few years, many people have asked me how I make my carbon fiber rockets. So when I had an opportunity to make a new fin can, I decided to document the process in detail.

The result of the build was the fin can shown below left and the "TooCarbYen Tutorial" presented in this article. Actually, tutorial isn't a particularly accurate name for the build since it implies instruction on the proper way to do something. This article isn't about the best way to build carbon fiber rockets, it's about how I build carbon fiber rockets, presented in enough detail to allow others to execute the process if they so choose.

GALLERY: The product of this article, Jim Jarvis has taken carbon construction to a zen-like art.

The fin can is the bottom half of the sustainer of my TooCarbYen two-stage rocket. This 4" by 3" two-stager was to fly at BALLS18 on a minimum diameter N4000-to-M1450 combination to perhaps as high as 70,000 feet. The flight did happen, and for about 15 seconds things went exactly as planned.

Then, at 21,000 feet, and at a speed of Mach 2.6, something went wrong. I don't know for sure what happened, but I suspect that I used the wrong nose cone and pushed it a little too hard. The fin section, which is at the heart of the tutorial, survived the shred and the subsequent hard landing. It will fly again at some point, so I stand by that aspect of the construction.

"Naked" carbon fiber rockets aren't for everyone, but if you plan to give it a try, remember to build safely. Carbon fiber can be hazardous, along with many of the other materials we use. And please feel free to ask questions on anything that is not presented clearly.

Project Description

On October 22, 2008, I flew the TooCarbYen two-stager in Wayside, Texas. It was a beautiful flight to about 50,000 feet, except that the sustainer fin can became detached and was lost. So, it is time to build the replacement. This text and photo tutorial will document the rebuild in detail, including the fabrication of the airframe tube and the fin section.

The original fin can is shown in the next two photos. It was designed to hold the AMW 75-6000 motor case, which allowed the use of the M1350 motor for the sustainer. The airframe was rolled from 5 wraps of 5.9-oz carbon fiber. The core of the fins was G-10 fiberglass from PML (a slightly thicker versions of their Nimbus fins), and they were covered with 5 layers of carbon on each side. After attachment, the fins were covered with 2 layers of tip-to-tip carbon. The zipperless coupler was made from Performance Rocketry carbon coupler tubing and contained several fiberglass bulkhead rings for strength.


The original TooCarbYen sustainer fin can (sized around the AMW 75-6000 case).


The original (with Cotronics epoxy applied to the fin edges).

The new fin can will be longer, and will be designed around the AMW 75-7600 motor case. This adds about 10" to the booster length and makes the entire rocket about 16' long. In all other respects, the design and construction will be the same.

Since the intended use of the fin can is as a two-stage sustainer, there are some things that are not quite standard. Mainly, the motor is used as the interstage coupler and hangs out of the back of the rocket by about 4". If 3" of the zipperless coupler tube is glued inside the top of the airframe, and if the 7600 case is about 41" long, the total tube length needs to be 41-4+3=40". I will plan to make a 42" tube and trim it to length.

Order Supplies
The first step is to order supplies. Here is my list:

Mandrel - For my mandrel, I am going to use PML coupler tubing. Unfortunately, PML does not sell 3" coupler tubing in sections longer than 36" — and I need to make a 42" tube. Therefore, I will request a longer section from them or I will splice two sections of coupler tubing together. Detail: PML tends to not sand their longer coupler tube sections. However, they do sand the short sections that they sell. Since the sections need to be the same diameter, I will get two 36" sections to splice together rather than a 36" section and a shorter section. When I construct the mandrel, I will foam-in a length of conduit tube to act as an axle (see the next photo for an example). So, I'll get some 2-part foam from PML.

Filling the mandrel with foam to lock the “axle” in place.

Mylar - I use 0.005" Mylar (PET film) from McMaster Carr. As it happens, I have a piece of this I can use for the fin can. The idea will be to butt-seam a 42" piece of this around the phenolic mandrel.

Carbon - I use 5.9-oz, 2x2 twill from Applied Vehicle Technology (AVT). A 5-wrap, 3" tube can be made using this 50" wide material. Therefore, I need a little over a yard for the airframe, about a yard for the fin lamination and about a yard for the tip-to-tip pieces. So, a little over 3 running yards total. Since I have some scrap pieces, I'll order three yards (at about $32 a yard). I will also order peel ply from AVT. I'll need a piece of peel ply for the airframe and 3 pieces for the tip-to-tip sections. A few yards will be plenty. I use just the plain peel ply, but the Teflon coated material might work too. I'm also going to order an extra can of the TR-104 high-temperature wax from AVT. This is used to wax the mandrel and the Mylar.

Laminating epoxy - I use Aeropoxy for laminating tubes and also for laminating the fin carbon and tip-to-tip carbon.

I use the 2032 resin and the 3665 SLOW hardener. I feel that the 3665 hardener is essential for providing the working time needed to make multiple-wrap tubes. It takes an oven to get this to set up. I have some leftover Aeropoxy, but I'll order another quart kit from AVT. I'll use some 3665 hardener too for making the fins.

High-temperature epoxy - I use Cotronics 4525 high-temperature epoxy for the fin attachment. I also use it to protect the leading edges of the fins and also other places where structure epoxy is needed (such as attaching the zipperless coupler). I am going to order of pint of it from Cotronics (this glue is a little expensive, so a group order is a good idea). I do not recommend using JB Weld.

Epoxy filler - An epoxy filler is used to form the fin fillets prior to the tip-to-tip carbon. I have used Superfil and Aeropoxy Light, and both work. As it turns out, I have enough Aeropoxy Light for this project (otherwise, I would order it from AVT).

Epoxy additives - I use three epoxy additives for this project. One is milled glass, which can be ordered from a number of places. This will be used with the Cotronics for the fin fillets and the fin leading edges. I also use the West Systems 404 high density adhesive filler and the West Systems graphite powder. Check with your local boat supply store for those. These are not essential, but I recommend them.

Everything else that is needed can be bought locally. This includes items such as chip brushes, foam rollers, parchment paper, blue tape, mixing containers, drop cloths, etc. It is rather essential to have a scale when working with the above epoxies, and the Cotronics in particular. The scale should weigh to the tenths of a gram.

The construction steps for making this rocket will include:

- Making the fins;
- Constructing the mandrel
- Making the airframe;
- Attaching the fins;
- Doing the tip-to-tip lamination; and
- Final finishing steps.

Making the Fins

The fins will start with a G-10 core, and 5 layers of carbon will be laminated to each side. Then, the fins will be tapered before they are attached to the air frame. I use a G-10 core because it is reasonably strong and less expensive to produce than solid carbon. Aft weight isn't a big issue on minimum diameter rockets, and I can purchase the fins pre-cut. It is also helpful to have cores that are a different color than the carbon lamination (as will be illustrated later).

For the sustainer, I will use the shape of the PML Nimbus fins, but I have ordered them to be a little thicker (0.125") than the 0.093" stock fins. These will be sanded with coarse sand paper and then cleaned with alcohol.

The fins will be laminated with 5 layers of carbon on each side of the fin. The fins are nominally 9" (cord) by 4" (semi-span). So, I need 30 pieces of roughly 11"x6" carbon. The following picture shows how I lay out the carbon with masking tape.

Here is how I laid out the carbon for the fin lamination. This is 19 of the 30 pieces. The cloth can be cut with a scissors a sharp knife, or with a “pizza cutter”. Cutting on the masking tape helps keep the airborne fibers to a minimum. I also use a vacuum cleaner to control the fibers when I cut this much carbon.

The tape minimizes airborne carbon fibers when the carbon is cut and also keeps the carbon cloth from unraveling.

There are many ways to do the fin lay-up. I don't have the proper equipment, so I just use common materials from Lowe's (and there is much room for improvement). The lay-up process I use consists of the following layers (from the G-10 fin outward):

Five layers of carbon fiber (the same 2x2 twill I use for the airframe);

A layer of peel ply (to provide a good secondary bonding surface for the tip-tip carbon that will be applied later);

A layer of parchment paper (nothing sticks to parchment paper);

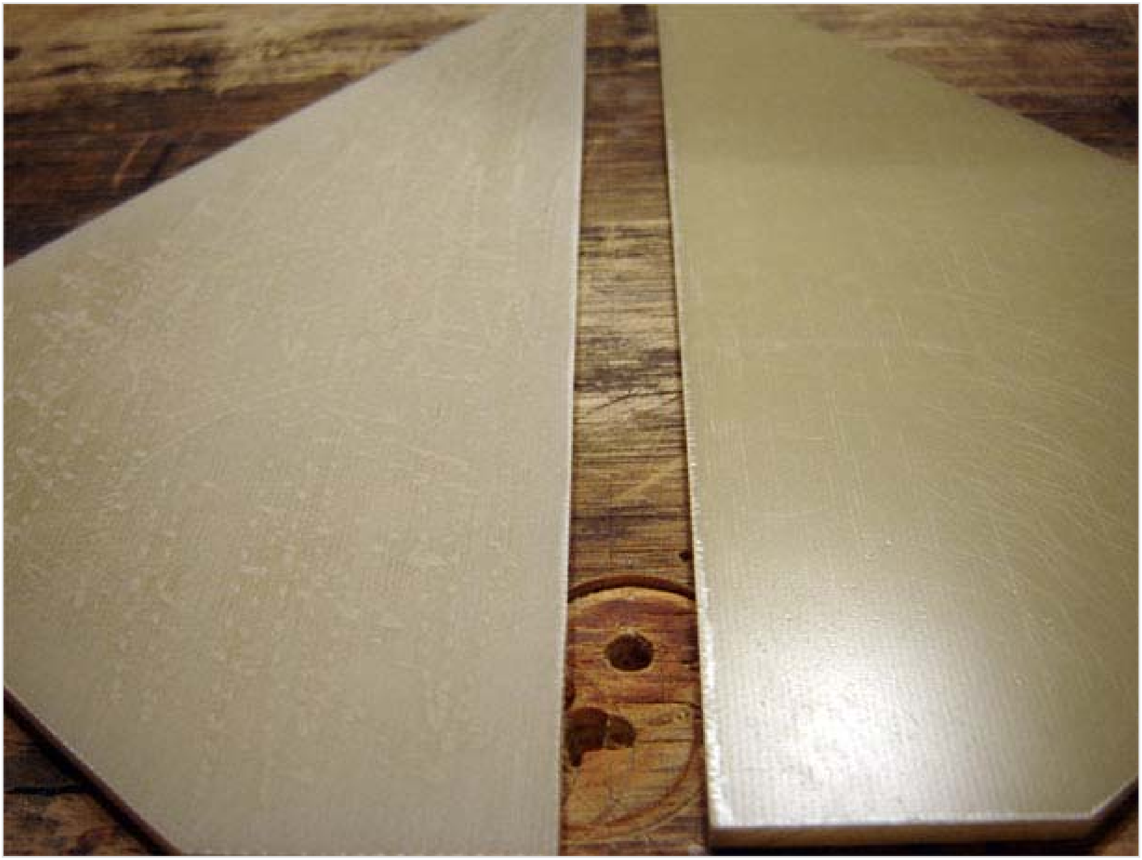
A layer of 3/32" sheet metal; and

A layer of white laminated shelving board (it's flat and inexpensive).

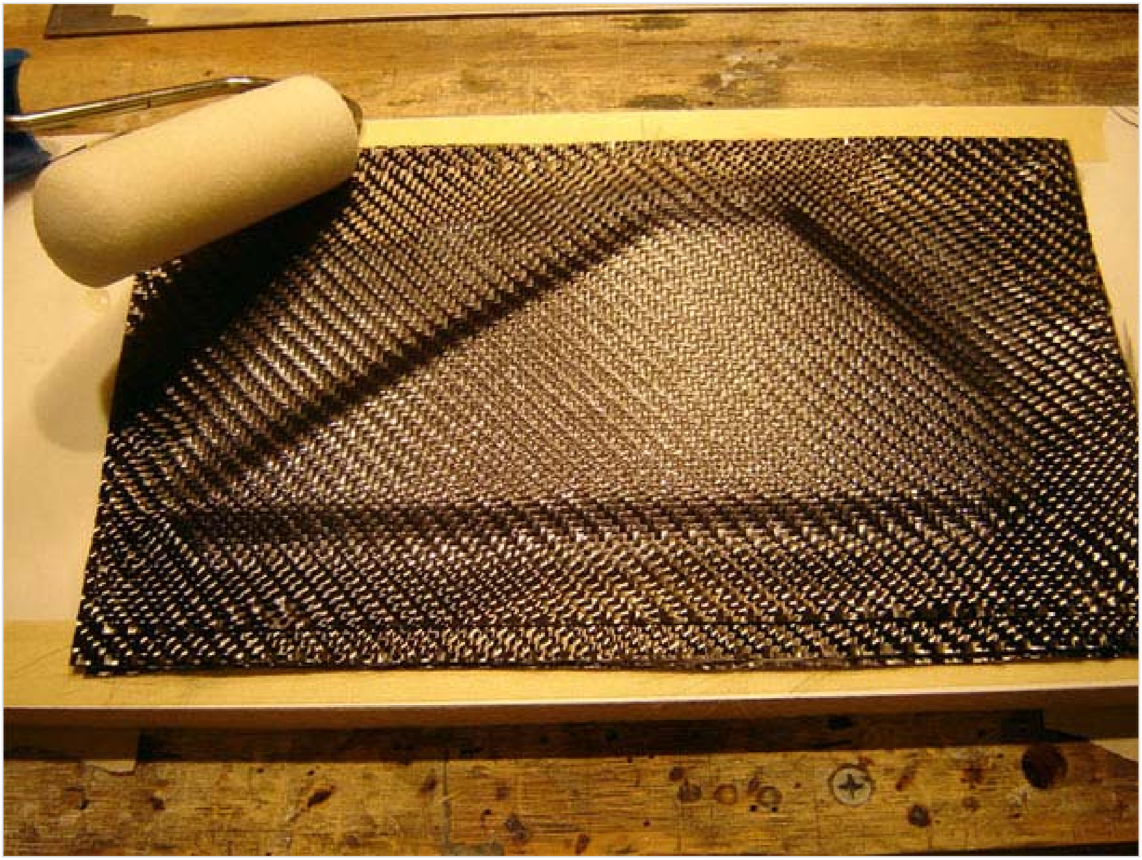
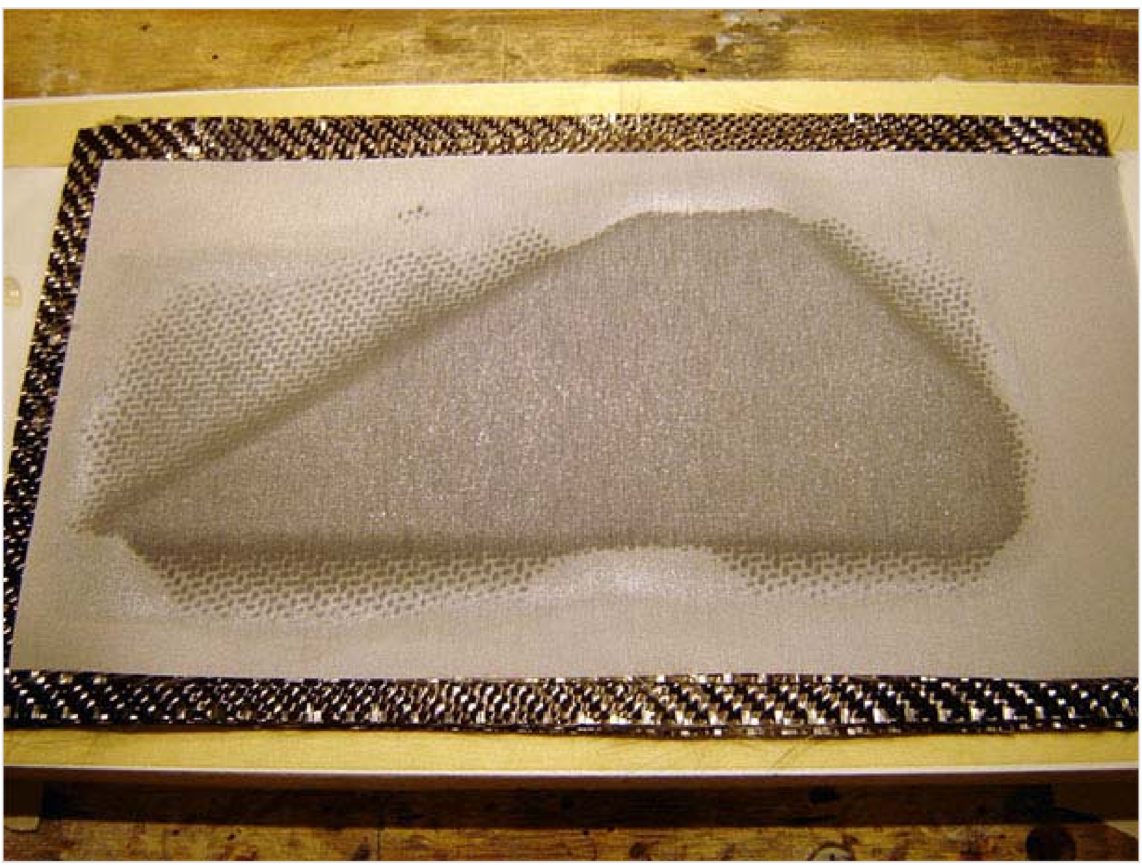
In past projects, I found that the G-10 could dent the shelving board under compression. I added the sheet metal layer to prevent that from happening.

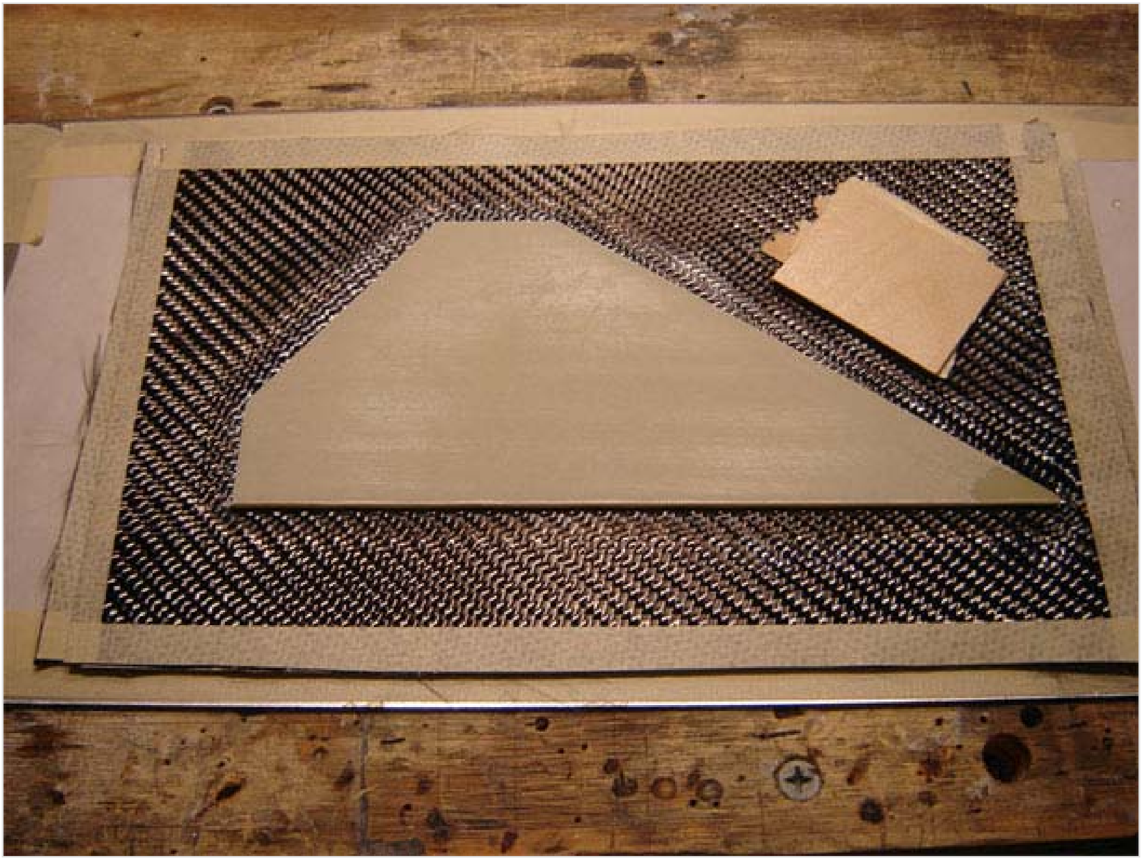
It is essential to have the peel ply surface on both the fins and on the lower portion of the airframe where the fins will be attached. This provides the best bonding for the tip-to-tip carbon layers.

For the fin lamination, I will use the 2032 Aeropoxy resin with the 3660 hardener. The following pictures show how the fin lamination is done:

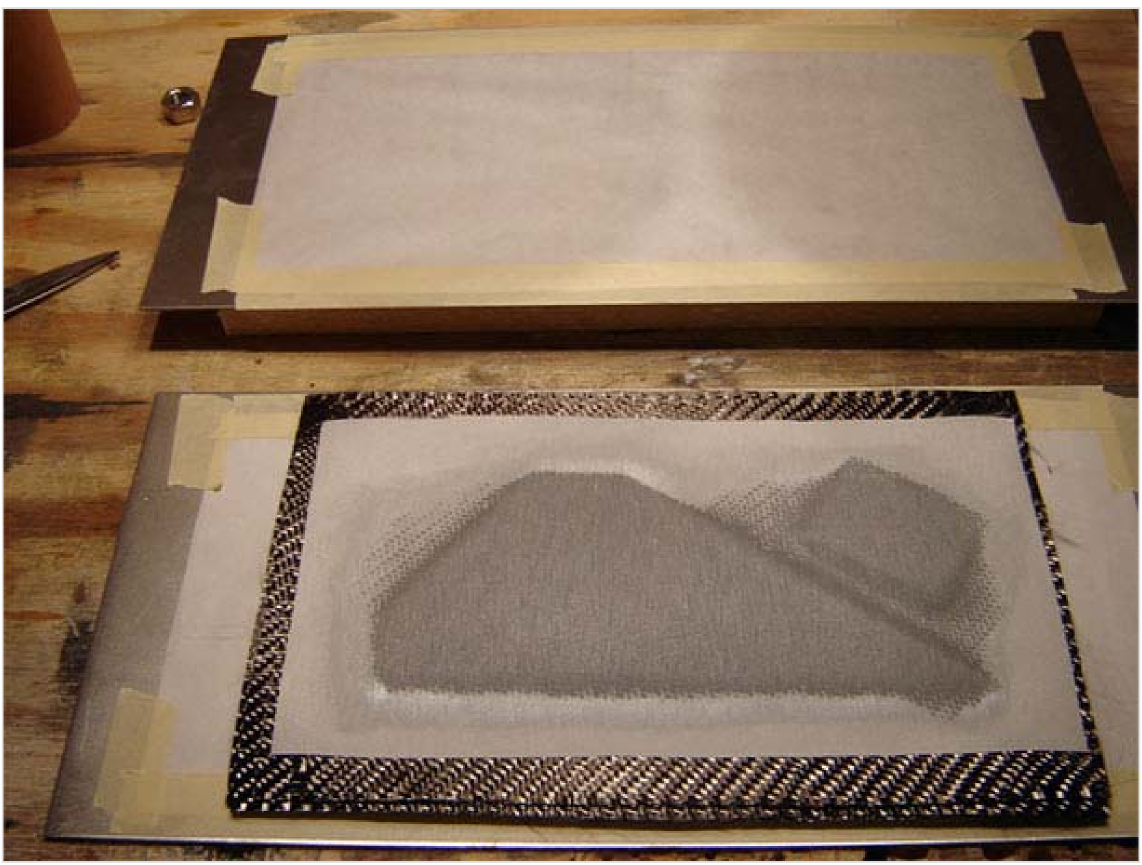

I like to scuff up the fin and then ding it up with a Dremel.

Starting the lamination.


All five layers applied. I use a foam roller.

Peel ply attached and fully wetted out.

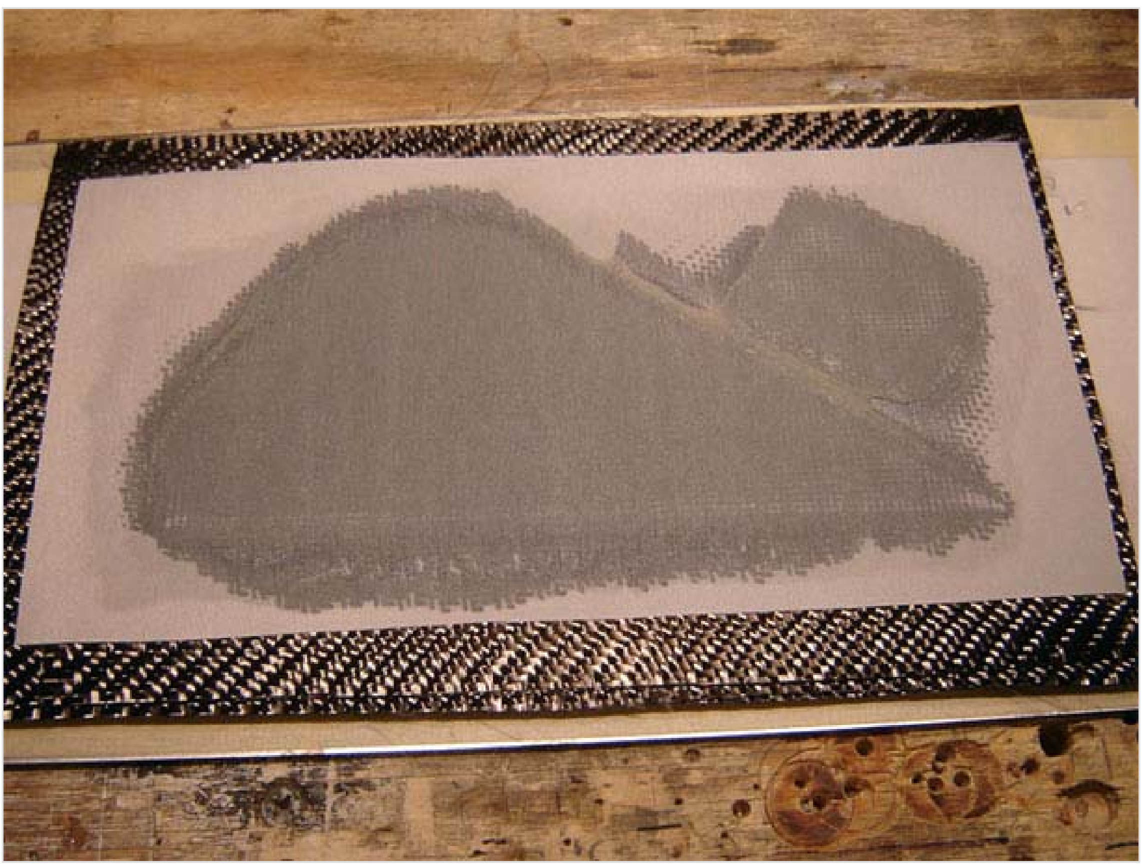


Starting the other side. The spacer in the upper right just makes it easier to apply even pressure later.

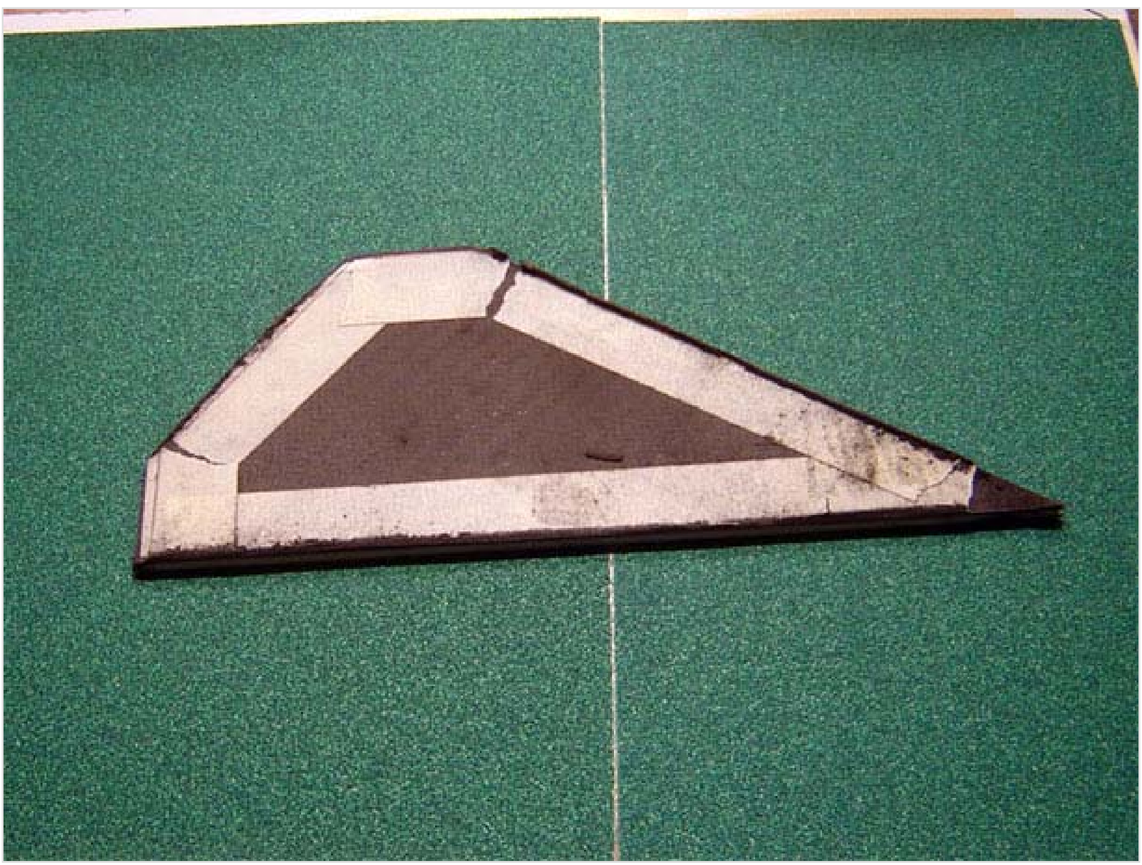


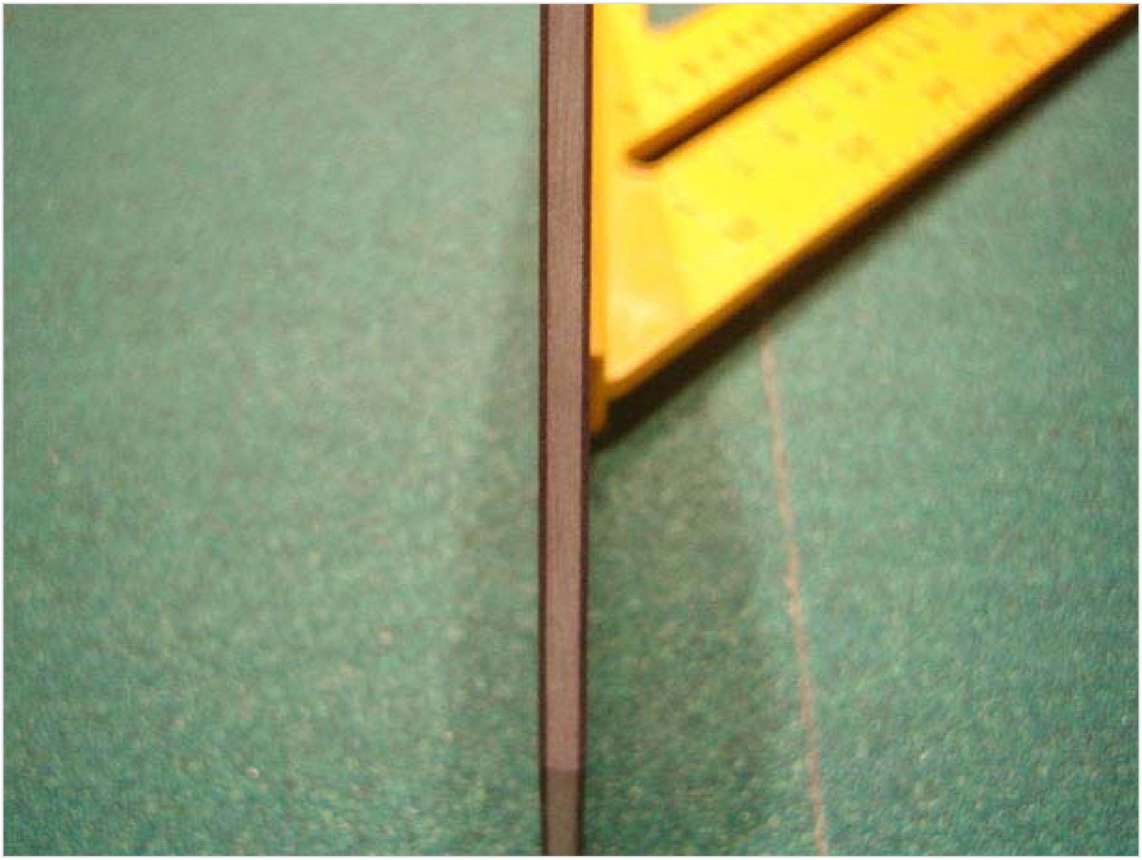
Again, the peel ply attached and wetted out.

Compression applied. Sure wish I had Mick's plate press!



This is the fin after compression and curing.


Peel ply removed.

Fin cut to basic shape and then the edges are sanded flat on this sandpaper-covered board.

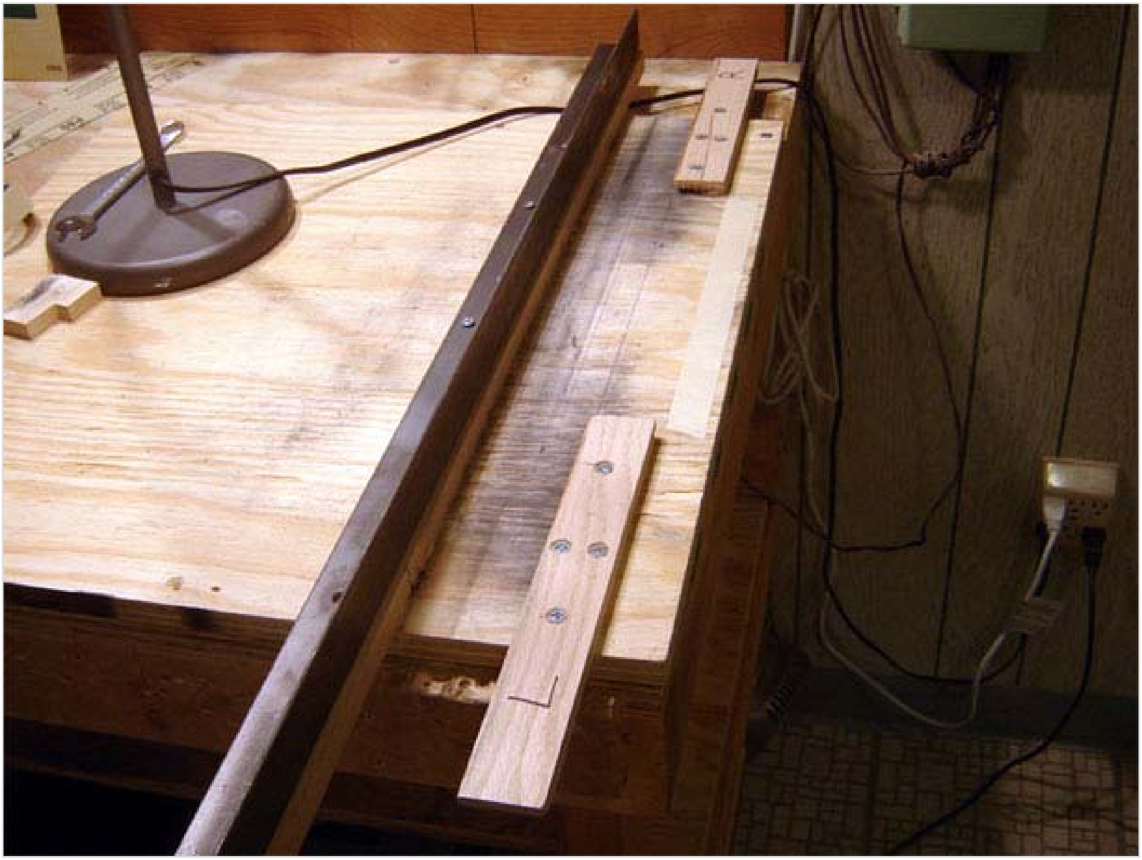


Final fin-sandwich. Compression reduces the thickness of the carbon layers from 0.011” to about 0.006”.

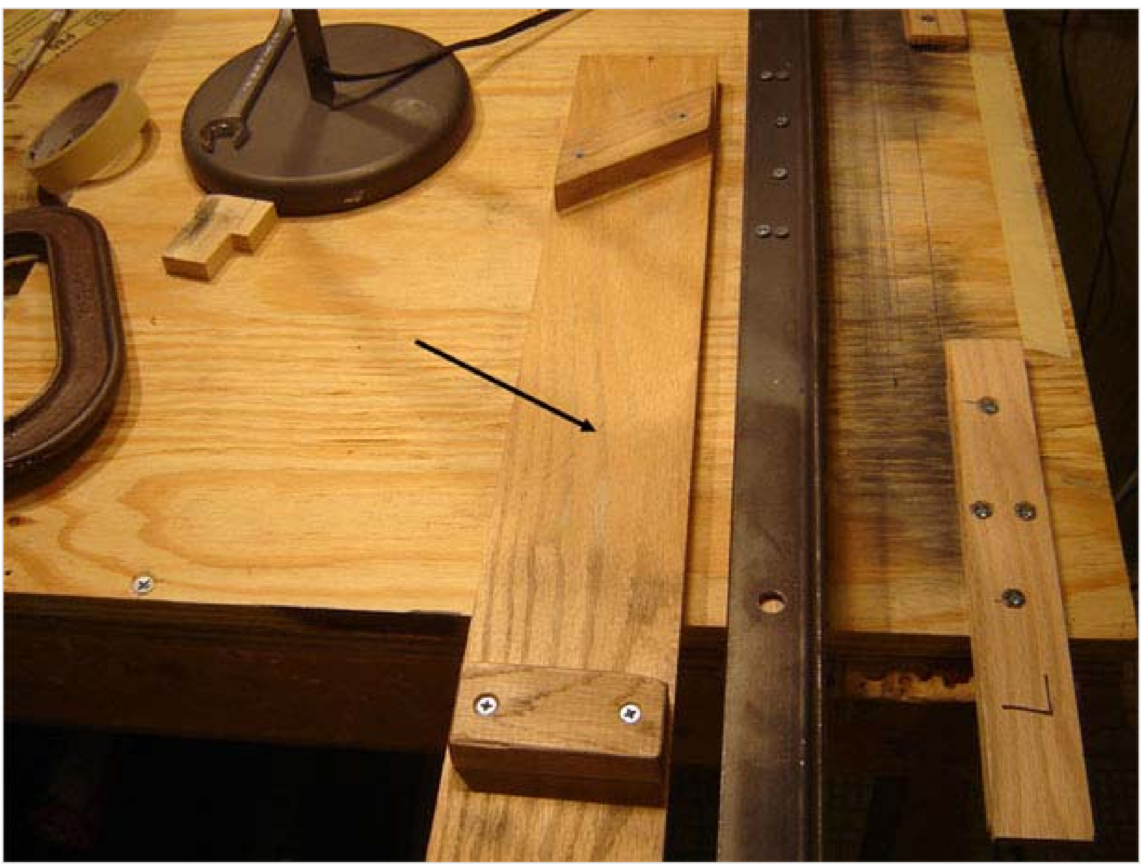
Now that the fins are laminated, they need to be beveled. Later, tip-to-tip carbon will be laminated to each fin. To help make the tip-to-tip carbon easier to install and finish, the fins need to be beveled so that they come to a relatively sharp edge around the perimeter of the fin, and so that there are no sharp edges or transitions.

I use a sanding jig to bevel the perimeter of each fin. The jig holds a sanding block at an angle so that a consistent bevel can be sanded on each edge. The jig can be easily constructed; however, it is very important that it be as square as possible.

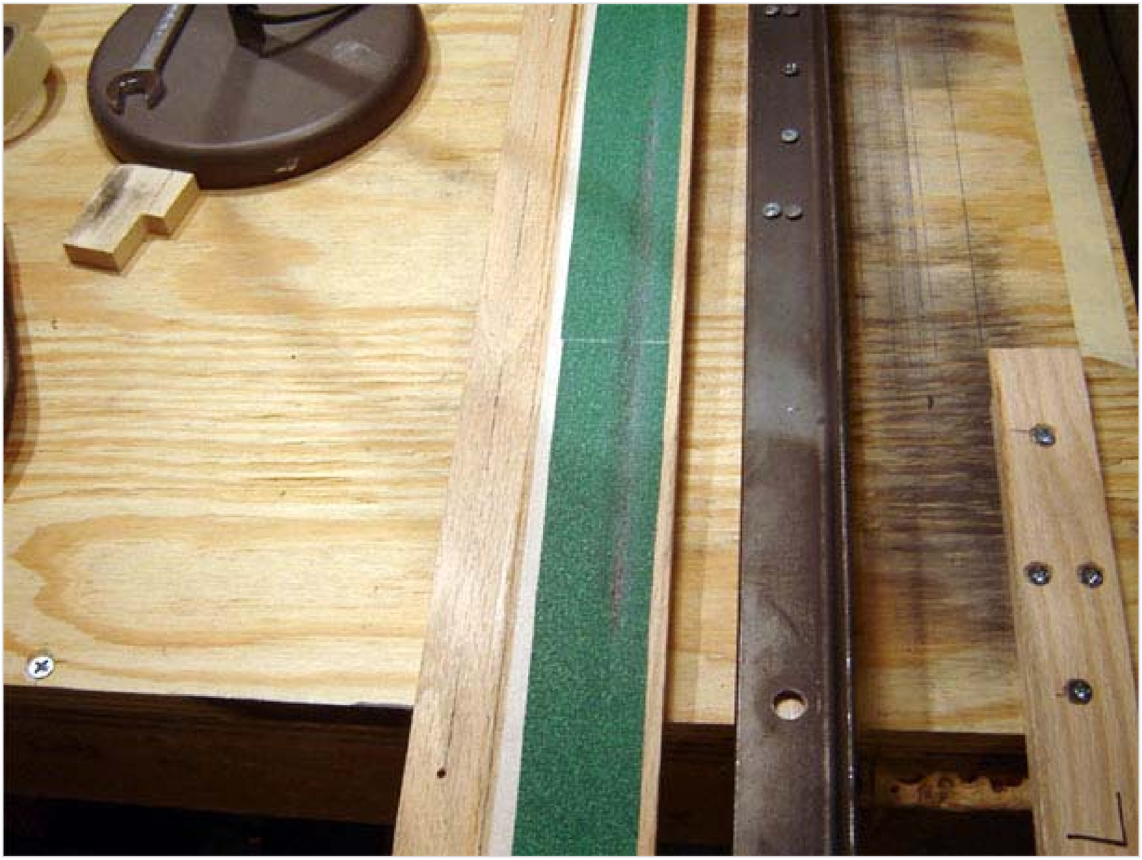
For this project, I will sand a bevel around the perimeter of each edge and then a second bevel at 1/2 of the original angle just to help smooth the transition. Then, the edges will be sanded a little more just to make sure everything is smooth. Finally, the peel ply finish on the flat portion of the fin will be lightly sanded to make sure there are no high spots. It is important to leave as much of the peel ply texture as possible so that the tip-to-tip carbon bond will be as strong as possible.



This is my sanding jig for fin beveling. I go through pains to make sure everything is square.



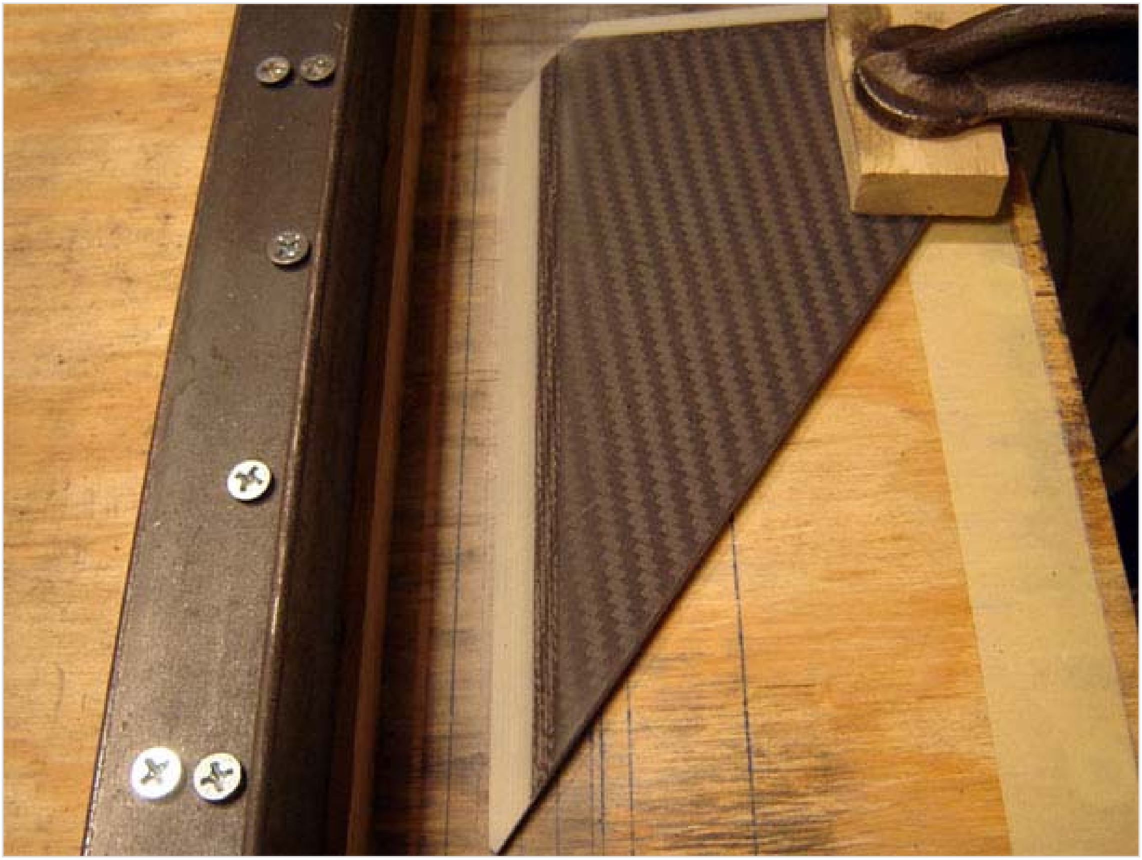
This is the sanding board that slides back and forth (black arrow).


It has sandpaper attached with double-sided tape. The geometry of the jig must be carefully thought out.

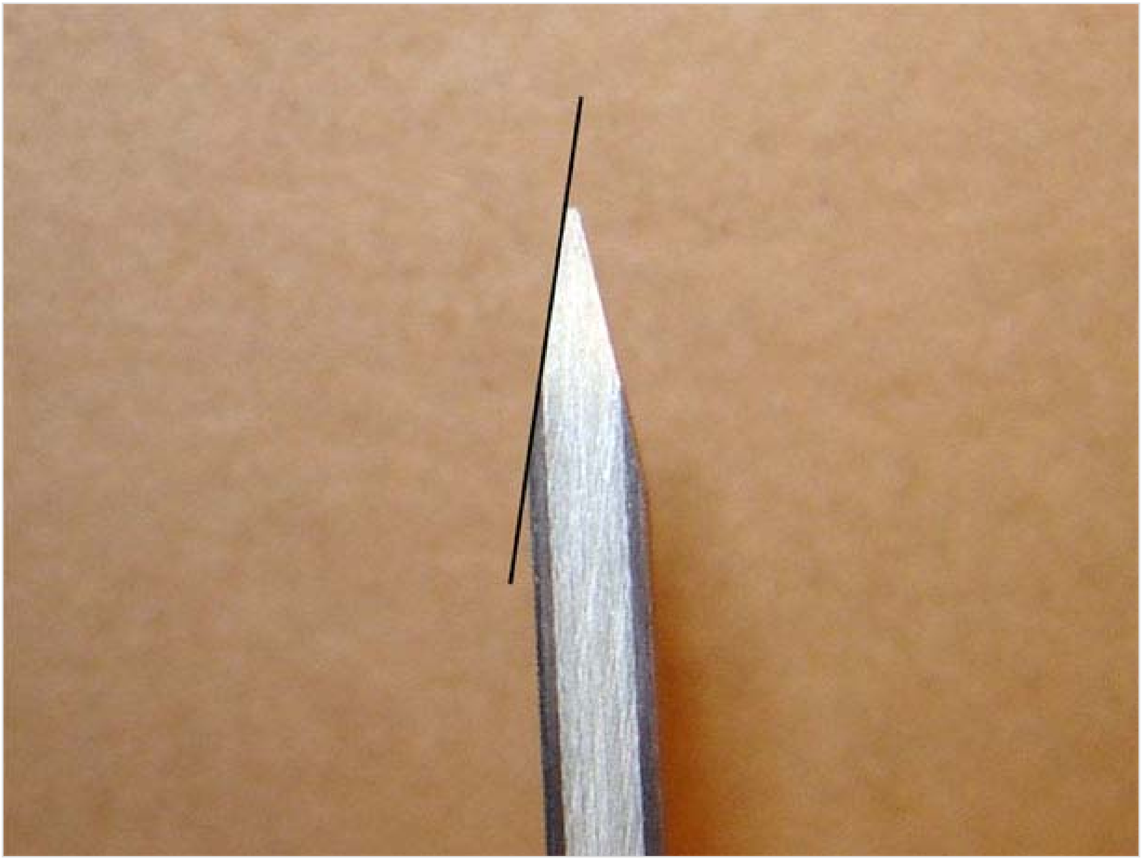
The board sits on the jig like this.

For the first bevel, the sanding block sits on top of two blocks (white arrow), which set the sanding angle. Later, one block will be removed to set a second bevel at a lower angle.

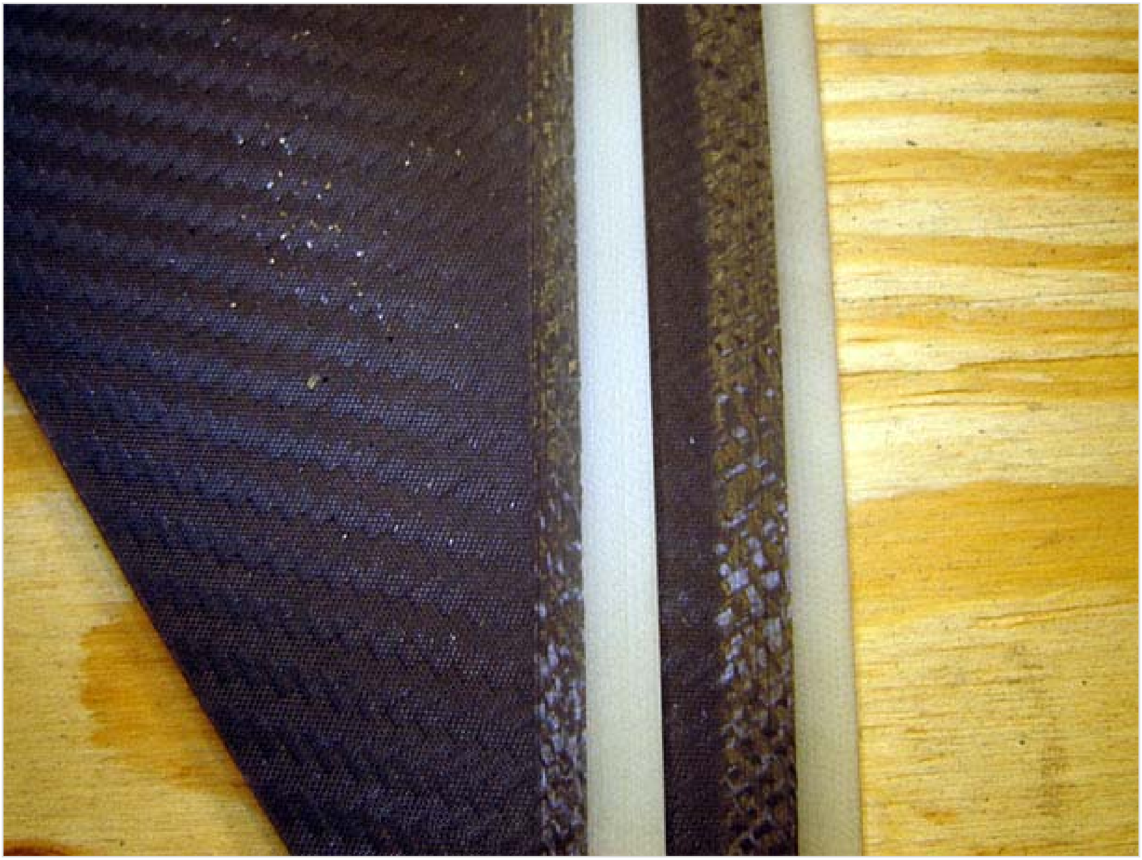
The fin is placed here and clamped flat.

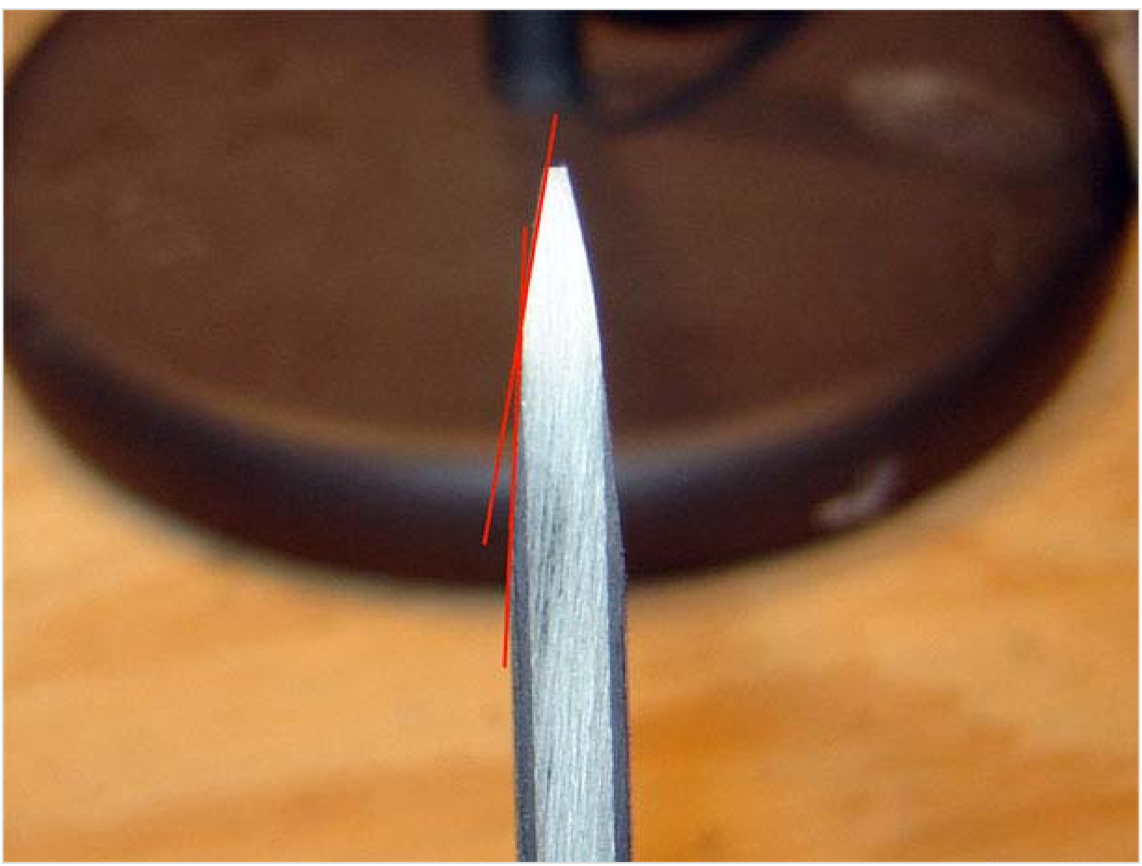

After sanding the bevel, the G-10 underneath is visible again.

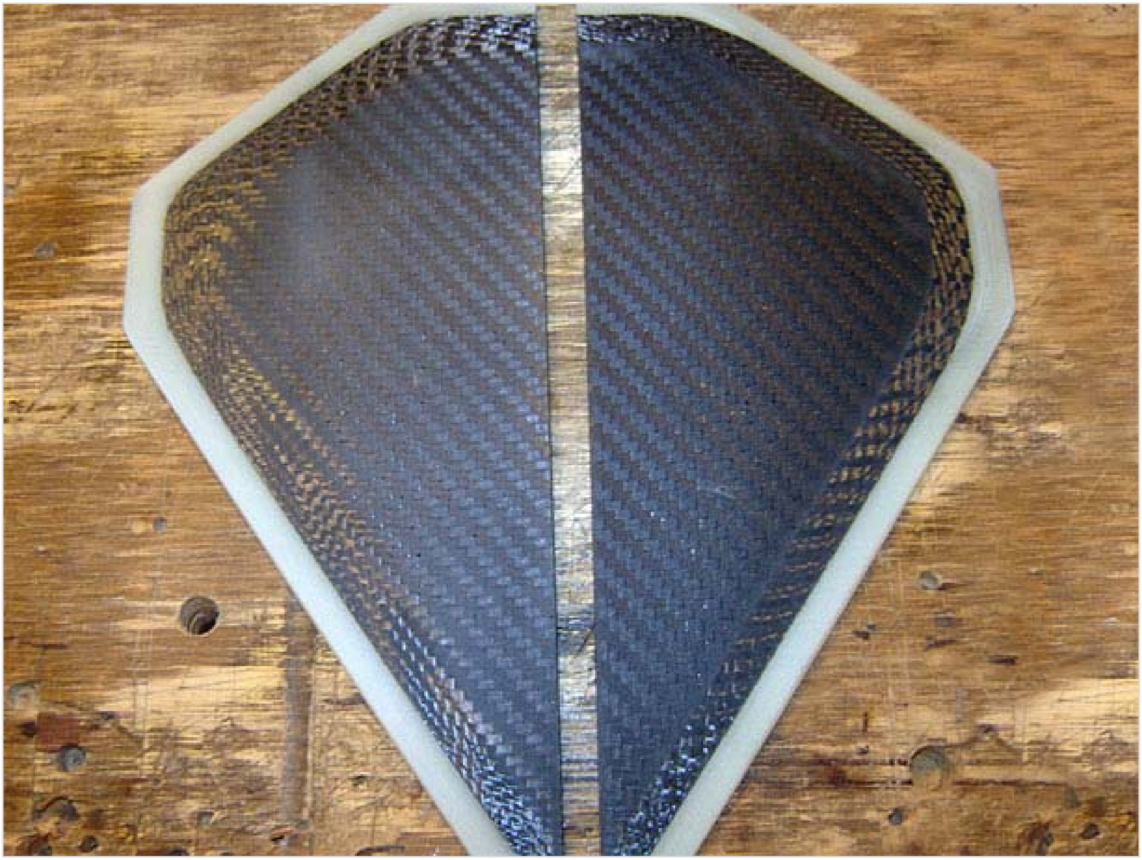

Here is the fin after sanding the first bevel around the perimeter.


Note the angle of the bevel (black line).

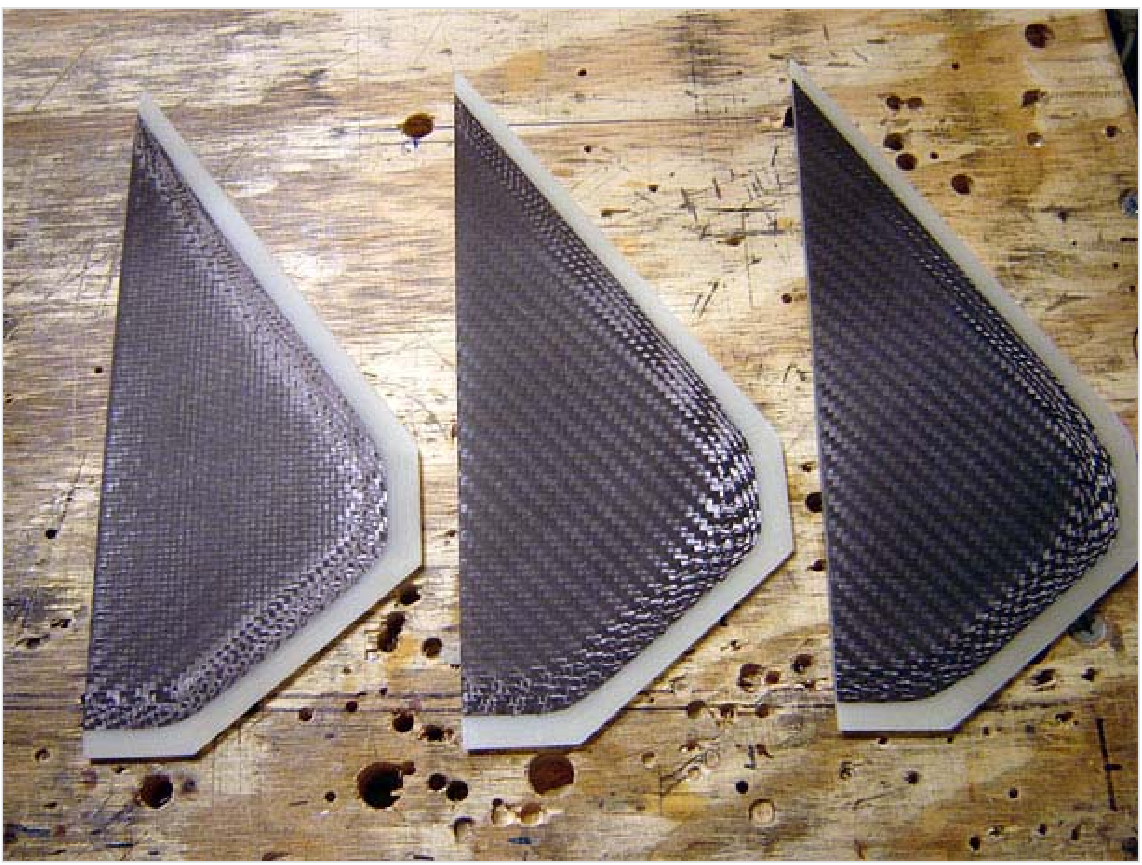

Next, one of the block is removed to cut a second bevel with 1/2 of the bevel angle (white arrow).


Here are the single- and double-beveled fins.


Note the double angle now (red lines). This will be tapered by hand to smooth out the edges a little.



On the left is the final fin after a little hand sanding. Note that the center of the fin has been very lightly sanded flat.



The fins are completed and ready to attach to the airframe.

Constructing the Mandrel

A good mandrel is essential for this project. Obviously, the mandrel is used to roll the airframe. However, in addition to that, I do many of the subsequent construction steps on the mandrel. This includes sanding the airframe, attaching the fins and the tip-to-tip carbon, and the final finishing.

I use the PML phenolic tubing for mandrels because it is dimensionally consistent. PML makes 36" coupler tubing that can be used to make 3" airframe. However, for this project, I am making a 40" tube. Therefore, I need to splice together two pieces of coupler tubing. It turns out that a LOC "stiffy" tube is a perfect fit inside the PML coupler tubing, so I will use that to splice the tubing together. The mandrel will be 50" long.

I will be using two pieces of 60" electrical conduit to make an axle for the mandrel. These are 1/2" and 3/4" metal tubes (galvanized steel I think). The 3/4" tube will be cut to 55" and foamed into the center of the mandrel, and the smaller tube will be fixed to the bench. Before I foam in the axle, I am going to cut 8 holes around the perimeter of the larger tubing (1/4"). I'll also cut 2 holes in the smaller axle. These will be cut so that I can turn the mandrel in 1/8-turn increments. I have found that 1/8th of a turn works well when laying up a tube. The hole-in-the-axle approach is a solid mechanical way of securing the mandrel for all of the subsequent steps.

The next step will be to foam-in the axle. I got some centering rings for the coupler tubing from PML. I'll use these to center the axle in the tubing while I pour in the foam. The foam makes the axle really solid and it also stands up to reasonable heating in the curing oven (although I'll remove the mandrel for any heating above 150F or so).

The final steps for the mandrel are to lightly sand it and then to coat it with 10 coats of high-temperature wax. I use TR-104 high-temperature wax to coat the mandrel and also the Mylar film that will be applied over the mandrel.

The following photos document the mandrel construction process:

Here are the PML coupler tubes and the LOC “stiffy” tube that fits inside of the coupler tubes. The inside of the coupler tubes were sanded and epoxy has been applied.

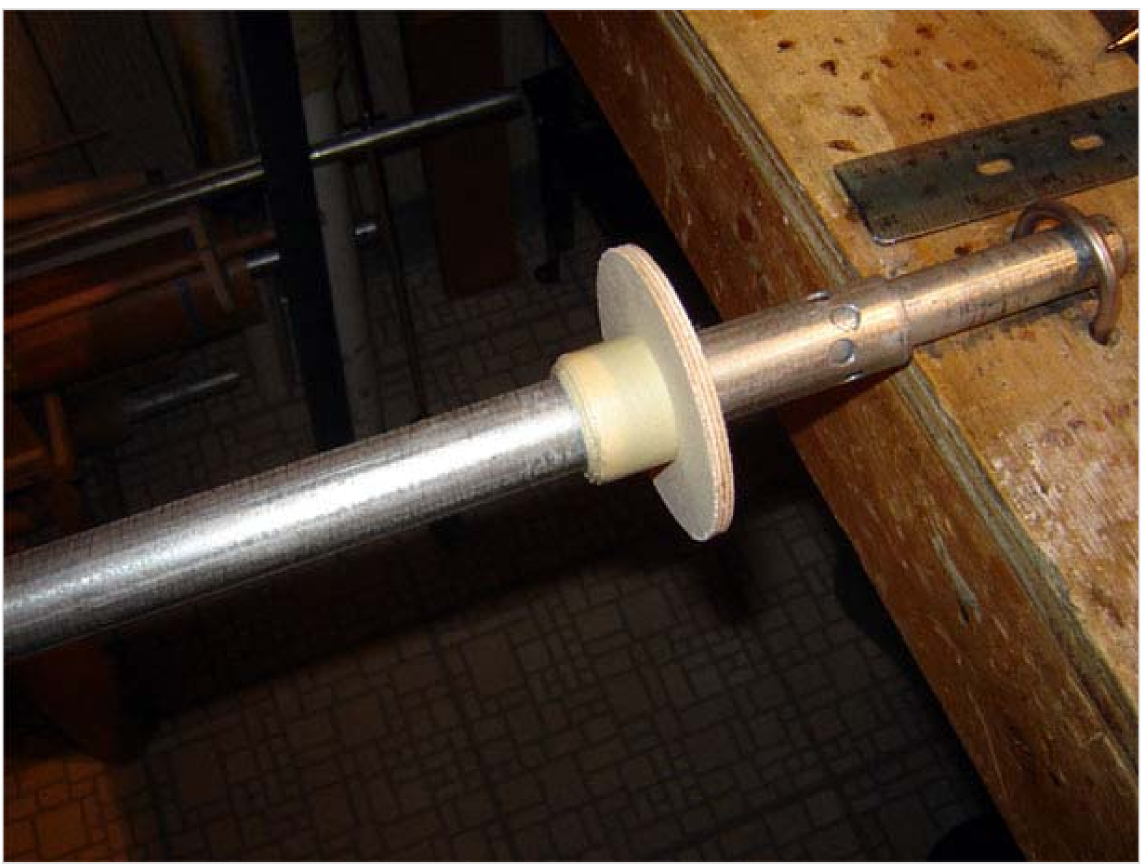

The stiffy tube installed with epoxy being applied.


The final joint.

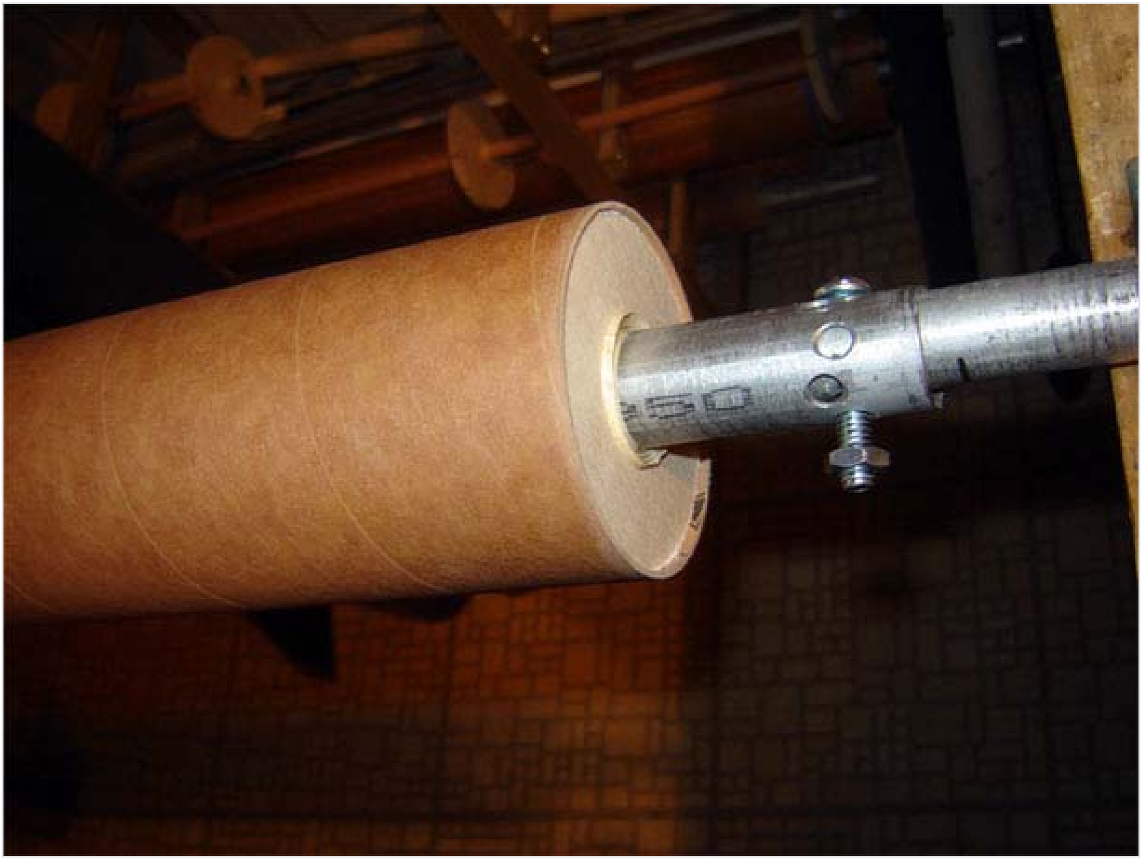

Note the 8 quarter-inch holes in the larger tube and the 2 quarter-inch holes in the smaller tubing.

Here, the holes in the tubes are aligned. Note the U-bolt that holds the smaller axle to the work bench.

Here, the two tubes are “pinned” to hold everything solidly in place.



This is the bottom centering ring for the mandrel.


The ring is glued into the bottom of the mandrel with CA.


The whole tube is then filled with foam, and another ring is installed on the opposite end of the mandrel. It's now ready to work with.

Rolling the Airframe
Now that the mandrel is waxed, it's time to roll the airframe. The layup will consist of the following layers:

- 0.005" mylar, waxed on both sides;
- 5 wraps of 5.7 oz, 2x2 twill carbon fiber cloth;
- A wrap of peel ply

The mylar will be butt-seamed so that there is no ridge. An overlap in the mylar actually leaves a ridge in the carbon surface that makes it harder to finish. The butt seam should have a gap of no more than 1mm, so it's actually pretty easy to cut. However, you don't want any of the mylar to be able to overlap, since this would ultimately produce a bulge in the tube. To size the mylar, I simply wrap the mylar around the tube, mark the overlap point along the length of the tube, and cut the mylar with a scissors. After the mylar is cut and the fit is checked, the inside surface of the mylar should be coated with a few layers of wax (follow the waxing directions carefully by the way).

Attaching the mylar to the mandrel is not an easy step. The objective will be to have the butt seam covered with a single layer of scotch tape. You also want the mylar to be as tight as possible around the mandrel. I start by pulling the seam area together with pieces of scotch tape applied crosswise to the seam. These tape pieces are placed about 1 to 2" apart along the length of the mylar. Since these pieces will be removed, I fold over the end of each piece so that I can more easily pull it off later.

The next step is to apply a piece of scotch tape along the length of the seam. I need a helper to do this step (my wife) because it takes three hands at a minimum. First, I cut a piece of tape longer than the seam. To apply it, I start by taping one end of the mylar seam up to the first piece of cross tape, pinching the mylar together as I go. My wife holds the tape at a low angle that is square to the seam. Then, I peel off the first piece of cross tape and continue to apply the seam tape up to the next cross tape. And so on, as shown in the following pictures:

This is the 0.005" mylar wrapped around the mandrel. I have marked the overlap point, and I will cut the mylar so that it leaves about a 1 mm gap.

After cutting, the mylar is waxed 3 times on the inside surface. This will help the mylar slide off the mandrel.

Here, the mylar has been wrapped around the mandrel. Note the 1mm gap. The mylar is wrapped as tightly as possible and secured with pieces of tape. I start in the middle and work toward the ends. Note the fold at the bottom of the tape pieces. These will make removing these pieces easier.

Here, the seam tape is applied. I use my thumb to press down the seal tape. The other hand removes the cross tape, and a third person holds the tape at an angle. This is a hard step to get perfect.

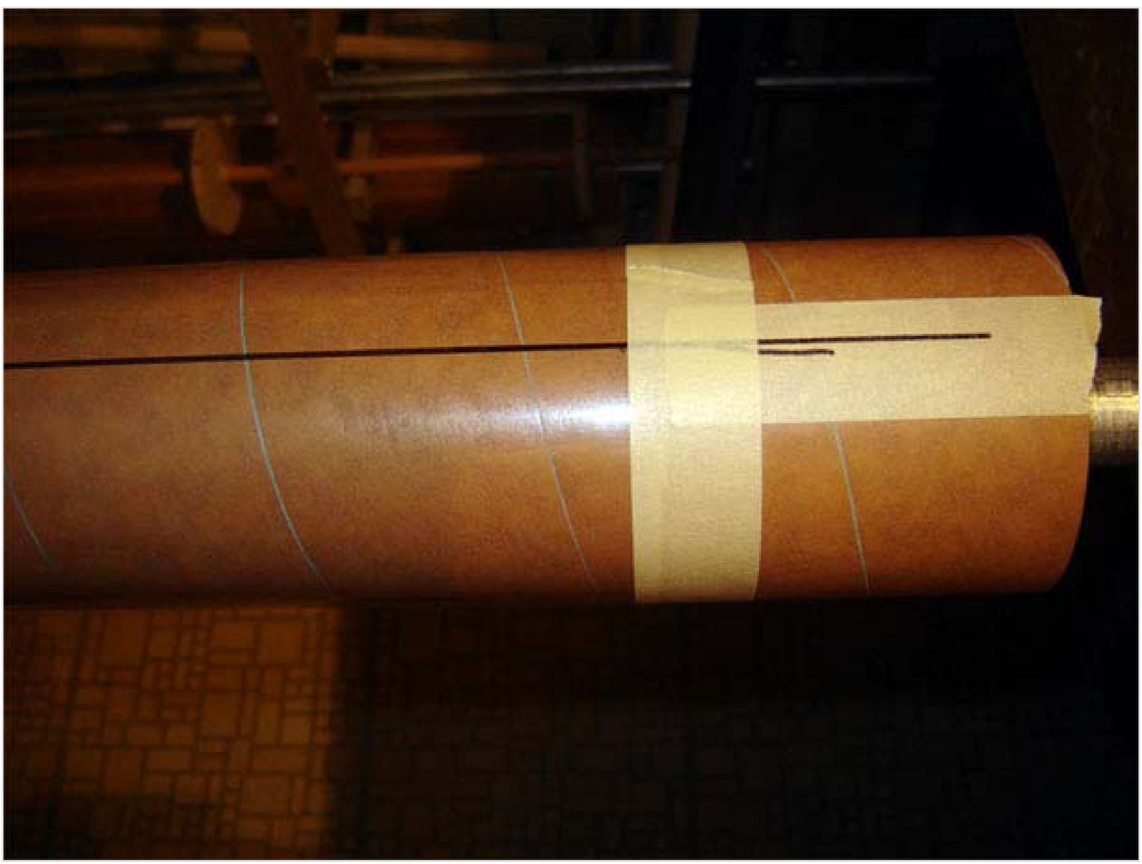
Here’s the completed seam. Got it on the first try this time!

Another view of the tape seam.

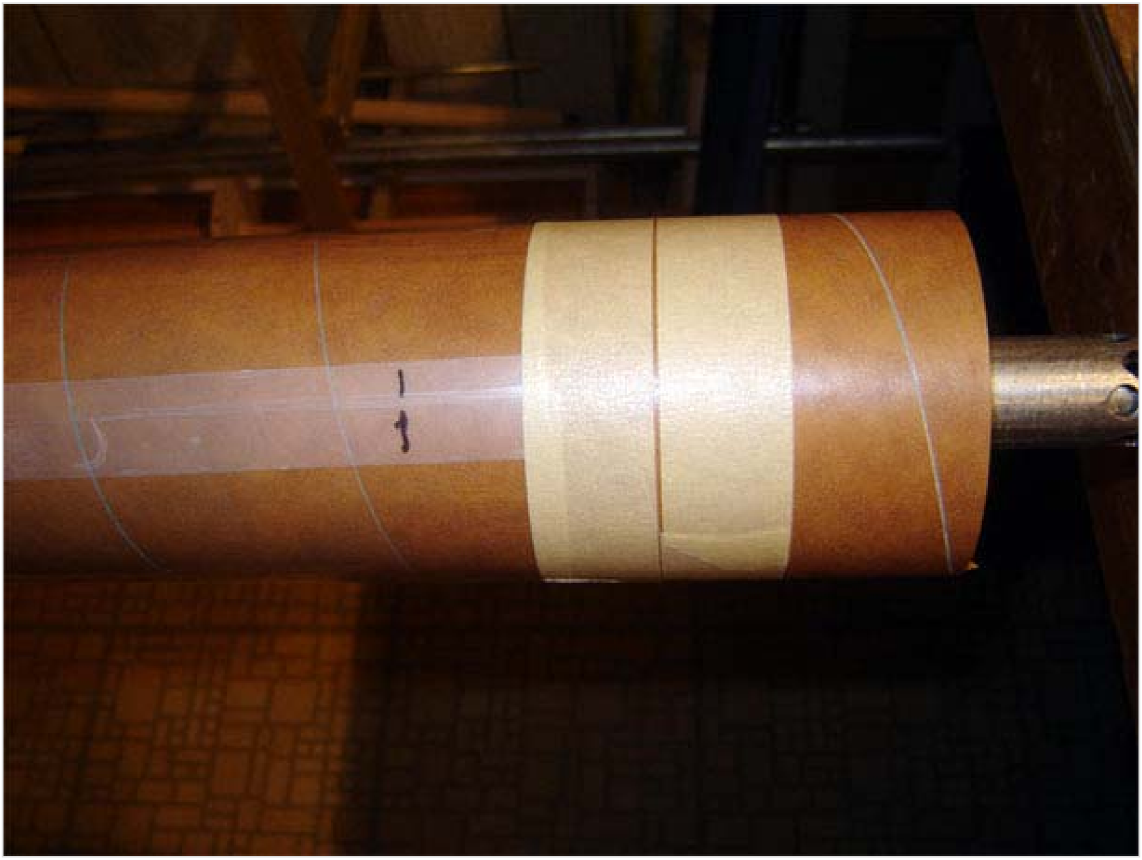
When the mylar is properly attached, it should be fairly tight. On this tube, it is possible to slide the mylar along the tube, but it's not easy. It is also important to make sure the mylar does not have any bulges or wrinkles. I often have to repeat this whole process several times before I'm satisfied with the fit. Once the tape is applied and all is well, several coats of wax should be applied to the mylar and the tape seam.

To set up for applying the carbon, I draw a line on the carbon using a piece of angle iron. This line is extended out beyond the airframe so that I will know where the initial seam is during the layup. Finally, I wrap the ends of the mylar with masking tape for two reasons. First, I don't want to get any epoxy under the mylar during the layup. Second, the masking tape will serve as a guide to keep the carbon going on straight. The distance between the outside edges of the masking tape is 44 inches, and I will cut the carbon to the same width. That will help to keep everything aligned as I roll the tube. Hopefully, I'll be able to remove this tape when the layup is complete. The following pictures show these steps:

I use a piece of angle iron to draw a straight line on the mylar that extends beyond the edge of the mylar. The carbon will be lined up using this line, and the extended line will help me keep track of where the initial seam is.



I've added a piece of masking tape to seal the mylar edge and to serve as a guide for the carbon. The carbon should line up with the outer edge of the tape.



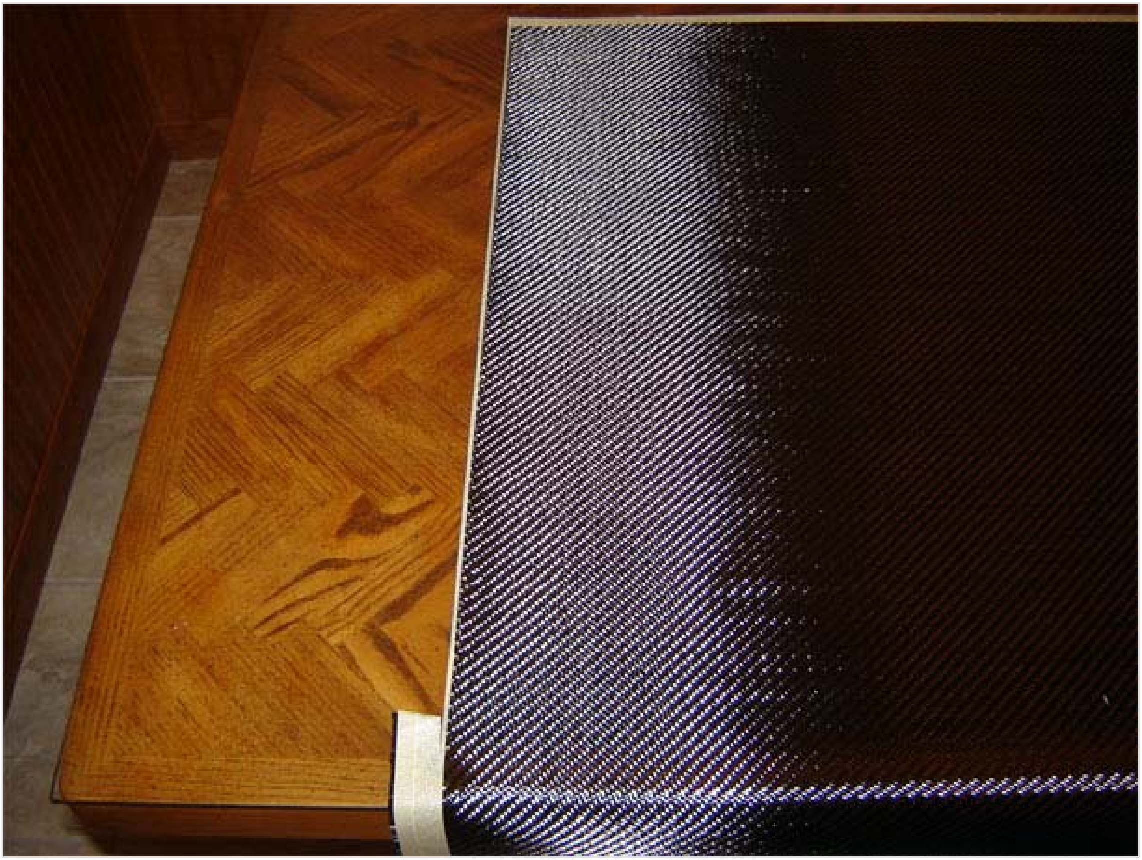
But, an extra line of tape just in case...

The mylar addition is complete, and the next step will be to coat it with epoxy.

The next step is to cut the carbon for the airframe. For this project, I need a 40" long tube. The mylar is 42" wide, and the carbon will be cut to about 44" wide. I try to lay out the carbon on a table so that the lines are as straight as possible (I use a long straightedge for this). Then, I place masking tape around the perimeter of the cloth. On the edge of the carbon that will first be placed on the mandrel, I leave a 1/8" width of tape to keep the carbon from unraveling.

On the opposite end of the carbon, I leave the full 1" width of the tape, but this will be cut off near the end of the laminating process. The length of the carbon "between the tape edges" is 5 full wraps plus 1" overlap. The width of the carbon is 44". However, each edge is covered with a 1/4" width of tape such that the width of the carbon "between the tape edges" is 43.5". When the carbon is cut, I roll it up on a cardboard tube, which will serve as the feeder tube when I roll the tube.

I use masking tape around the edges of the carbon to keep it from fraying. The widths are 1/8” at the point where the carbon is first applied to the tube, 1/4” along the sides of the carbon, and 1” along the last seam (this tape will be cut off later).



I cut the carbon with an X-acto® knife right on the glass table. My wife has now bought me a cutting mat, and bought herself a new piece of glass.

Here’s the carbon rolled up on a tube and ready to go!

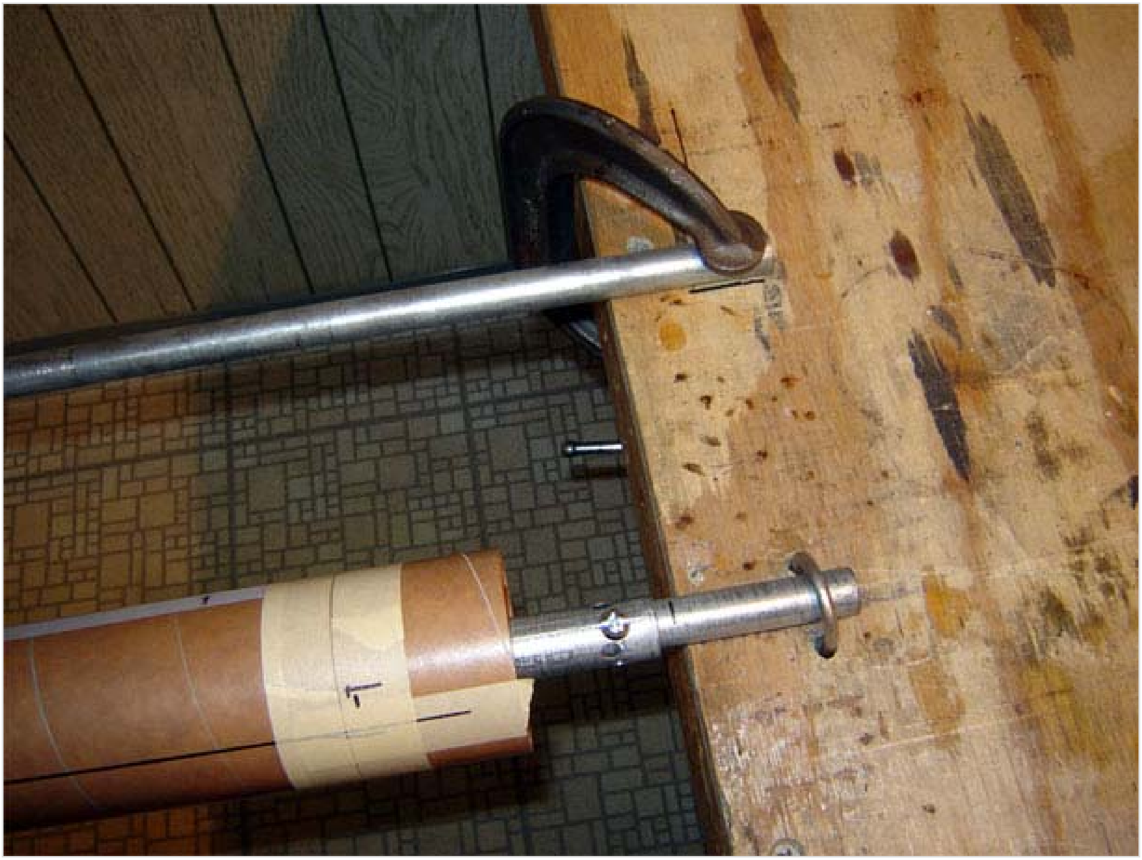
Now it's time to roll the tube. To review, this will be a five-wrap tube made with Aeropoxy 2032 resin and 3665 hardener. The very slow 3665 hardener is essential in order to have enough time to complete all of the steps.

I'll start the lamination by coating the mylar with a layer of epoxy. Then, I position the seam using the line on the mandrel as a guide. It is important that the whole setup be as square as possible so that the carbon feeds smoothly onto the mandrel.

For the first four wraps, I add a little milled glass to the epoxy. After that, I don't add anything to the epoxy. I use a relatively heavy amount of epoxy for the first two wraps. This ensures that the inside surface of the tube is solid with no dry areas. I ease up a little on the third wrap, and then use no epoxy at all on the fourth wrap. The idea here is to bring up the excess epoxy from the first two wraps so that the total amount of epoxy added is reasonable when the tube is completed. I use a foam roller for doing the layup. Nothing touches the carbon — ever — except the foam roller.

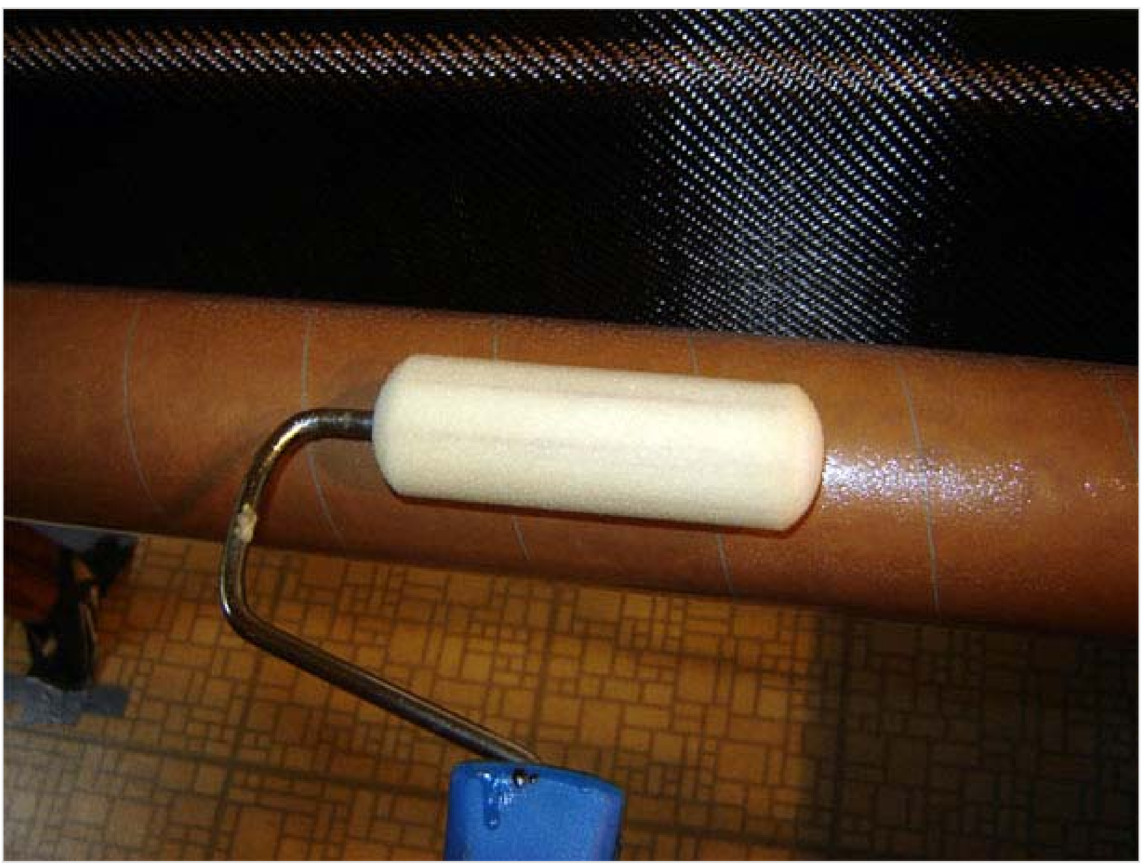
The following pictures illustrate the procedure:

Here’s the left side of my setup with a little ventilation (a must!).



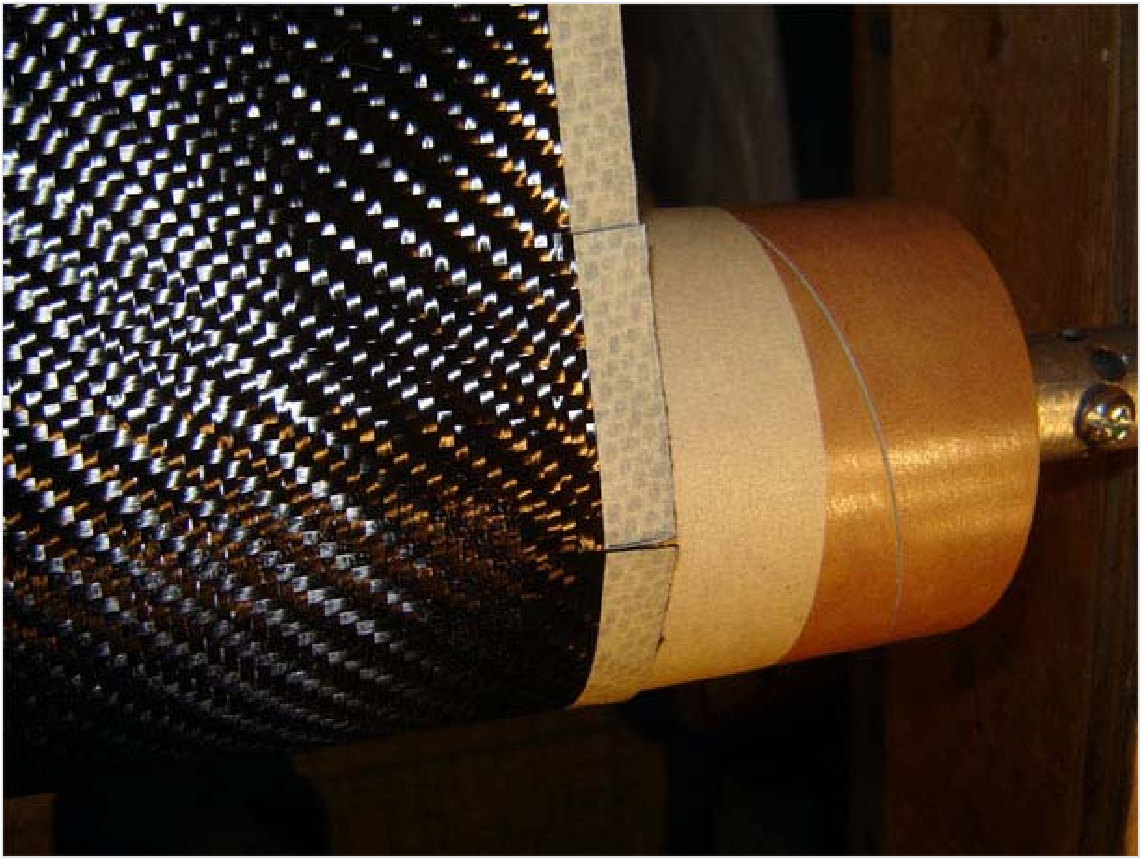
And the right side. The two rollers must be exactly parallel.

The carbon is positioned and I’m ready to start.

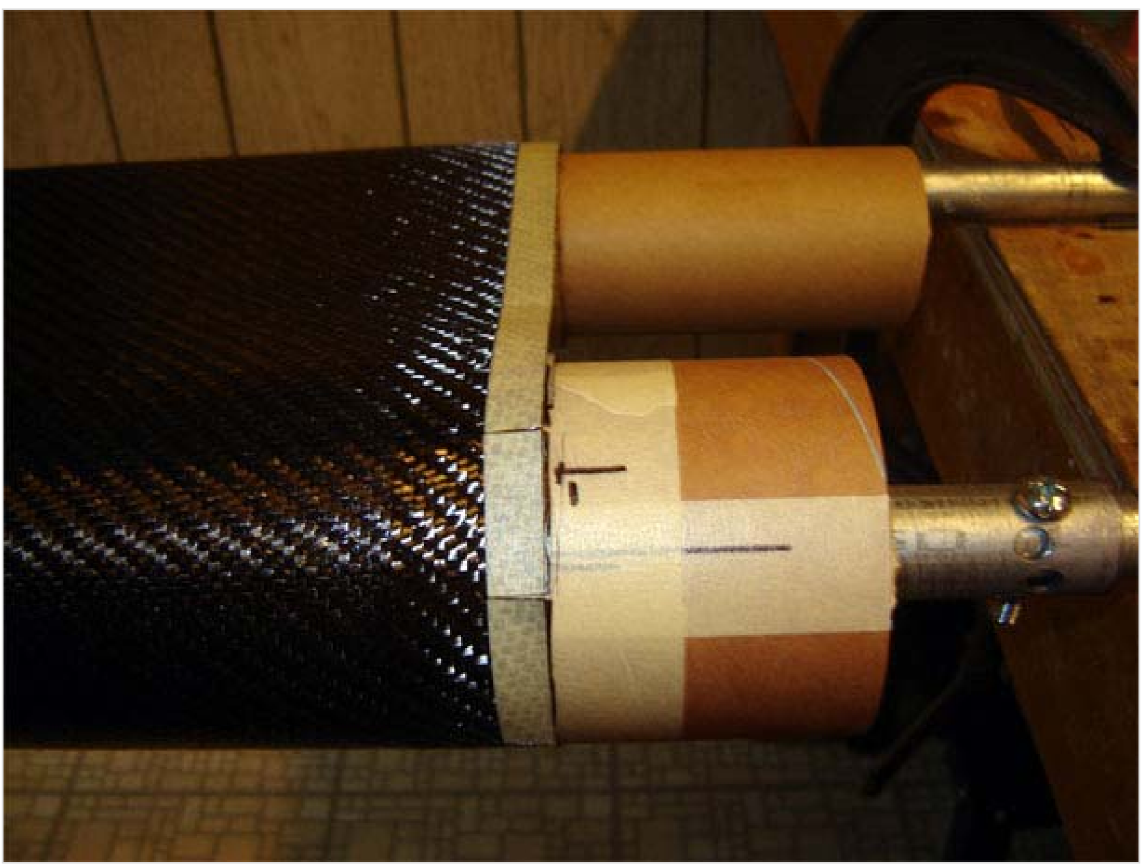

I add about this much milled glass to 100 grams of epoxy.

First, I coat the mylar with epoxy.

Then, I position the seam using the mandrel line as a guide. An extra pair of hands helps here.

Note how everything is square and tight, and the carbon is lined up with my masking tape guides on each side of the mylar. I'll be advancing the carbon at 1/8-turn intervals.

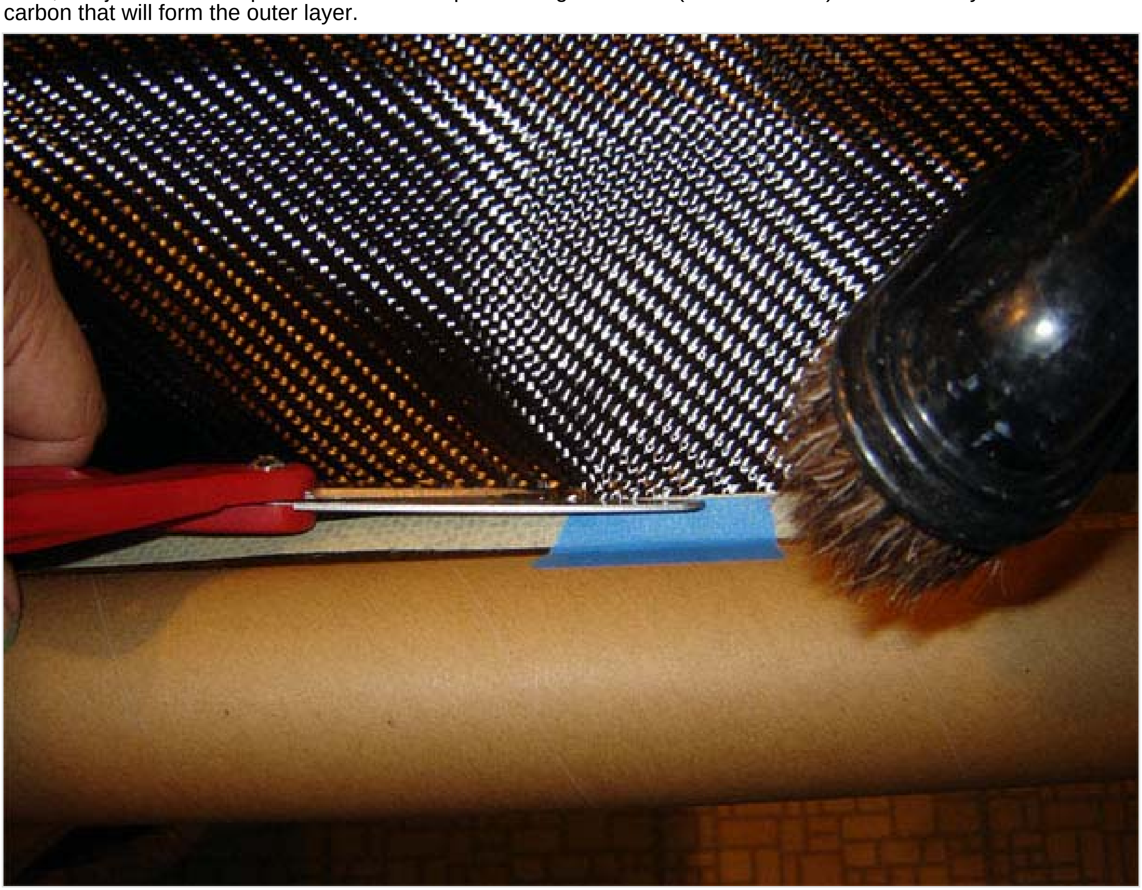


As I advance the carbon, I cut slits in the masking tape so that it doesn't bunch up as the number of wraps increases.



Here's how things look after the first wrap.

Here, I've just about completed the fourth wrap. I'm using a vacuum (on low suction) to remove any "stuff" from the carbon that will form the outer layer.



At the point where the carbon is about to come off the feed role, I cut the carbon at the tape line. A sharp pair of scissors helps and a vacuum is needed to collect the fibers that are released.

Here, I've completed wrapping the tube, and sealed down the seam.

The final step in rolling the tube is to apply the peel ply. This is the step that gives the tube its smooth surface and nails down the seam. The peel ply also helps to control the amount of excess epoxy.

To begin the application, I drape the peel ply over the middle of the tube. The idea is to apply it with no wrinkles, and to at least try to wet it out as much as possible using only the epoxy already contained in the carbon. It takes quite a bit of time to do this. Ideally, after an hour or so of working the peel ply with the roller, the peel ply will only be partly wetted out (this means that not too much epoxy was applied to begin with). After getting up as much epoxy as possible, I add extra epoxy to the peel ply to finish wetting it out. This application of peel ply took a little over 2 hours.

After the peel ply is applied, the tube is cured in an oven (the 3665 hardener requires the use of an oven). However, for this particular step, the oven temperature must be maintained at no more than 90F. Otherwise, the peel ply will lift off of the carbon in large "bubbles", which are very difficult to repair. The following pictures illustrate the application of the peel ply:

I start the application of the peel ply by draping it evenly over the mandrel.

I'll work the peel ply with the roller to start bringing up the epoxy from below.

Here, I've worked the peel ply backward to the first seam. Note the position of the carbon seam (white arrow). The carbon and peel ply seams should not overlap each other. Note also the air trapped below the peel ply. When the application is complete, this air will be mostly gone.

I've added a little extra epoxy to the peel ply overlap area, as this double layer of peel ply is very difficult to wet out (white area).

The initial application of the peel ply is complete. Again, a little extra epoxy over the seam helps to wet it out.

After about an hour of working on the tube with the roller, the number of air pockets has been reduced, but there is still too much air. At this point, additional epoxy can be added on top of the peel ply to finish wetting it out.

Here is the appearance of the peel ply after adding some epoxy over the top of the peel ply (and then spending some more time with the roller). The idea is to remove as much of the air below the peel ply as possible.

And then into the oven it goes. It is critical to cure the tube at no more than 90F. At higher temperatures, the peel ply will lift off the carbon, and this is difficult to repair. It takes about 24 hours to cure the epoxy before the peel ply can be removed.

After 24 hours in the oven, it is time to remove the peel ply. The first step (for this tube) was to remove some of the excess carbon from around the edge of the mylar. Then, I pulled the tube off the mandrel. It was surprisingly difficult (took about 10 minutes, a quarter-inch at a time). Then, I removed the mylar by separating it from around the tube with a sharpened stick. It is easy to remove the mylar when the tube is cured at 90F. The inside surface of the tube turned out perfectly. Finally, I cut down the tube to the edge of the peel ply, and this is the tube that I'll work with for a while. I leave the peel ply on the tube during these steps to minimize touching the carbon.

The peel ply is just, well, peeled off the tube. The point where the peel ply seam touches the carbon can be troublesome as the loose threads tend to become embedded in the epoxy. It helps to remove the peel ply seam as slowly as possible (this actually pulls the threads out of the epoxy). Then, any remaining threads can be pulled out.

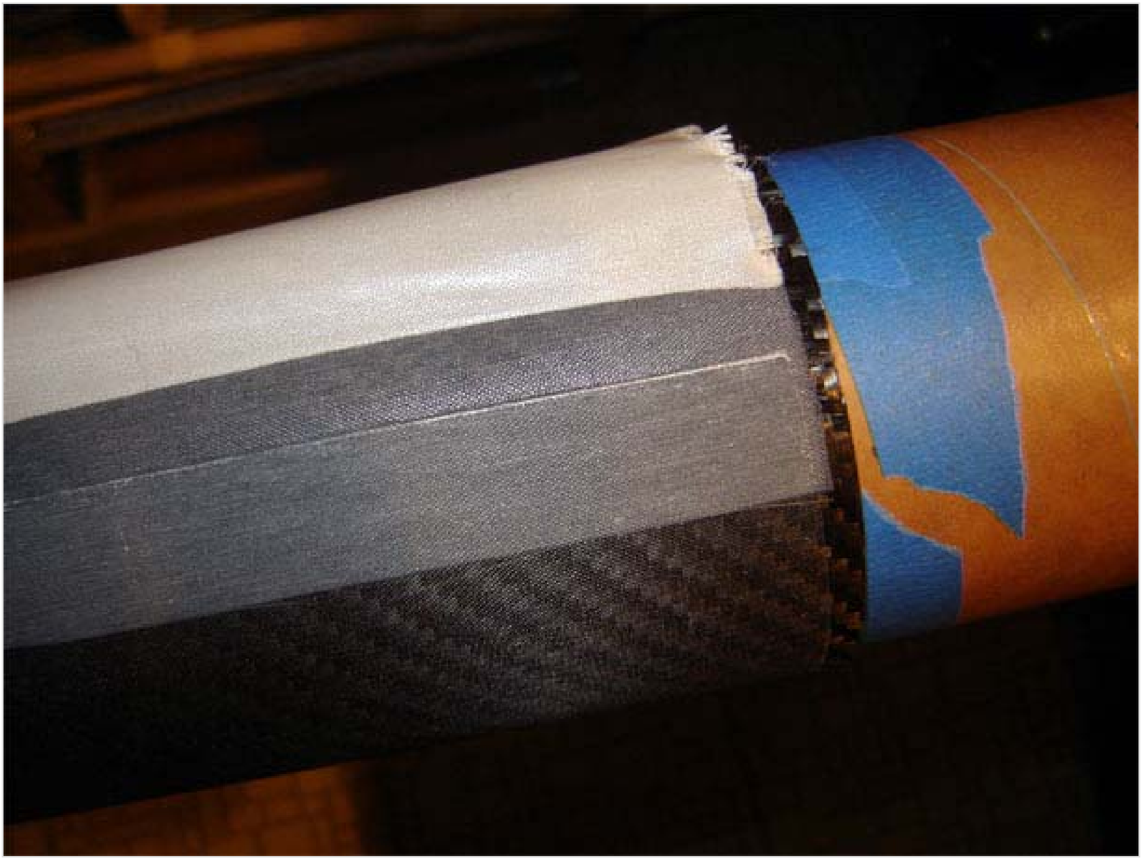
This tube has turned out pretty well. There are no problem areas, and the amount of epoxy in the tube is 48% by weight. Not too bad for a hand layup.

After curing for 24 hours, I trimmed back some of the carbon and then pulled the tube off the mandrel. It was not easy to remove!

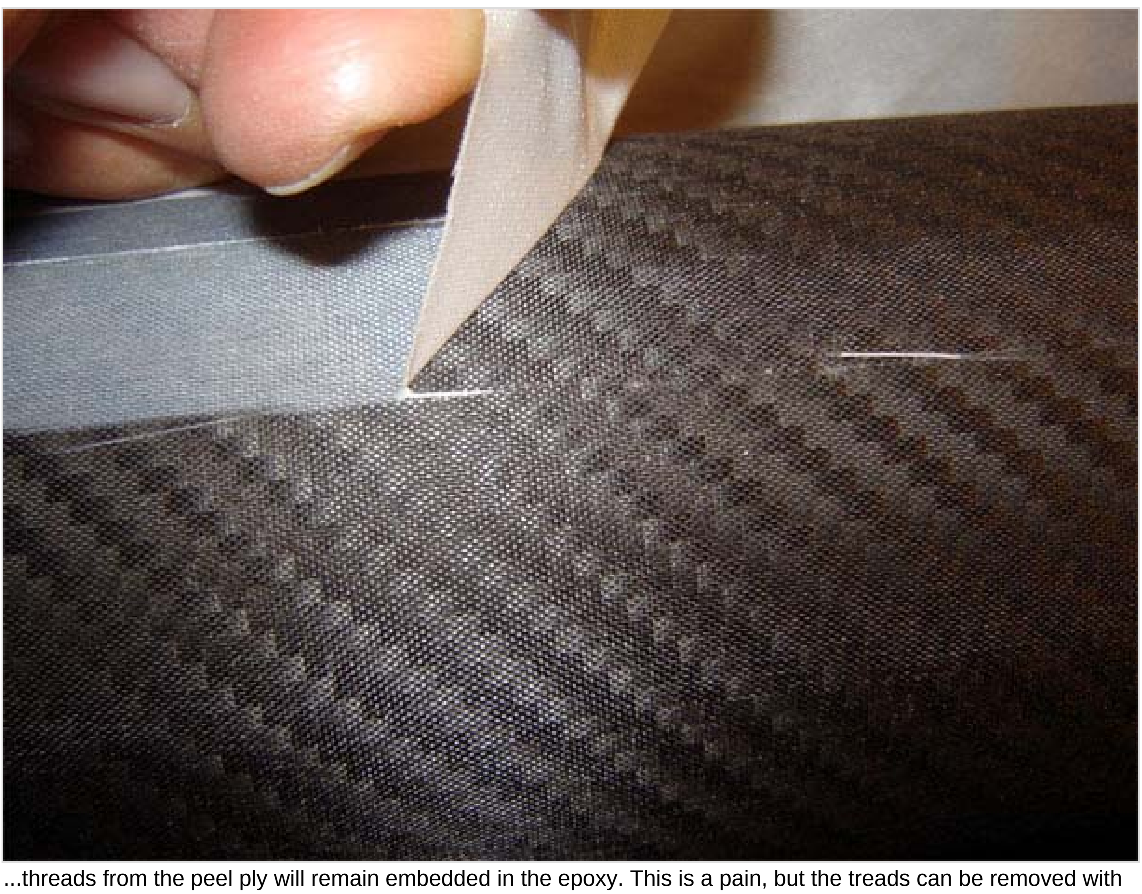
The mylar comes out next. By curing at only 90F, the mylar comes out easily.

I trimmed back the tube to near the peel ply. This is the tube I will work with. Eventually, I will need to cut about 1/2" off both ends.

Now is the time to remove the peel ply. I try not to touch the carbon.



Here, I've removed the peel ply down to the area where the peel ply seam is in contact with the carbon. This seam must be removed slowly and carefully because...



...threads from the peel ply will remain embedded in the epoxy. This is a pain, but the treads can be removed with a little care.

Here's the carbon seam. Really! The peel ply does a particularly good job of nailing down the carbon seam. Notice how the surface of the tube is smooth, but has the rough peel ply texture.

The next few steps consist of finishing the upper part of the airframe (leaving the peel ply finish in the lower part of the airframe for fin attachment), heat treating the airframe, and then attaching the fins and tip-to-tip carbon. I believe that the best surface finish is obtained by working on the tube while the epoxy hasn't yet fully cured. Therefore, I'll finish the surface of the upper airframe first. This will take about a week (note that I arrange to have about a week available before I roll a tube). This choice delays the heat-treating of the airframe. However, with the slow epoxy I use, heat treating after a week should still provide some benefit.

In short, I'll finish the upper part of the airframe by painting it with epoxy 6 times to fill in the low spots, and then sanding it down smooth. This will remove most of the added epoxy, but will leave a very smooth tube. I'm not going to sand before the first coat (the peel ply finish), but after that, I'll sand the tube lightly between each coat of epoxy. After the sixth coat (with 24 hours to cure each coat), I'll sand most of the epoxy off using 180, 220 and 320-grit paper. If there are any imperfections or air pockets, I'll fix them at that time.

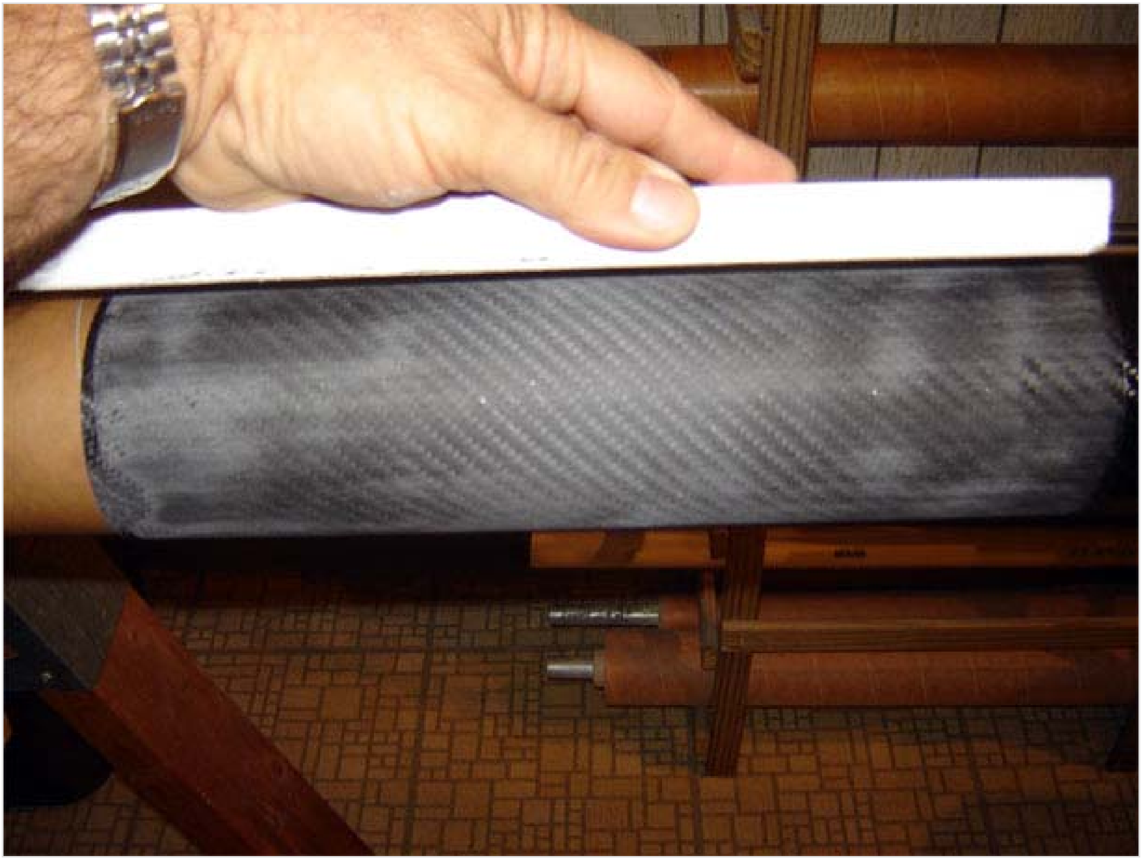
The upper portion of the tube will be finished to it’s final smoothness. The peel ply texture on the lower 12” of the tube will be retained to provide the maximum bonding for the fins and the tip-to-tip carbon.

Here is the first coat of epoxy applied to the upper portion of the tube. A total of six coats will be applied, and then most of it will be sanded off. The tube is lightly sanded between each coat (but not before this first coat).

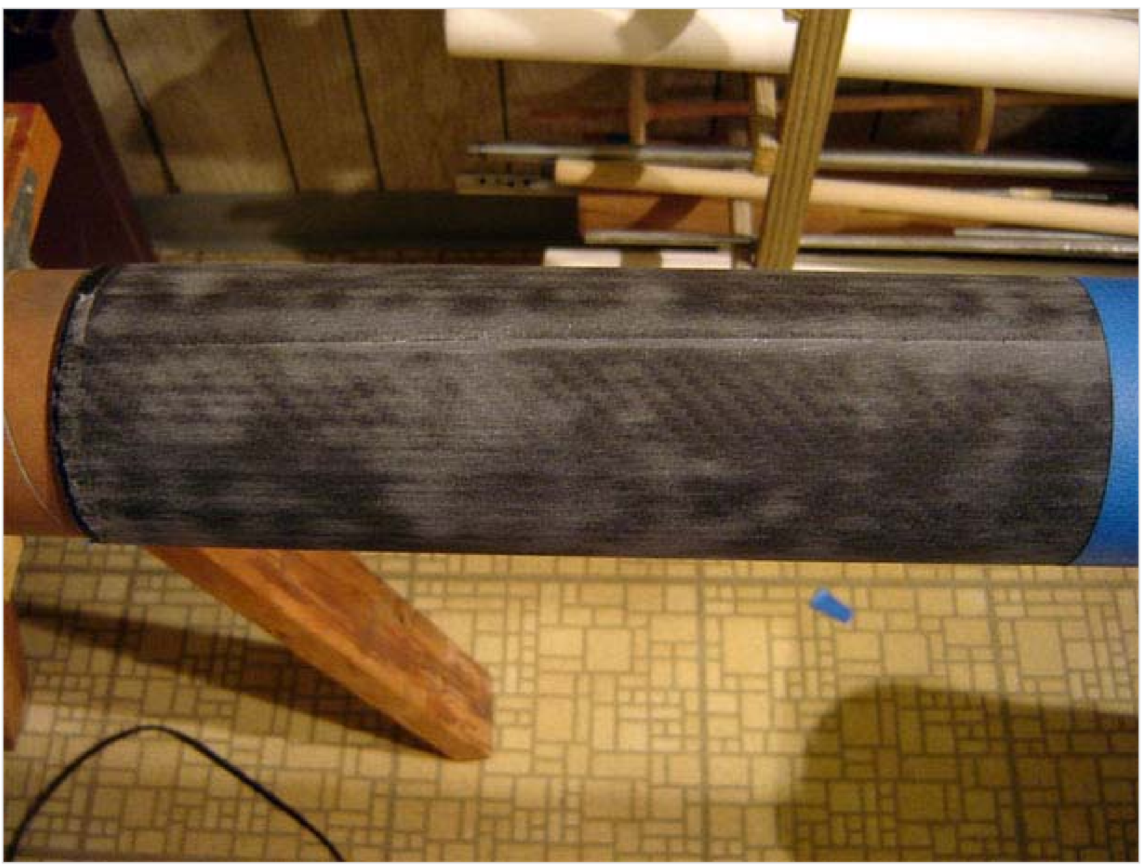
I have now applied 3 of the 6 coats of epoxy, and it's time to take care of a very important step that will make it easier to finish the lower portion of the airframe. At this point, the lower portion of the airframe still has the peel ply finish. After the fins are applied, the tip-to-tip carbon will be applied, and then I will try to achieve a smooth finish of the fins, the fillet and the airframe between the fins. I have found that it is very helpful to lightly sand the lower portion of the fin can before applying the fins. This reduces high spots that would persist after the tip-to-tip carbon is applied. If I don't remove these high spots now, it will be almost impossible to sand down the surface later on without sanding into the carbon itself.

Although I want to sand off the high spots, I also want to retain as much of the peel ply finish as possible (the peel ply finish helps with bonding of the tip-to-tip carbon, which helps keep the fins attached at high speeds). So, I am going to compromise and sand off the high spots without sanding the entire surface flat. I use a flat board with sandpaper to do this sanding. Have I mentioned how handy double-sided tape is? The following pictures show how I execute this step.

This is what the lower portion of the airframe looks like with the original peel ply finish and before any sanding.



I use a flat board to sand the high spots off the lower portion of the airframe. Don’t sand off too much here though, as the peel ply finish gives a better secondary bond than a sanded surface.



Here is what the lower portion of the airframe looks like after sanding off the high spots. Note that the peel ply finish is still present on much of the surface. However, sanding off the high spots will make it much easier to finish the fin area later on.

At this point, the upper portion of the airframe has been painted 6 times with epoxy. Each coat was applied with a roller, and then brushed out with a chip brush. The tube was sanded very lightly between coats, mainly to remove anything that got lodged in the epoxy while it was curing. Now, the tube must be sanded smooth.

For the initial sanding, I used 180, 220 and 320-grit dry sandpaper. I again used 1/8-turn increments and sanded using a "shoeshine" method. I made 4 passes with the 180 grit and two passes each with the 220 and 320 grit. That got everything flat with no shiny, un-sanded spots. This tube turned out very well, as I normally have to sand a little more. By way of weights, the initial tube was 505 grams. The 6 coat of epoxy increased the weight to 541 grams. The sanding with 180, 220 and 320 papers decreased the weights to 535, 531 and 529 grams. Hopefully, this provides some idea of how much material I added and then removed in these steps.

This particular tube turned out very well. Most of the time at this point, it is necessary to sand off more of the epoxy (and get closer to the carbon) in order to get everything flat. Although there is more epoxy to sand off, I'm in good shape at this point.

There are two typical types of defects. These are small depressions that appear shiny, and pit marks or small holes. The shiny areas can sometimes be removed with a little spot sanding. The holes can be filled and spot sanded. I have had tubes that required dozens of repairs. This tube had only one spot to fix.

I have now used the 8-hole axle to first lay up the tube and now to sand down the tube. So far, this approach has worked extremely well.

This is what the tube looks like after 6 coats of epoxy. Now, it’s time to sand down the tube.

Here's the tube after the 180 grit paper. Much of the tube is smooth, but the seam area still shows some shine, and there are some small depressions below the seam area. But this is the time to go to the finer, 220 grit.

Here's the tube after 220 grit – not too many flaws! My shoeshine sander is on the left. I find this setup much easier on my hands.

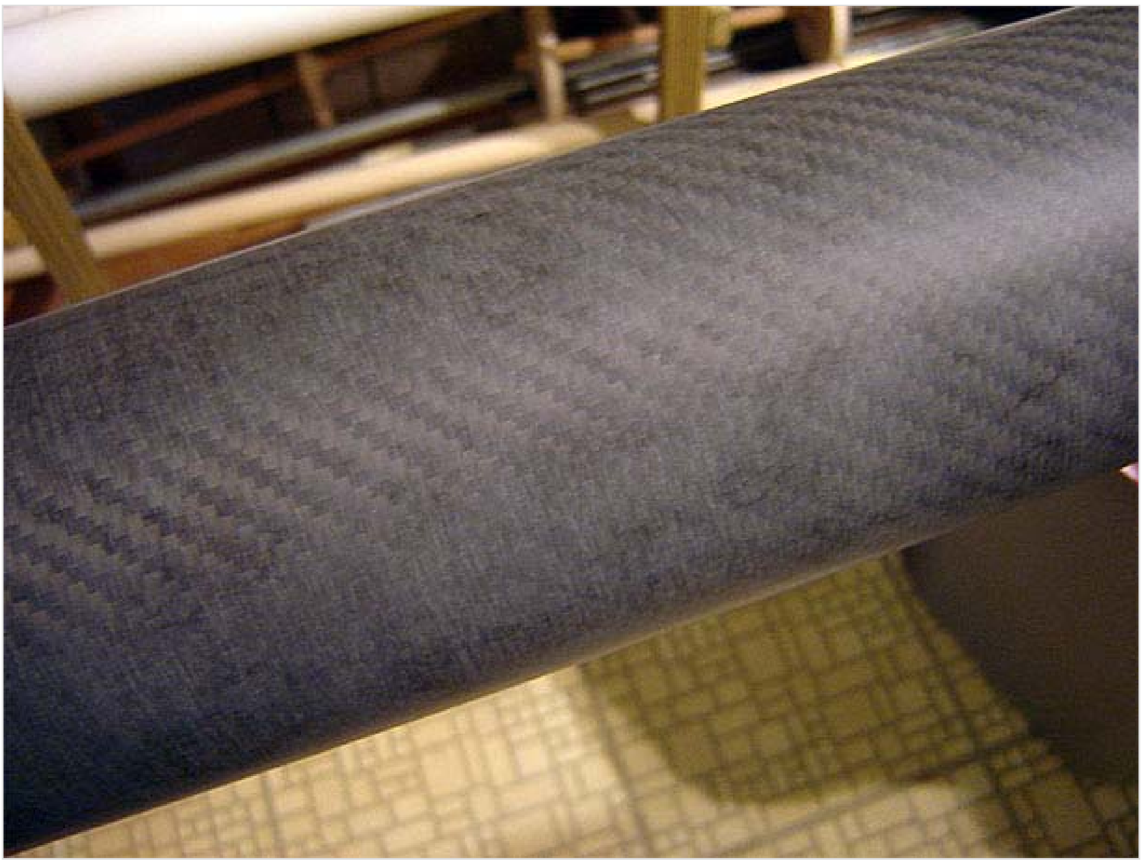
Here’s the tube after 320 grit paper. I only found one “dimple” flaw.

The little dimple flaws can just be sanded out at this point with a strip of sandpaper. Go easy though.

At this point, the tube has been sanded down with 320 grit paper and has no defects or areas where I've sanded into the carbon. However, looking at the tube reveals that the dry sanding marks (scratches) are very prominent. In the past, I would switch to wet sanding at this point. However, it took a lot of wet sanding to remove enough material to get "below" these scratches. In addition to adding a lot of work, this often would cause me to sand into the carbon.

By accident, I found a way to remove these scratches. Basically, I coat the tube with a very thin layer of epoxy and then try to wipe off as much of it as I can. I use a lint-free rag, and I literally try to wipe off as much of the epoxy as I can. This leaves the tube looking shiny, but with no obvious new epoxy coating. What happens, however, is that the epoxy fills the scratches very nicely, which means that I don't have to sand the tube down to remove them.

I'm going to use two coats of this epoxy wipe, and then I'm going to resume the finishing process by wet sanding with 600, 800 and 1000-grit paper.

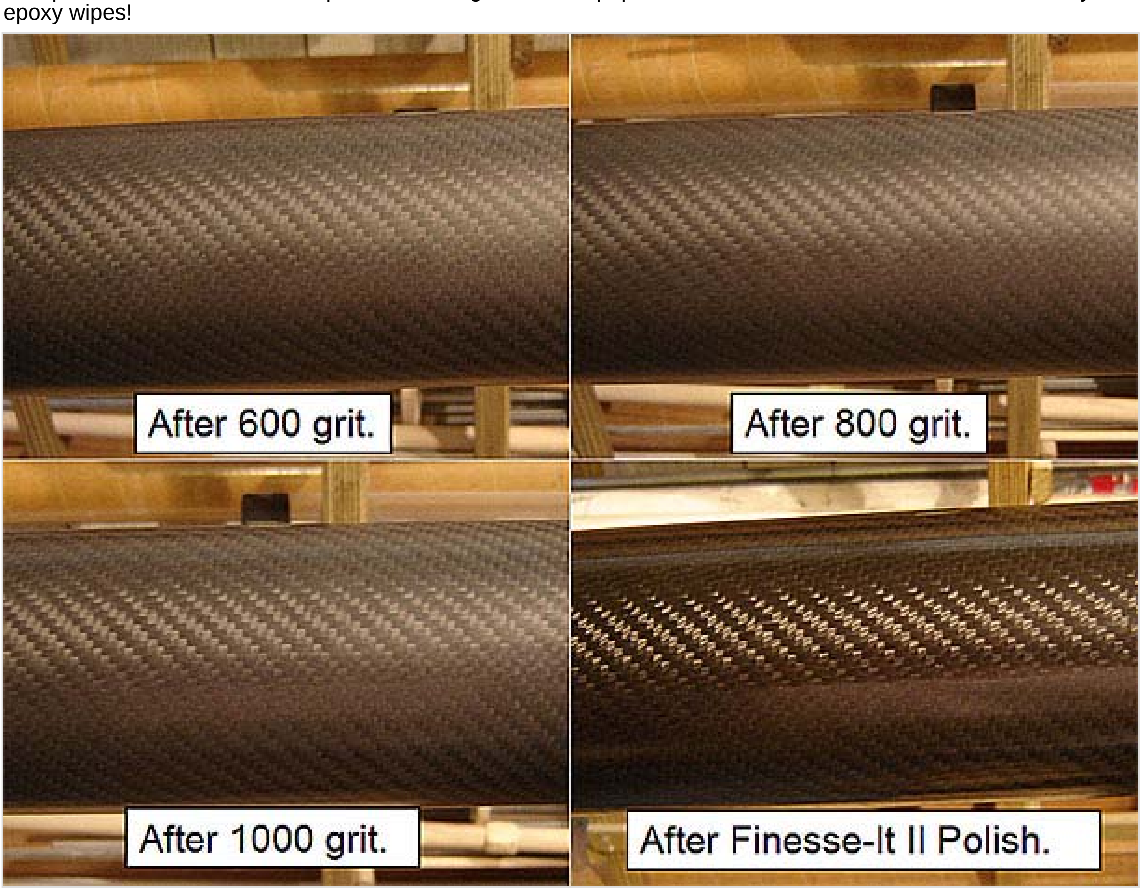


Here’s the nice smooth tube after 320 grit paper. But look at all of those scratches! It turns out that these can be filled (without having to repeat all of the dry sanding) by simply wiping on a really, really thin layer of epoxy. I’m going to do that twice, and then begin wet sanding.

Here's the tube after wiping on the first coat of epoxy. You could almost stop here, but there is still room to improve the finish.

This is after the second wipe coat of epoxy. No sanding between these two coats.

This picture was taken after one pass with 600-grit wet sandpaper. Note how the scratches have been filled by the epoxy wipes!



I used 3M Finesse-It II to polish the tube after the 1000-grit wet sanding (see the previous two pictures). This stuff is great and adds a nice wet-look, semi-gloss to the tube. It can be purchased at auto paint specialty stores. Perhaps a little wax later on? Note that I didn't polish about 2 inches of the airframe above the lower peel ply section. This is because the tip-to-tip carbon will be glued up to about this point later on.

A few final statistics. The two epoxy wipes added no measurable weight to the tube. Then, the wet-sanding process removed about two more grams of epoxy. Therefore, a total of 35 grams of epoxy was added to the original 505-gram tube, and 14 grams of this epoxy was sanded off in the finishing process.

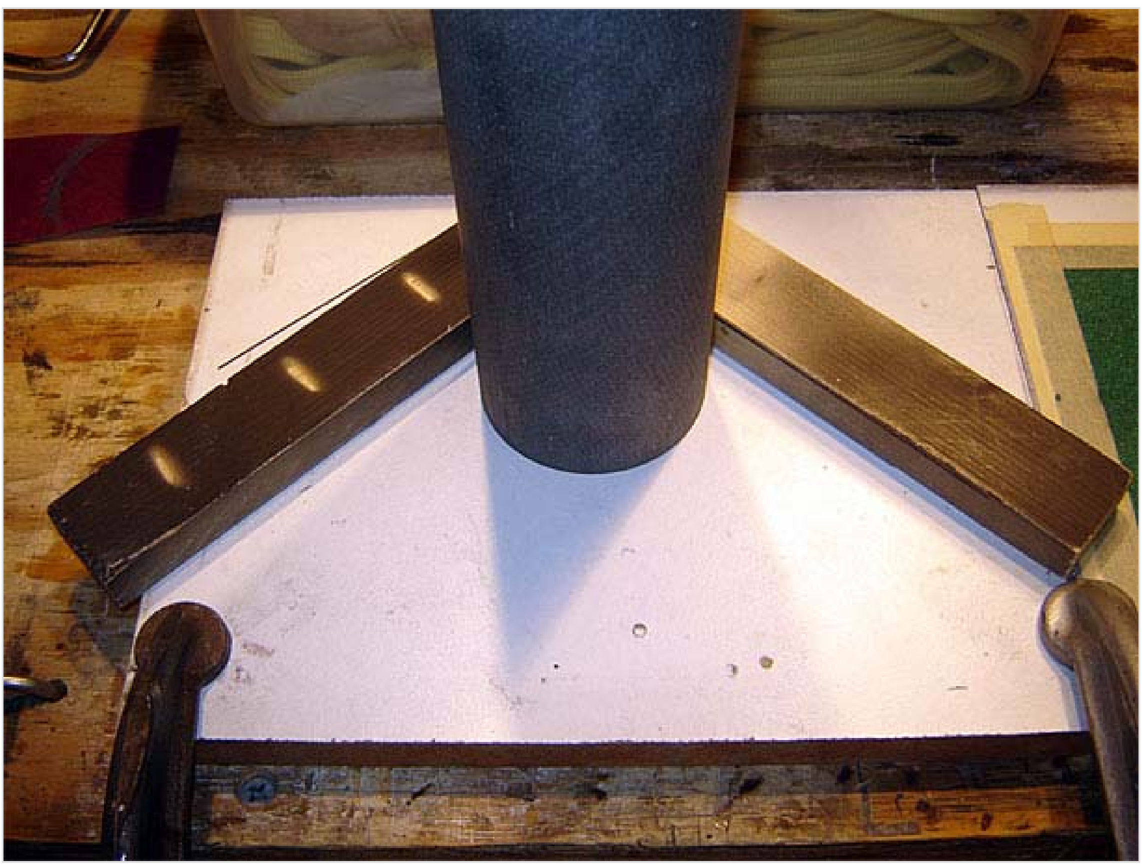
Now that the tube is finished, I will heat treat it before attaching the fins. I will heat-treat at temperatures of 130, 150, 170 and 190 for two hours each, and then back it down on the same schedule.

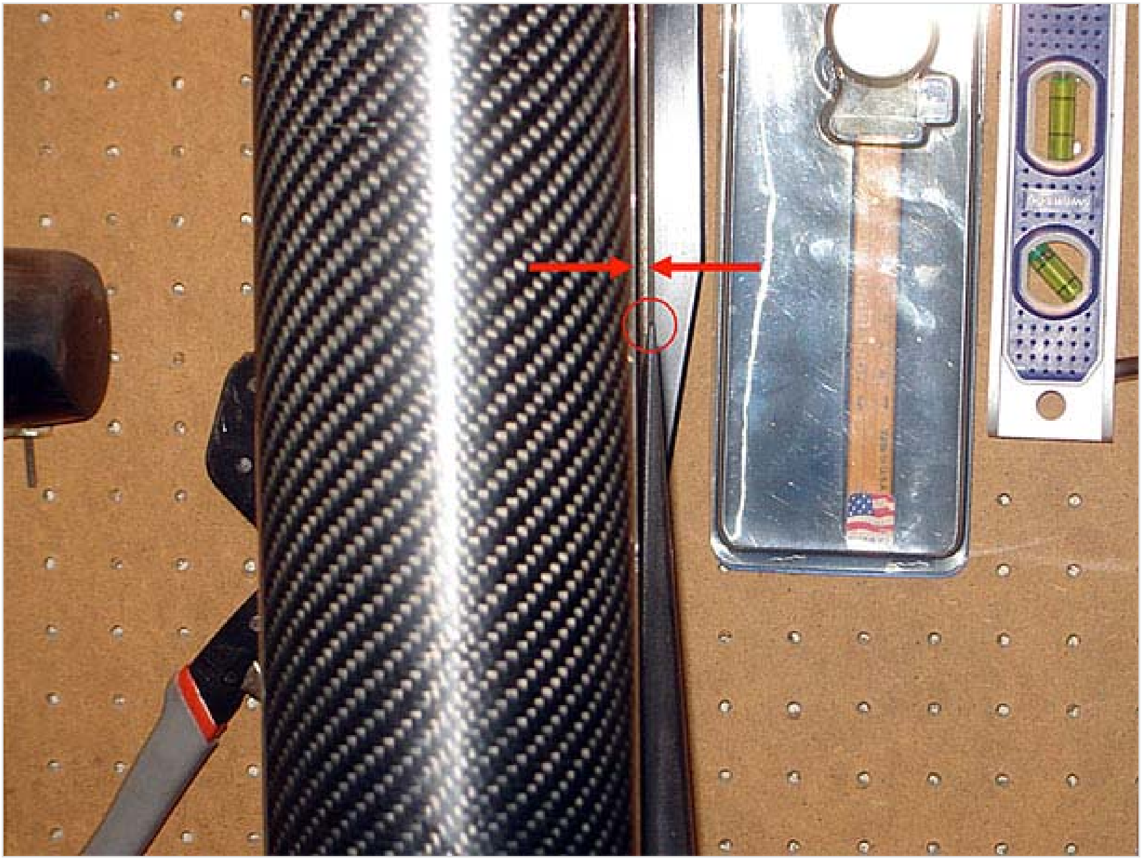
The final step to complete the airframe is to cut off and square the ends of the tube. Since the TooCarbYen is nearly 18 feet tall with numerous breaks in the airframe, it is very important that the ends of the tubes be true and square. I have a way of doing this that is very accurate. This is difficult to describe, so take a look at the pictures that follow. I have a flat board that has two pieces of wood attached to it in the form of a "V". The tube can be set on end and pushed up against this "V". This allows me to rotate the tube without moving the position of the tube. As I rotate the tube, I look for the upper part of the tube to wobble. If the tube wobbles, I sand off the high spot, flatten the end of the tube on a sandpaper board, and check again for wobble. The process works because any error in the trueness of the tube is magnified along the length of the tube. For a 3" diameter tube that is 36" long, this represents a factor of 12.

I use a target on the wall along with an intermediate target to help spot any wobble in the tube. In this case, the intermediate target was the tip of a nose cone. This approach helps me to keep my eye aligned so that I can see exactly how much the tube is out of square. I can typically reduce the wobble to within about 1/32". This means that the end of the tube will be square to within about 0.0025".

This is the final airframe. Now it’s time to attach the fins.


The flat board with the “V” shaped pieces is clamped to the workbench.


The tube is then set against this “V”. Now, the tube can be rotated without changing its position left or right.



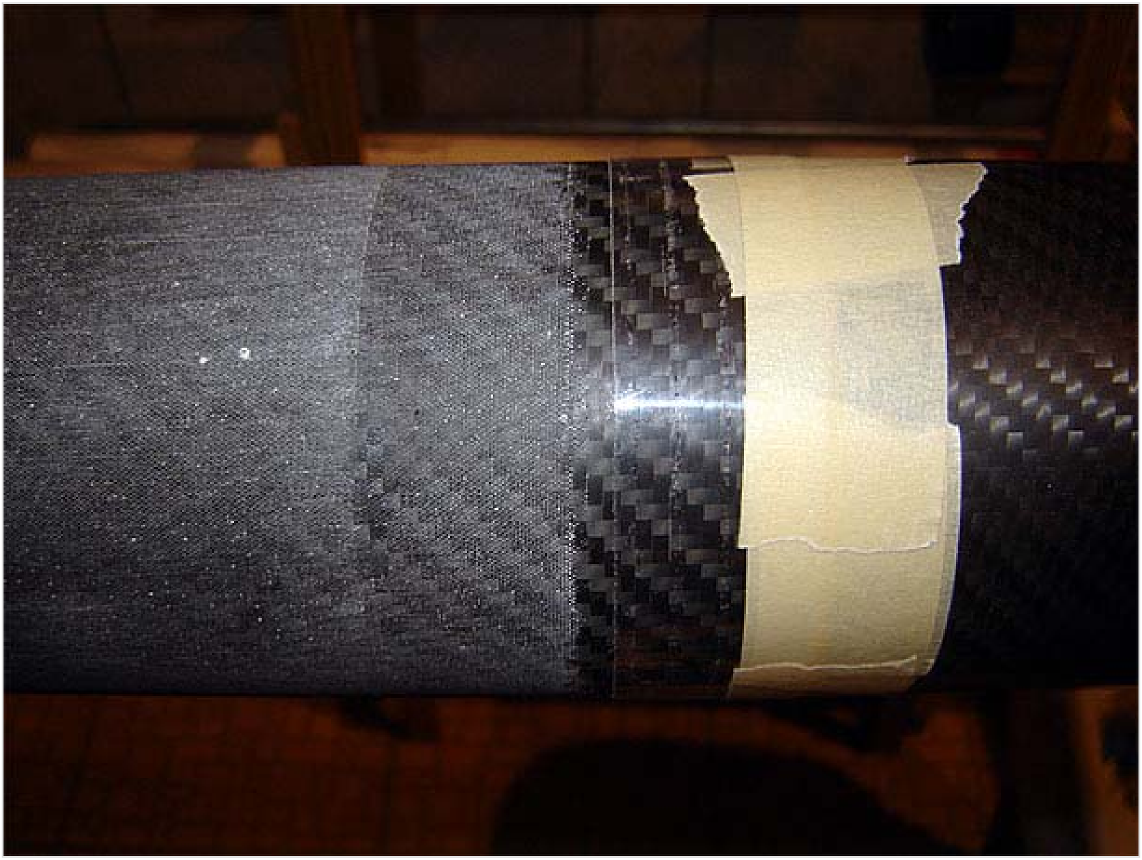
If the tip of the nose cone is centered, and the width of the gap is constant as the tube is rotated, then the tube is square. The idea is to rotate the tube and watch for wobble higher up on the tube. Here, I'm using the tip of a nose cone as an intermediate sight, and I'll keep the tip of the cone centered in the gap on the wall.

Attaching the Fins

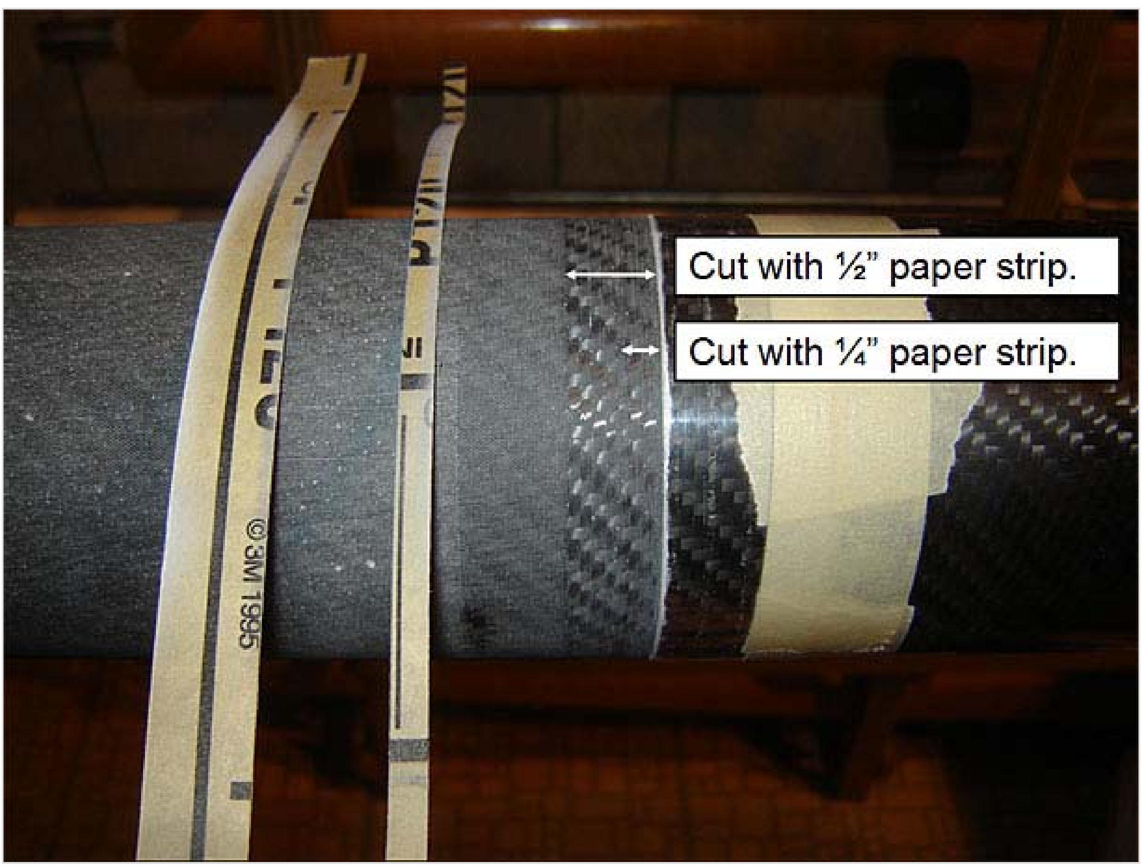
Now it's time to attach the fins. Everyone has their favorite method to do this. My rockets tend to fly very straight, which I believe must mean that my method works pretty well. So, I'll document it here.

But before I get to the fin attachment, I want to perform one more step that will help later on to prepare for the tip-to-tip carbon attachment. Since the tip-to-tip carbon will need to "blend in" to the carbon tube, I want to make that process as easy to accomplish as possible. One thing that helps is to sand a channel into the tube at the point where the top of each carbon layer will end. This slightly recesses the top edge of the tip-to-tip carbon into the tube, which makes finishing easier.

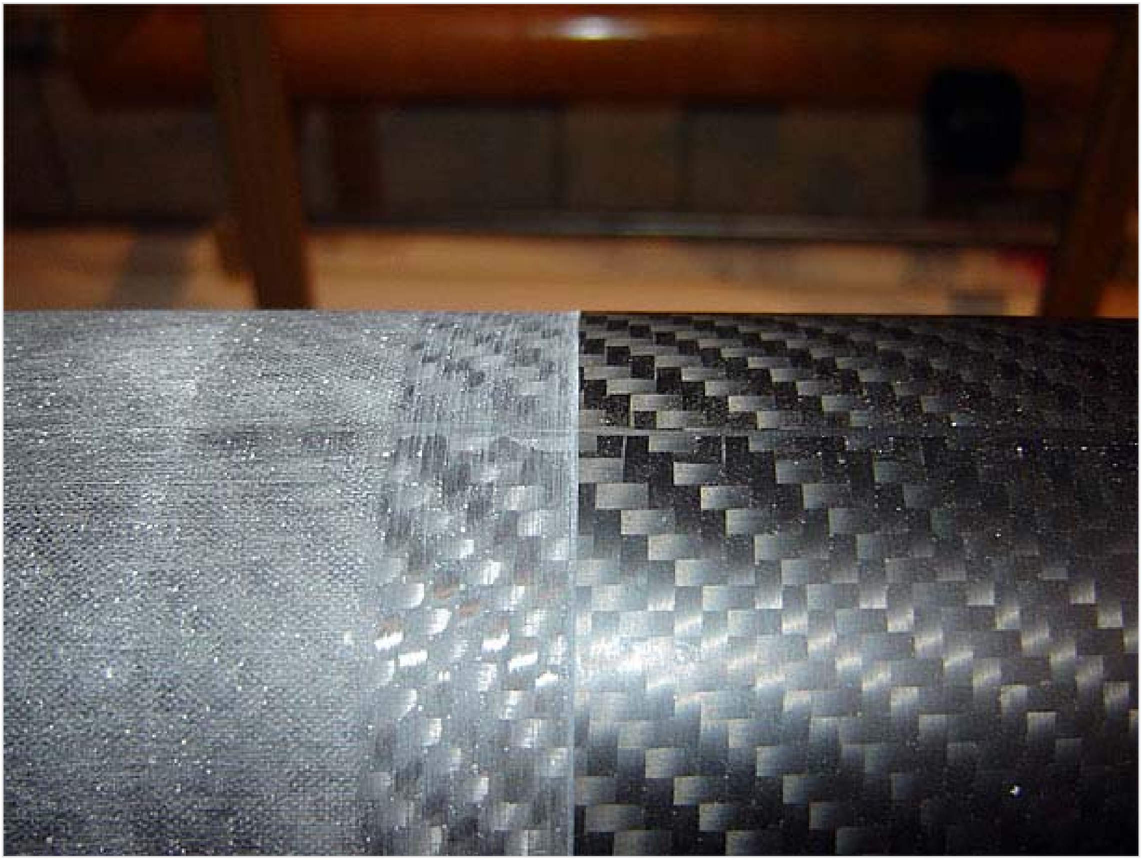
In my design, one layer of tip-to-tip carbon will terminate 1" above the top of the fins. The second layer will terminate 1-7/8" above the top of the fins. Although this process cuts into the top layer of the carbon, with 5-wrap tubes, there is plenty of margin.



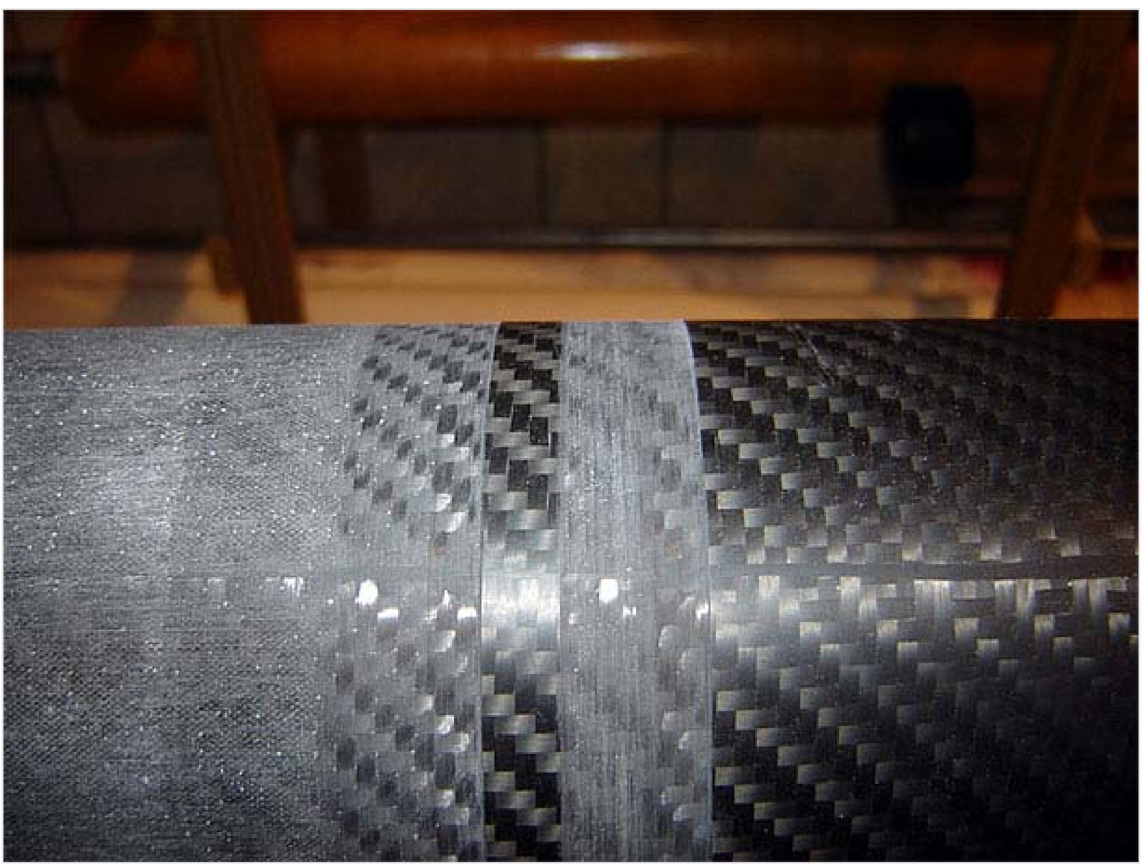
I use a piece of plastic as a sanding guide. The objective is to sand a channel to recess the top of the tip-to-tip carbon into the tube. Here, I've applied the plastic guide around the tube.



Here, I used 1/2" and 1/4" pieces of sandpaper to cut a groove around the tube. I cut half of the depth with the 1/2" inch paper, and then the full depth with the 1/4" paper.



Here is the first groove with the plastic removed. It isn't very deep, but it will help in finishing the airframe and as an alignment guide for the tip-to-tip carbon.

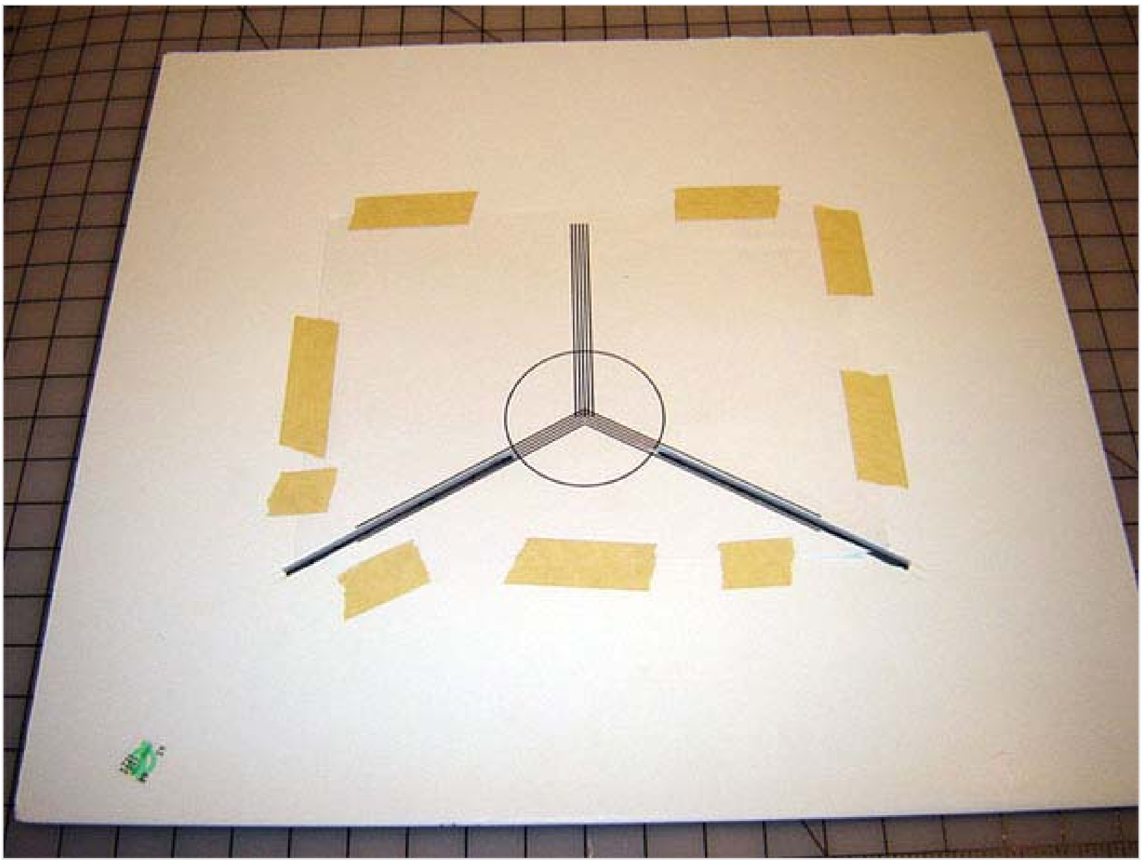


Here is the second set of grooves located 7/8” ahead of the first set. The first tip-to-tip layer will terminate at the first set of grooves and the second tip-to-tip layer will terminate at the second set of grooves.

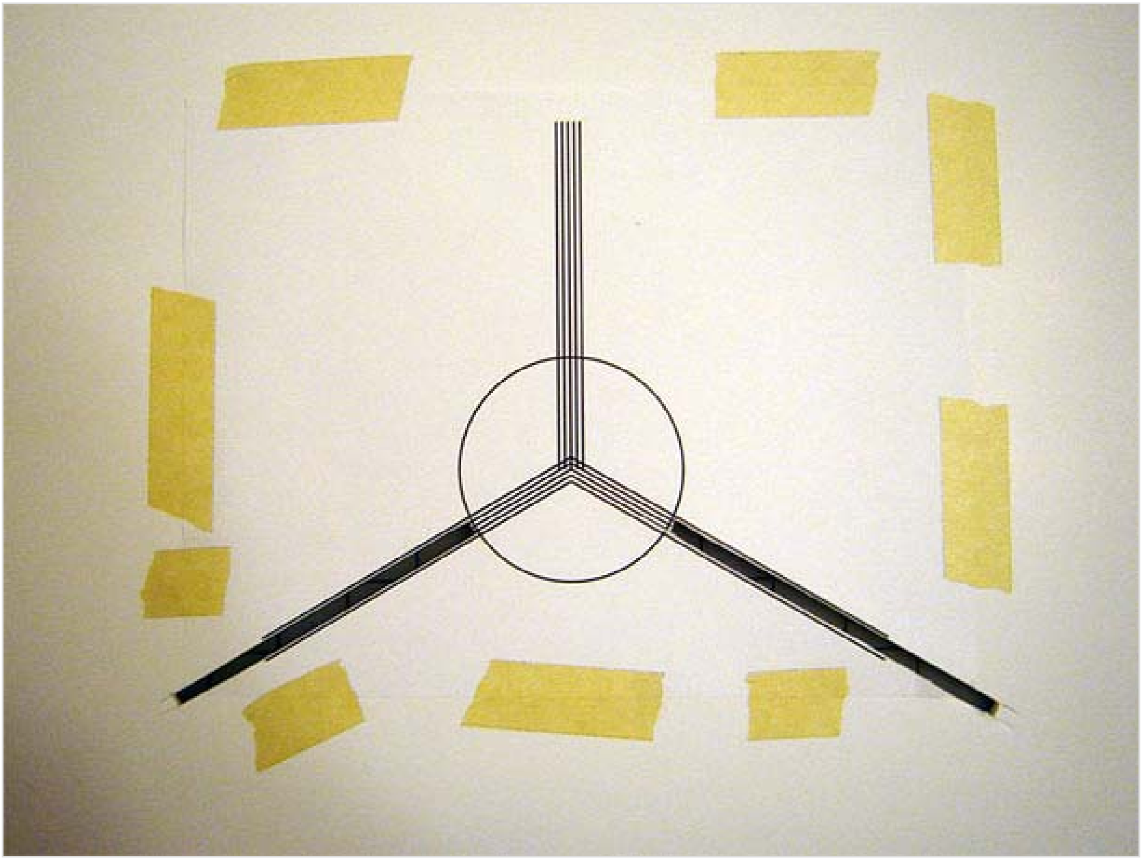
With the channels cut, I can proceed to laying out the position of the fins. My fins will need to be placed exactly 3/4" from the bottom of the airframe. In addition, the fins must be reasonably equidistant around the tube (these are requirements because the base of the fin can must fit into an existing interstage coupler).

I use two alignment aids. First, I have foam board alignment jig that keeps the fins perpendicular to the airframe. Second, I draw vertical alignment lines in the locations where the fins will be placed. I use some angle iron to do this, and I use a knife to lightly score the tube itself. From the geometry of the situation, if the fin roots are aligned with the tube and the fins are perpendicular to the tube, then the fins are as aligned as they are going to get.

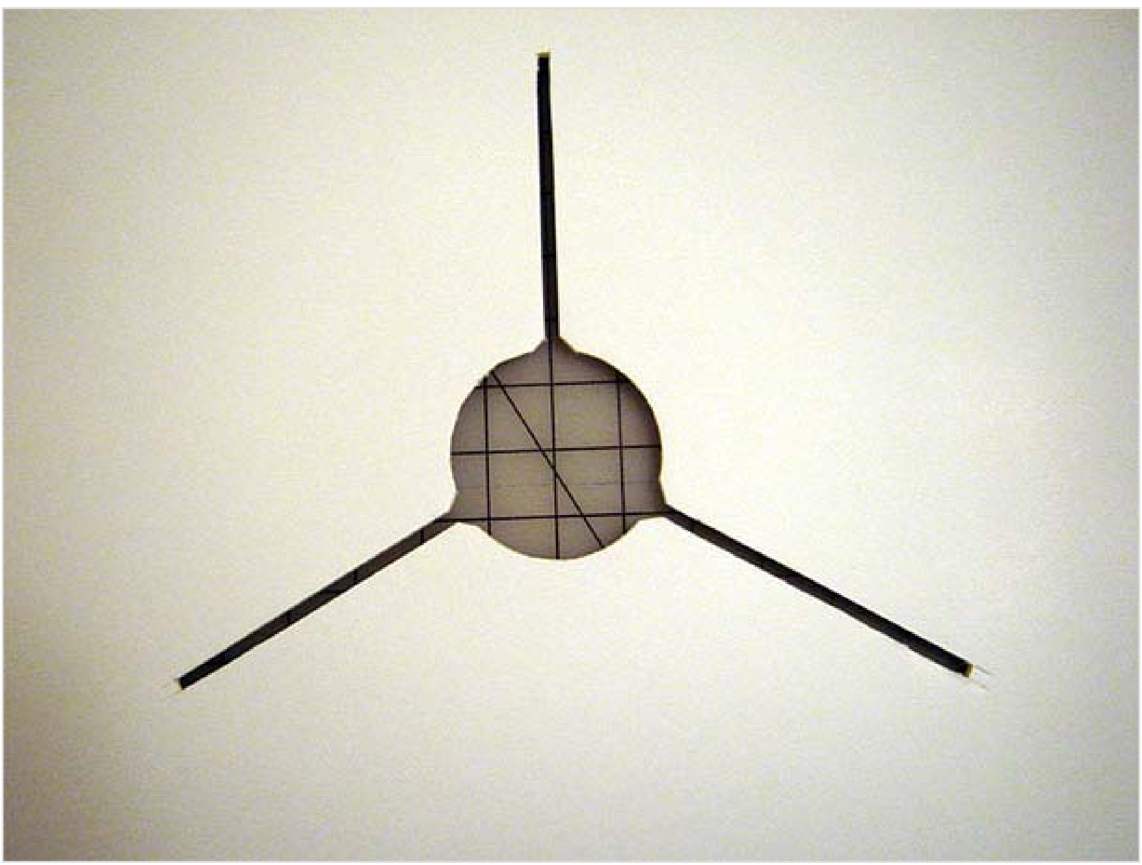
In previous rockets, I used a Dremel to cut a serrated edge into the root of each fin. I decided to do that here also as a method of providing a little more surface area for the glue. The following pictures show the fin alignment guide, the lay-out of the fin position on the airframe and tacking on the fins themselves.



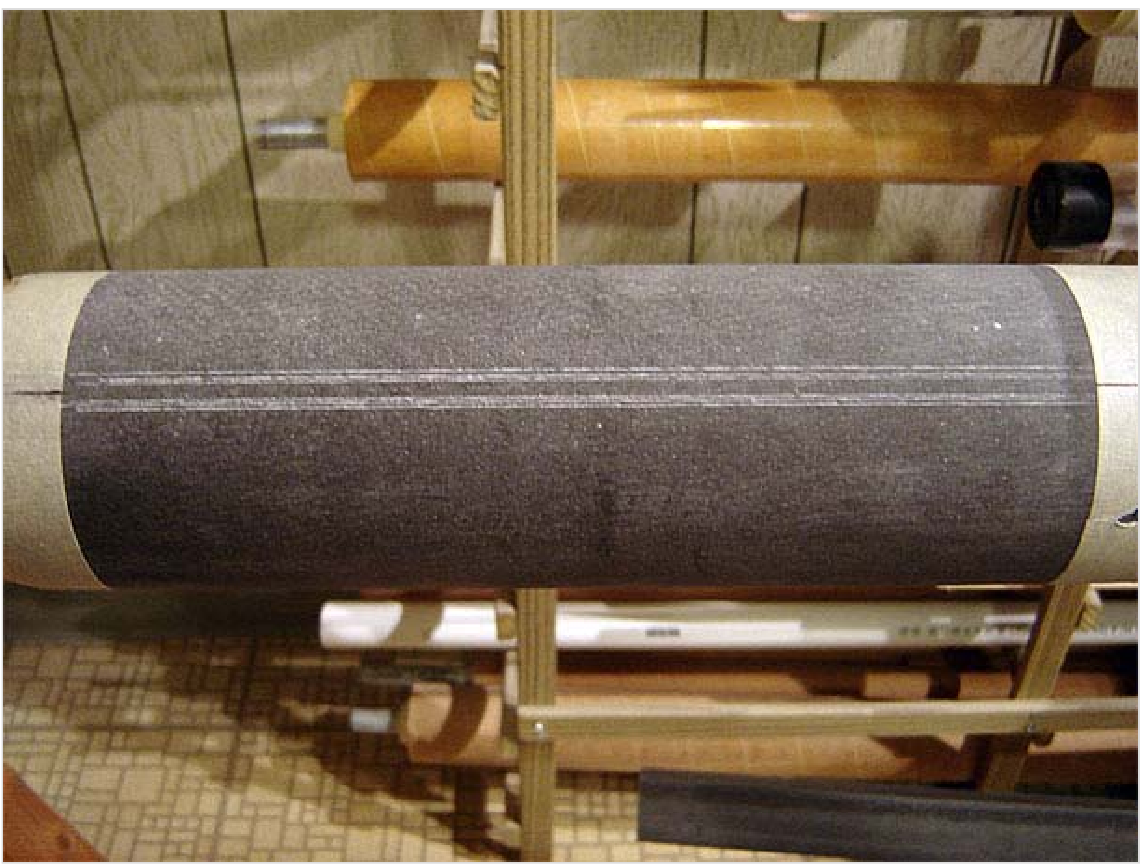
Here, a fin template is taped onto a piece of foam board.



I'll try to cut out the fin guides to the actual width of the fins as carefully as I can.



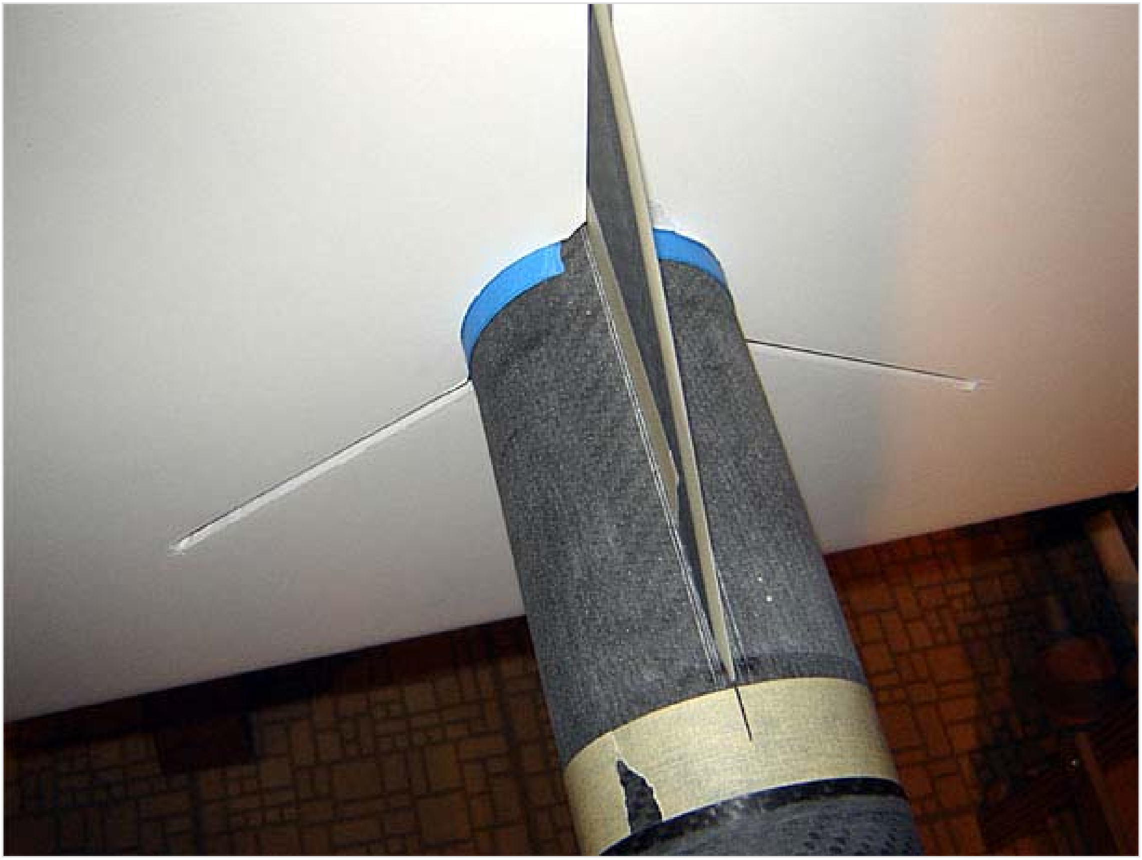
Here, the fins and the body tube have been cut out. The jig slides over the end of the body tube and holds the fins perpendicular to the body tube.


Here, I will use a piece of angle iron to score alignment lines along the airframe.

Here are what the lines look like when the process is completed.

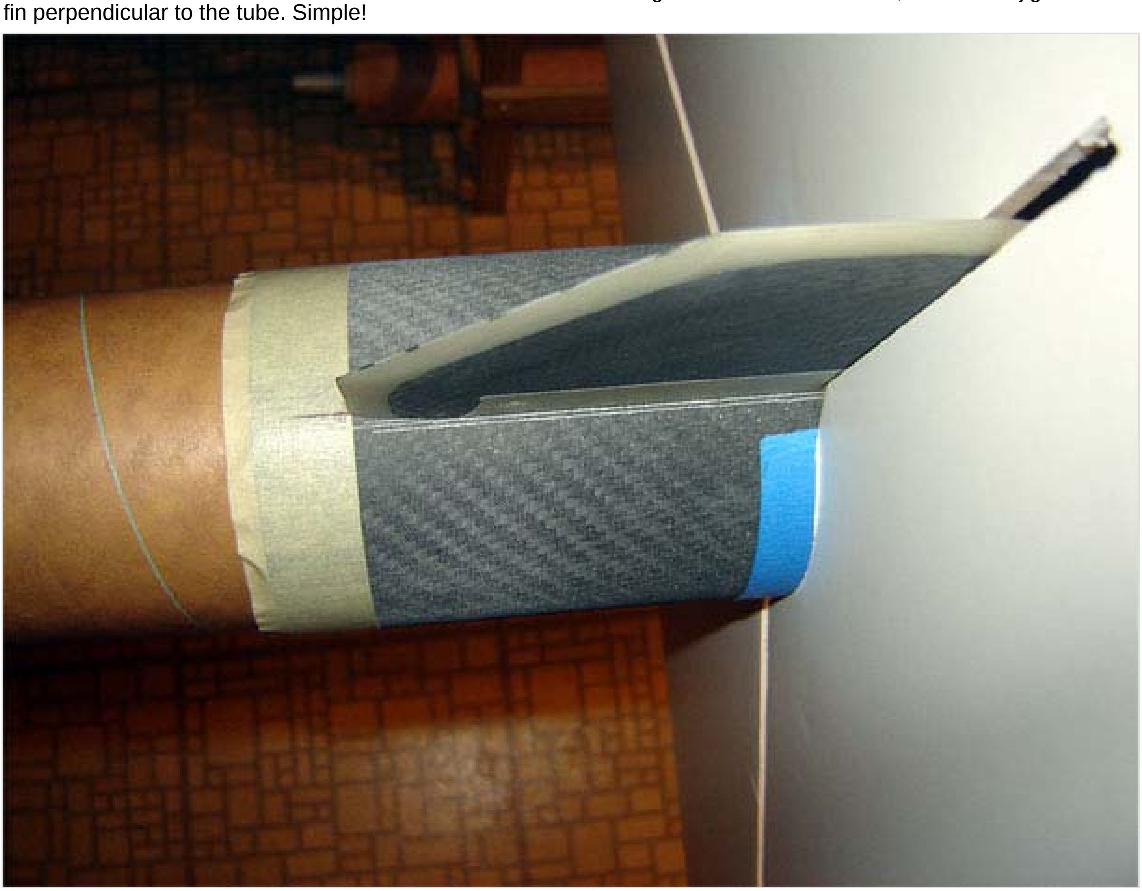
I used a Dremel to serrate the root edge of the fin. This will provide more surface area for the glue. Also, I added tape so that it would be easier to see the edge of the fin in relation to the scored lines on the body tube.

I've applied some Aeropoxy to tack on the fins. The fillets will be made with Cotronics high-temperature epoxy, and

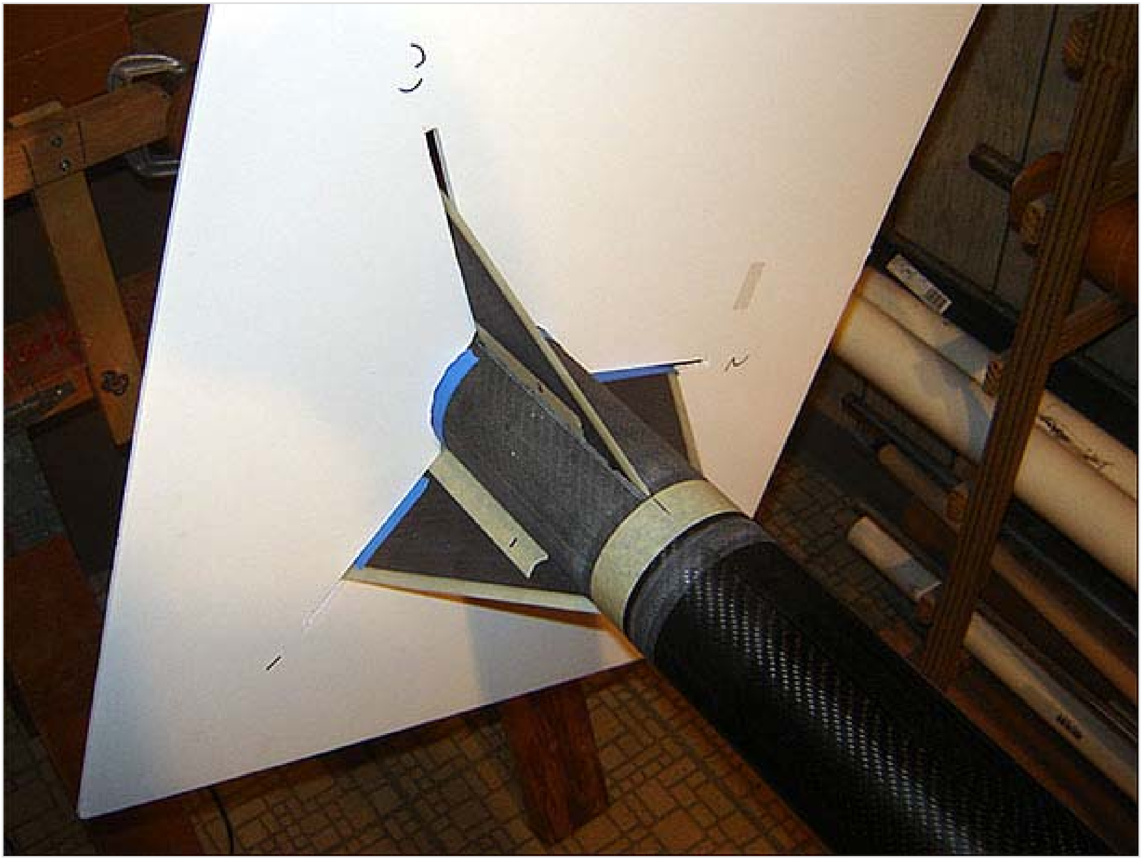
I'll try to force some of that glue into the serrated edge.



Here is the first fin installed. Note how the front half of the fin is aligned with the score lines, and the fin jig holds the fin perpendicular to the tube. Simple!



Here is the back half of the fin with the fin located 3/4” ahead of the end of the tube.



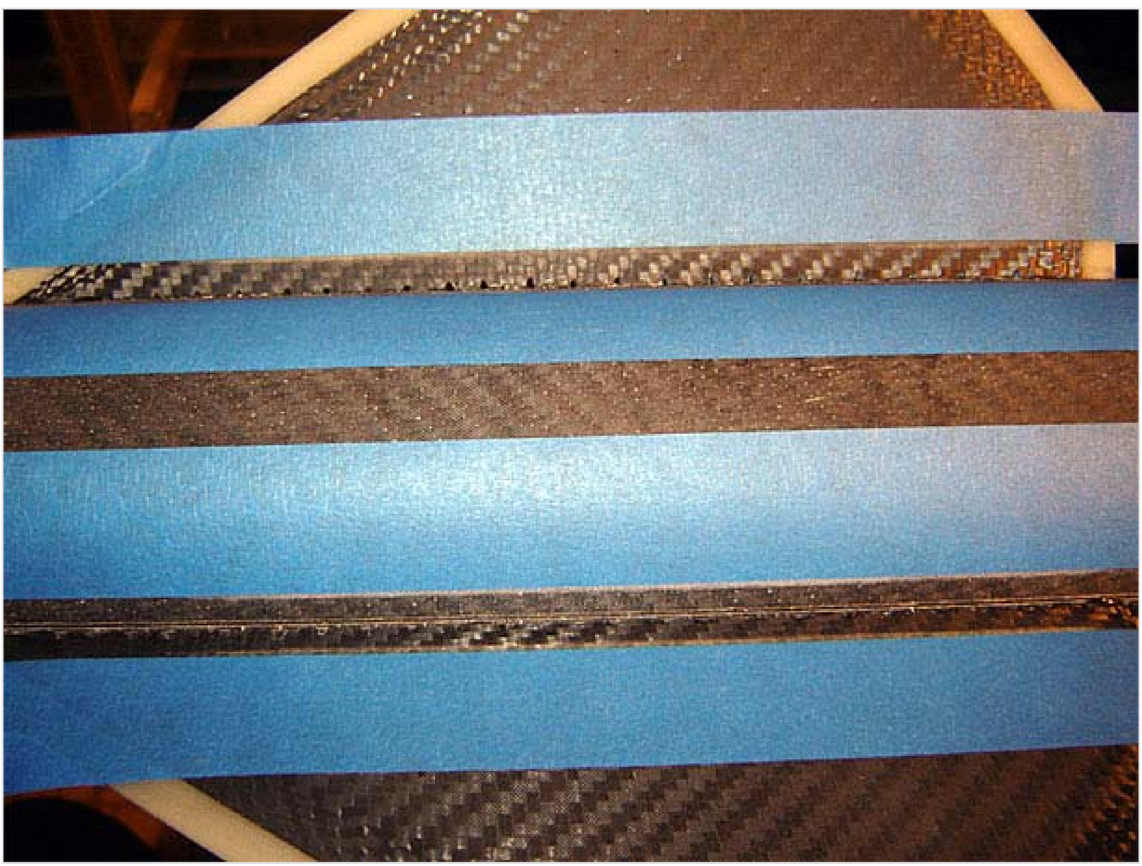
All three fins are attached.

Making the fillets is a three-step process. First, I'll make a glue fillet using Cotronics high-temperature epoxy. Since this is a minimum-diameter rocket, a high-temperature fillet is a good idea. I use a 5/8" dowel to score the tube so that I can see where the fillet will go. Then, I use the same dowel to form the fillet. I add a little milled glass and a little chopped Kevlar® to the epoxy.

Second, I make a large-radius fillet over the top of the Cotronics using Aeropoxy Light filler. The purpose of the large radius is to maximize the strength of the tip-to-tip carbon by avoid sharp turns in the carbon. This process makes a structure around the base of the fin that is extremely strong.

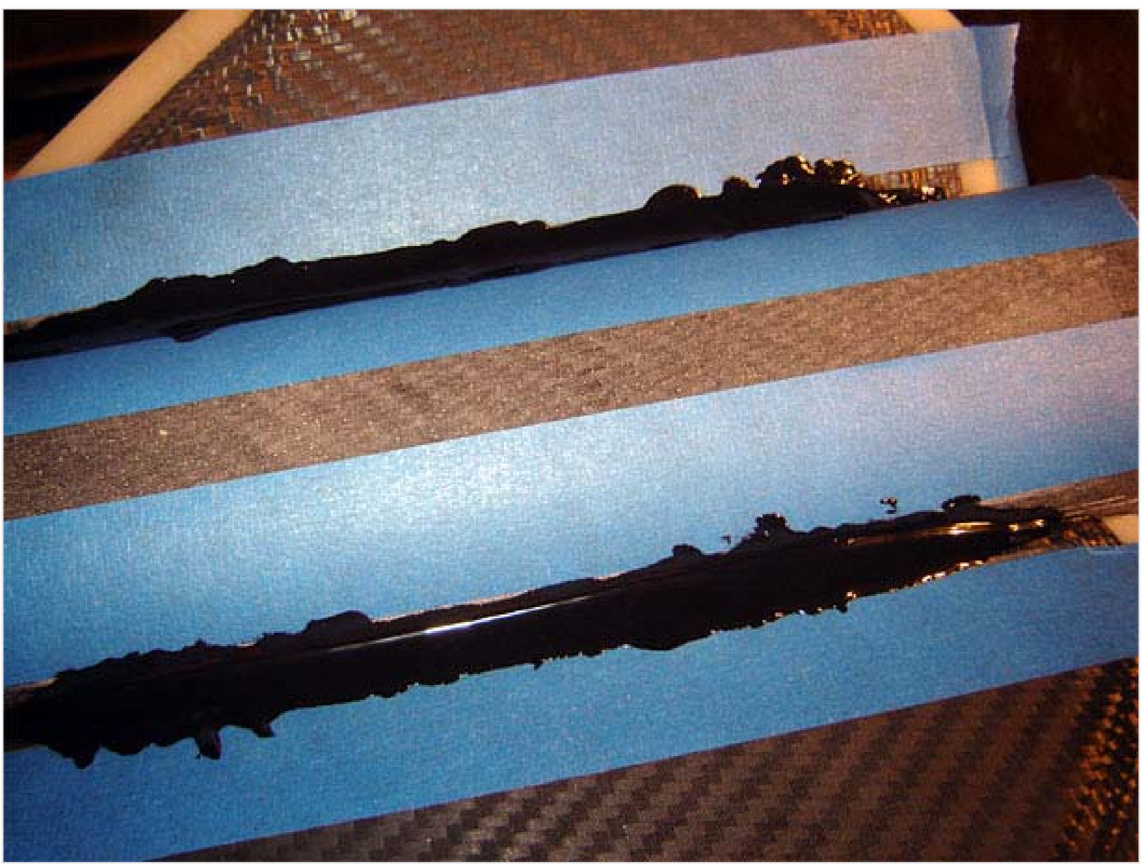
Third, I need to sand the radius of the fillet a little, and I also need to sand the leading and trailing edges of the fillet. At the front of the fillet, I'm going to sand the transition to leading edge starting 1-1/8" behind the tip of the fin. At the aft edge of the fin, I'm going to start the transition 3/4" from the edge of the fin. These distances coincide with the points where the fin tapers begin (for reasons that will become apparent later on).

For making the fillets, I will use two dowels – a 5/8" dowel and a 1" dowel. Here, I'm using the 5/8" dowel to score lines for making the Cotronics fillets.



The score lines are just used as guides for tape. But I want to make sure that the Cotronics fillets will not be too large.

For the fillets, I use Cotronics 4525 high-temperature glue. It’s really good glue, but a bit expensive, so I just make a little at a time. I add a little milled glass and a little chopped Kevlar.

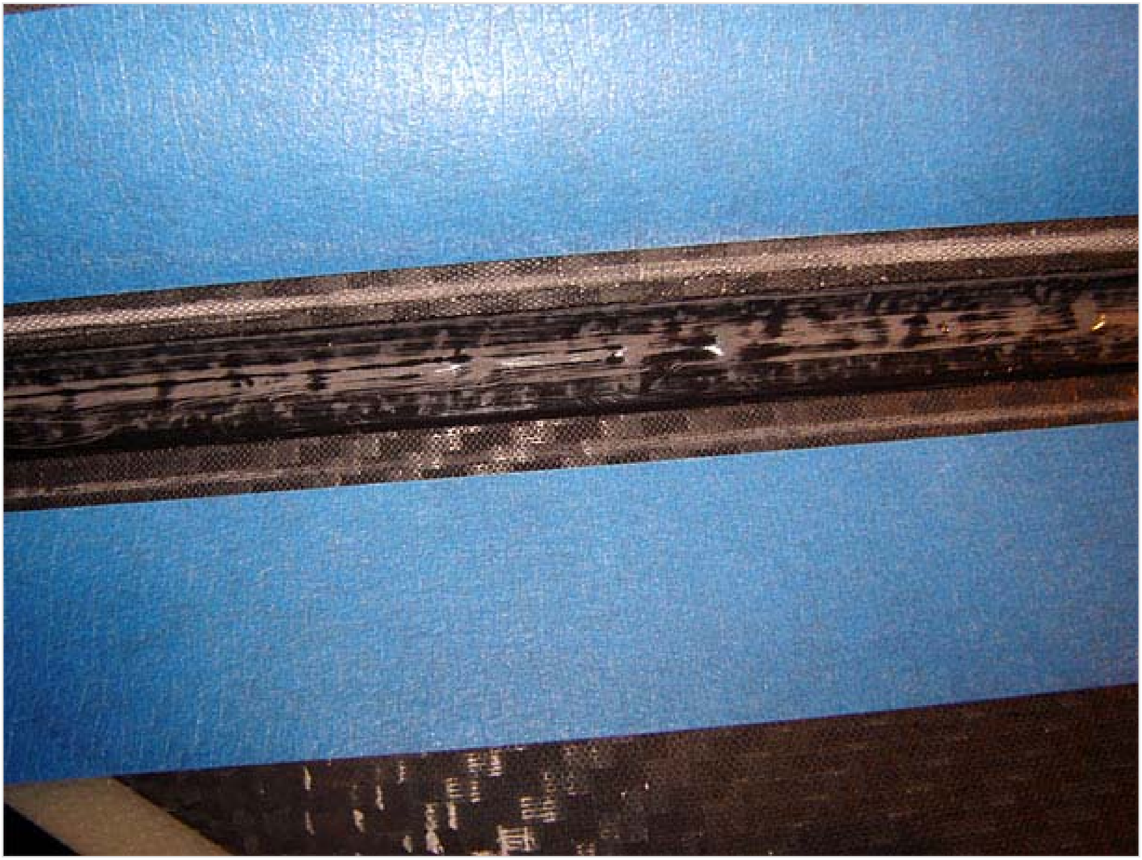


I apply the glue, and then after it sets up a little, I use the 5/8” dowel to actually form the fillet.

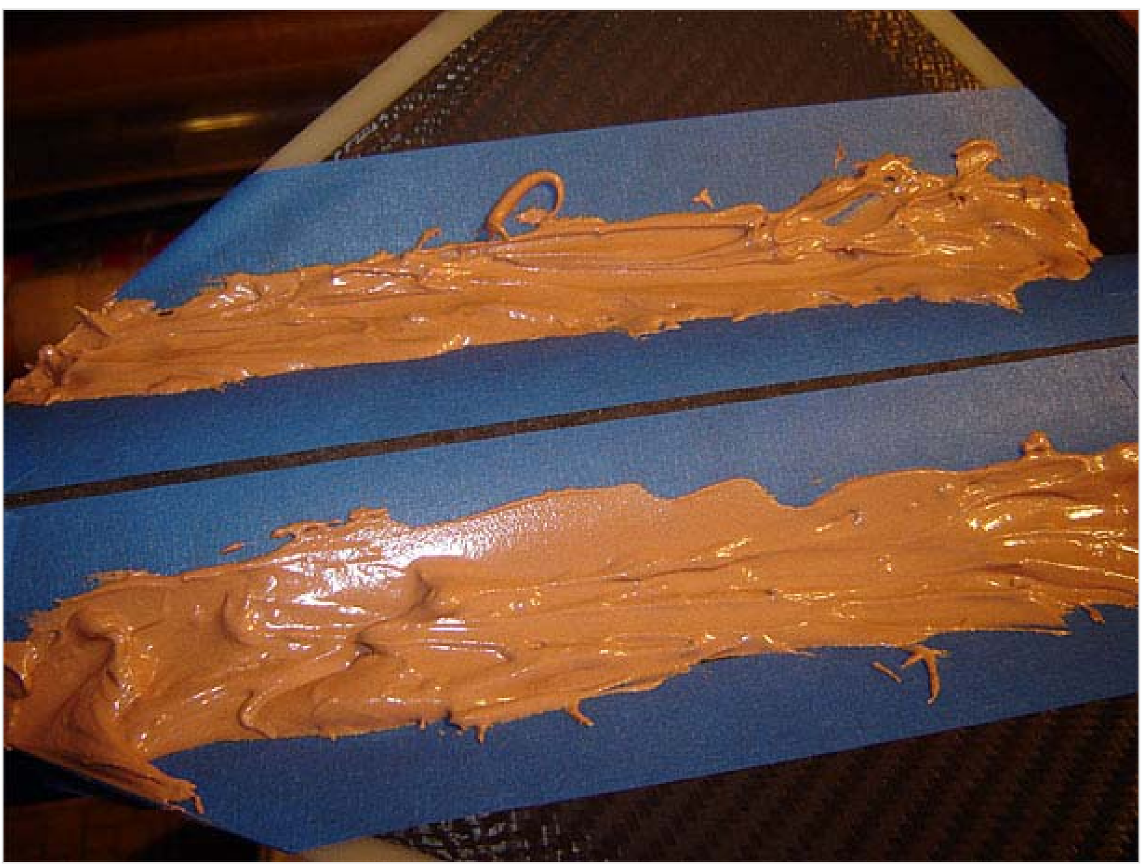
Here are the completed fillets. I heat-treated these after they were complete at 180F.

Now, I’m going to make a large-radius fillet out of Aeropoxy Light. I start by scoring more lines, but this time, with a

1” dowel.

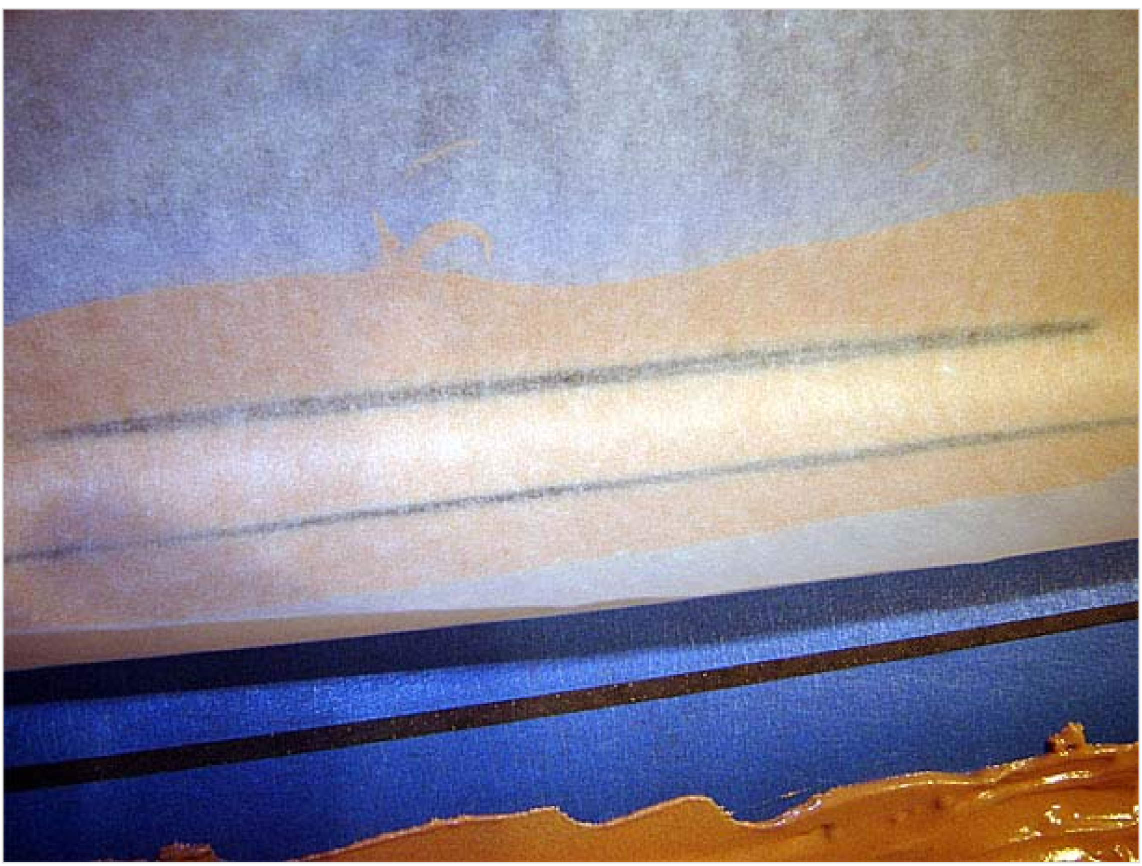


Again, I’m going to add some tape to keep the filler off of the airframe, but in this case, the tape is placed a little outside of the score lines.



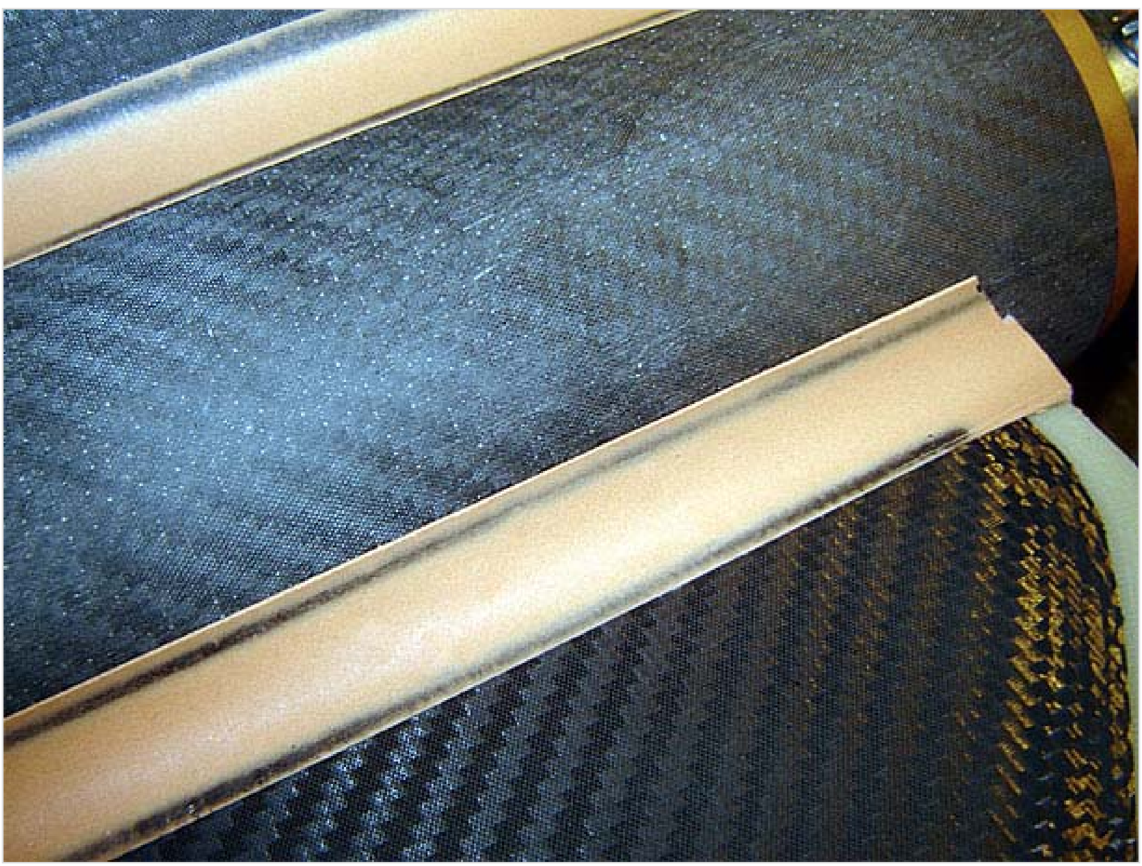
Here is the Aeropoxy light applied to the fillets.

To form the radius of the fillet, I place parchment paper over the Aeropoxy Light, and then form the fillet with the 1" dowel.



I push down on the dowel as hard as necessary so that when the dowel is removed, the airframe is visible under the parchment paper. This will make a consistent radius.

After the Aeropoxy Light is partially cured, the parchment paper can be removed.



The blue tape pulls up easily, leaving a fillet that will be easy to sand.

The next step is to sand the fillet, including the leading and trailing edges. This step is important because the smoothness of these surfaces will translate directly into the smoothness of the tip-to-tip carbon.

The fillet was formed from a 1" dowel (or more precisely, a 0.97" dowel). I will sand it with a sandpaper-covered dowel that has a diameter of 0.93". This is produced from a 7/8" dowel, built up with a few layers of tape. These dimensions will help me to sand the fillet without sanding into the carbon. I simply move the dowel back and forth, going slowly, and watching for the carbon tube to appear consistently on each side of the fillet. Don't sand into the tube itself!

The forward and aft portions of the fillet need to be tapered into an aerodynamic shape. I do this with two small wood files. Note that I mark positions that are 9/8" from the leading edge of the fin and 3/4" from the trailing edge of the fin. I do not taper the fillet inside of these lines. The following pictures show how the final fillets are formed. With this step completed, the fin can is ready for the application of the tip-to-tip carbon.

The original fillet was formed with a 0.97" dowel. I will sand it with a 7/8" dowel that is built up to 0.93" with tape. The 0.93" size is slightly smaller than the original fillet, which helps me to stay out of the carbon tube.

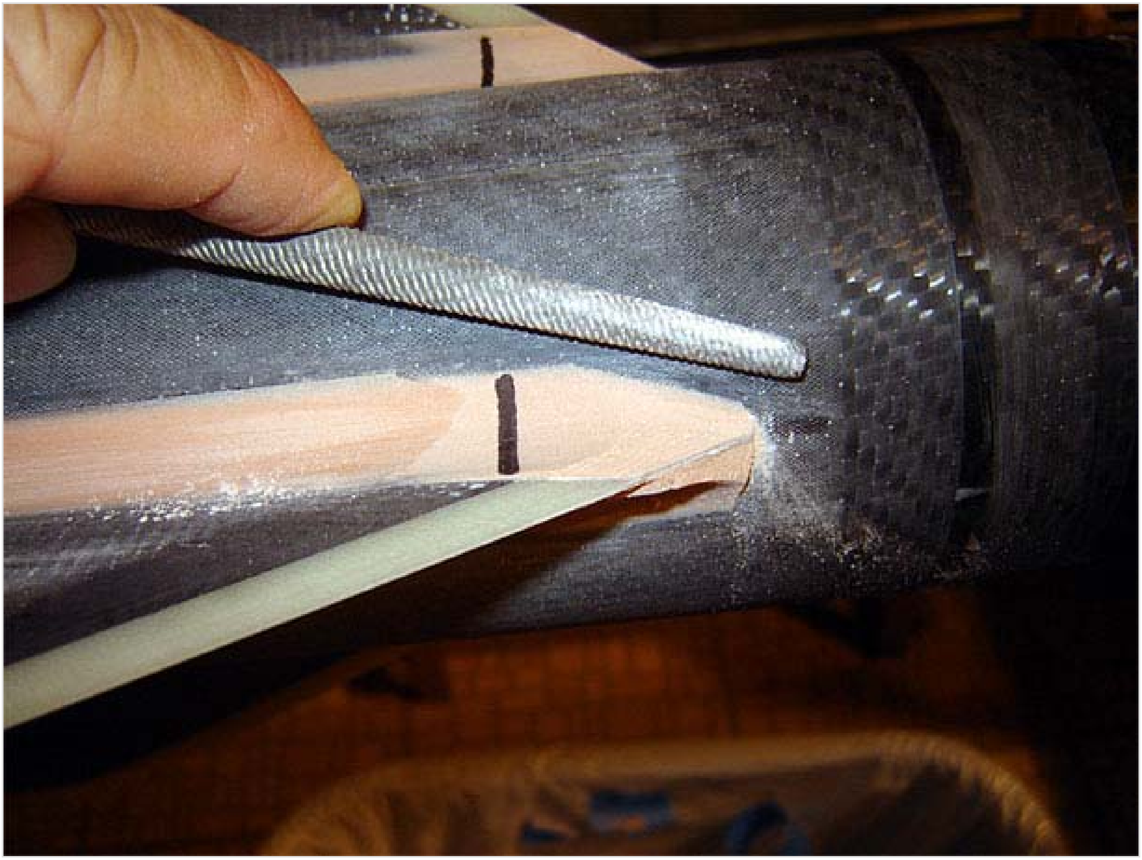

The sandpaper is taped on so that about 180 degrees of the dowel is covered. I used 180 grit for sanding the Aeropoxy Light filler.


Here is the fillet after sanding with the slightly undersized dowel. All of the fillet surface has been “hit”, and the

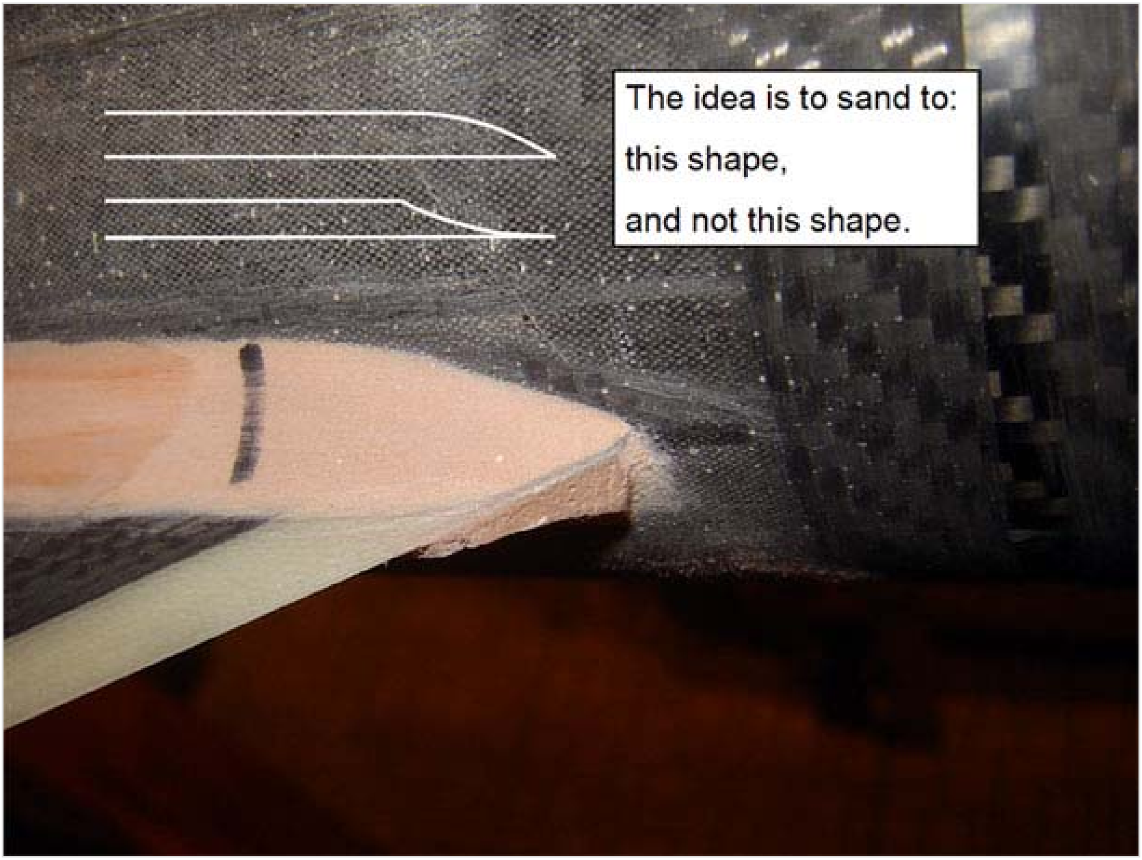
carbon tube is just appearing at the edges. Go slow and don't sand into the carbon!

The material outside of the lines can be sanded off with a sanding block.

For the forward fillet, I have marked a location 9/8" behind the front of the fin. I will only taper the fillet ahead of this line. I like to use round wood files to taper the fillet. These are the only tools I will use.



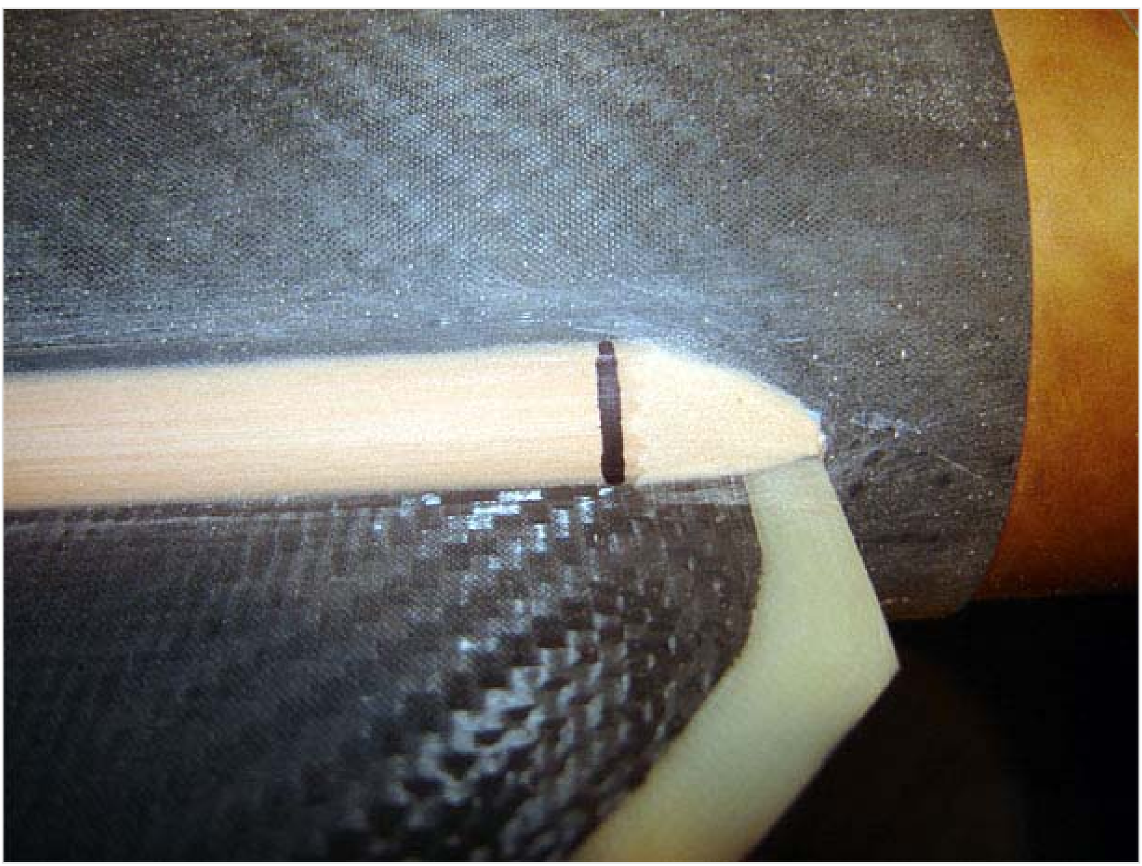
I cut away material using the file and the angle shown. I remove everything until I hit either the leading edge of the fin or the body tube. The small file is then used to remove more material right at the joint between the fin and the tube.



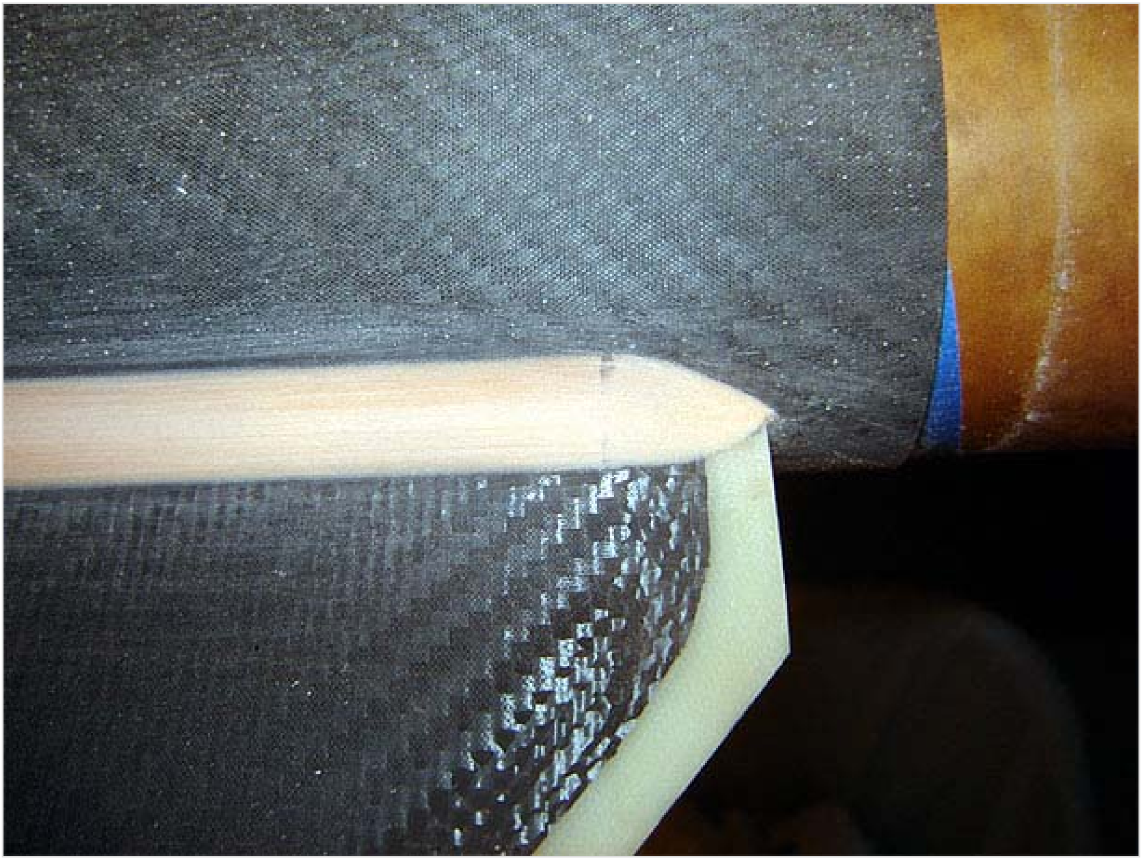
I make a second pass holding the file at about half the angle of the first pass. This goes close to the line. From there, it is a matter of smoothing out the fillet, particularly in the area behind the leading edge. A little sandpaper smooths everything out.

The final forward fillet.

The aft fillet is the same, except the fillet will stop 7/8" ahead of the rear of the fin.



A second pass at a lower angle...

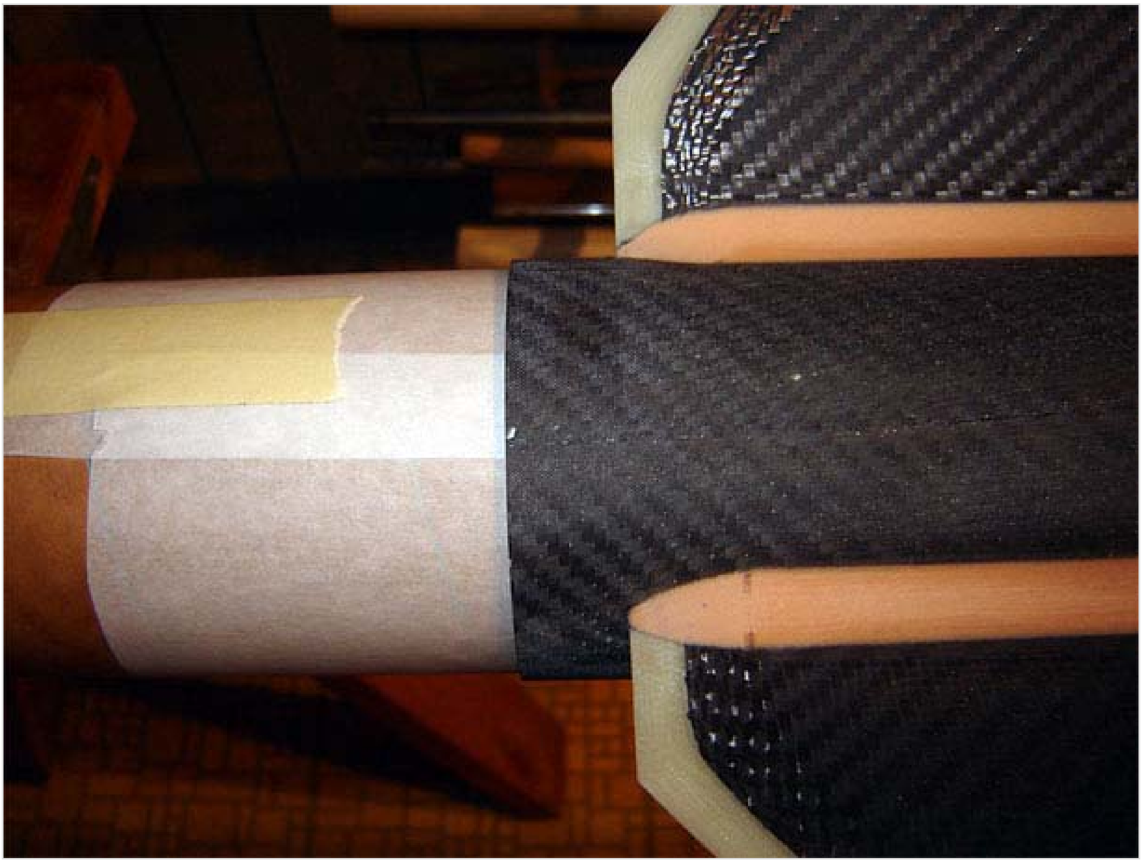

And then a little smoothing and sanding completes the fillet.

The fin can is now ready for application of the tip-to-tip carbon.

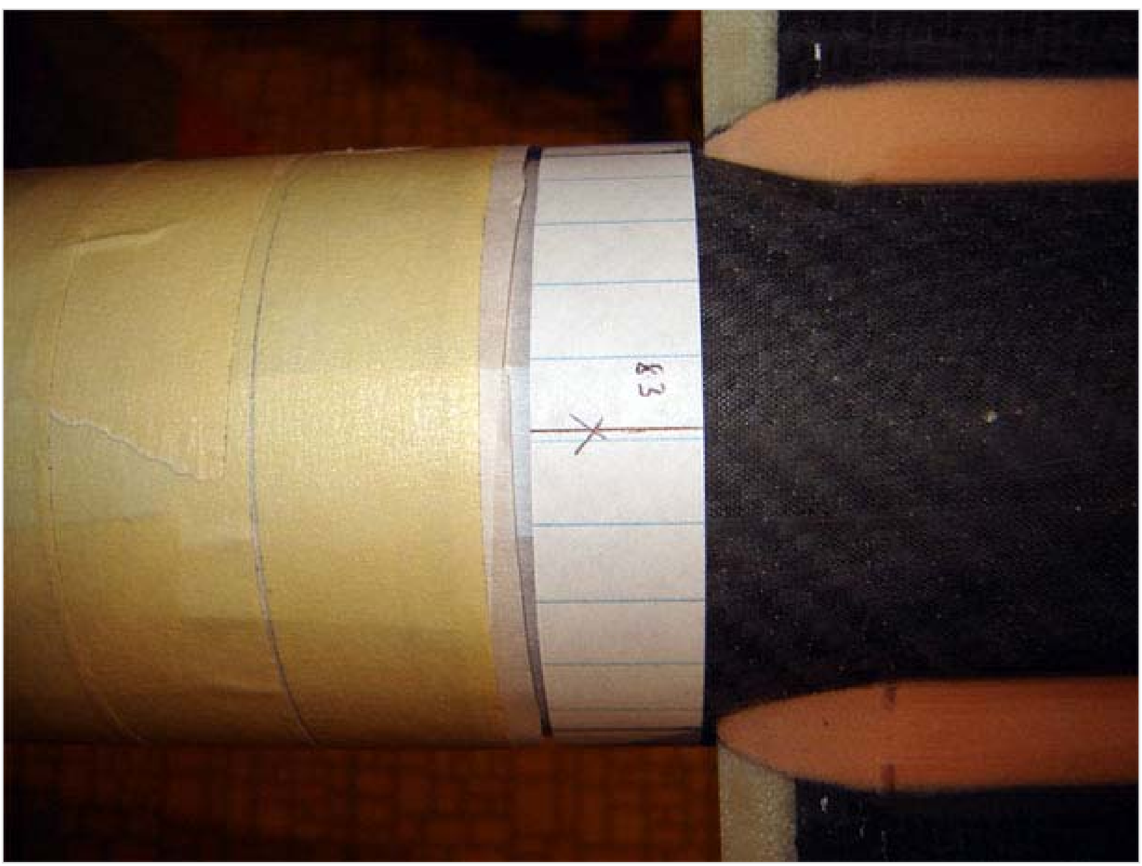
Applying the Tip-to-Tip Carbon

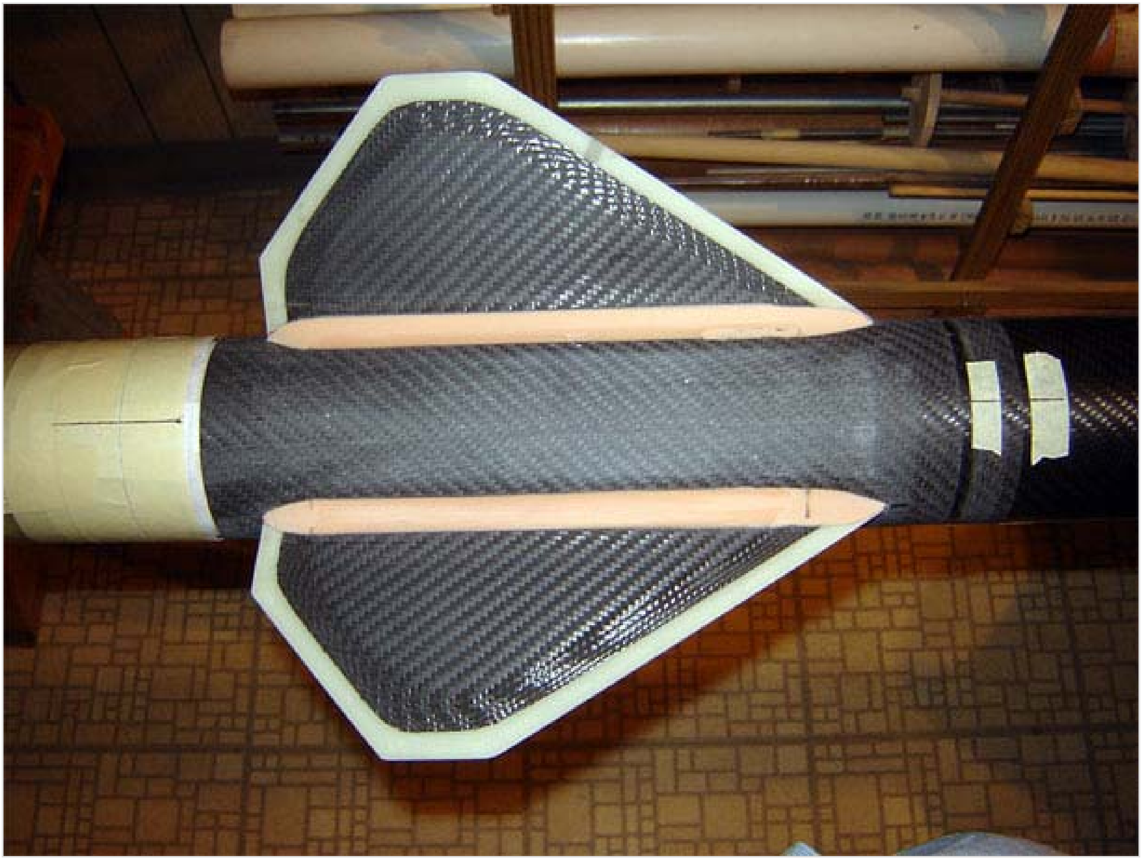
If there is a difficult step in constructing this rocket, the tip-to-tip application is it. I use a lot of little tricks to make this easier, and each time I do it, the application is a little less stressful. There are a few things that are important for having everything work out. First, it is important to mark the centerline of the rocket and the carbon pieces so that each piece can be positioned correctly. Second, it is important to cut the pieces as accurately as possible. If things are hanging up because the cuts aren't in the correct locations, it won't be possible to achieve a nice surface finish. Finally, several of the steps are easier to do with relatively soft epoxy. With the slow epoxy I use, I apply the cloth in one area on one day and then clean it up the next day while it's still soft. I make sure my schedule can support this process before I start.

I'll be adding two layers of carbon plus a layer of peel ply in each fin section. As with the airframe, I use the 3665 hardener (although the 3660 hardener could probably be used here instead).



The parchment paper under the tube will keep epoxy off of the mandrel.


A section of body tube behind the tube will provide some support for the carbon and will help to mark the centerline of the tube.

Here, I'm marking the exact center between the fins.



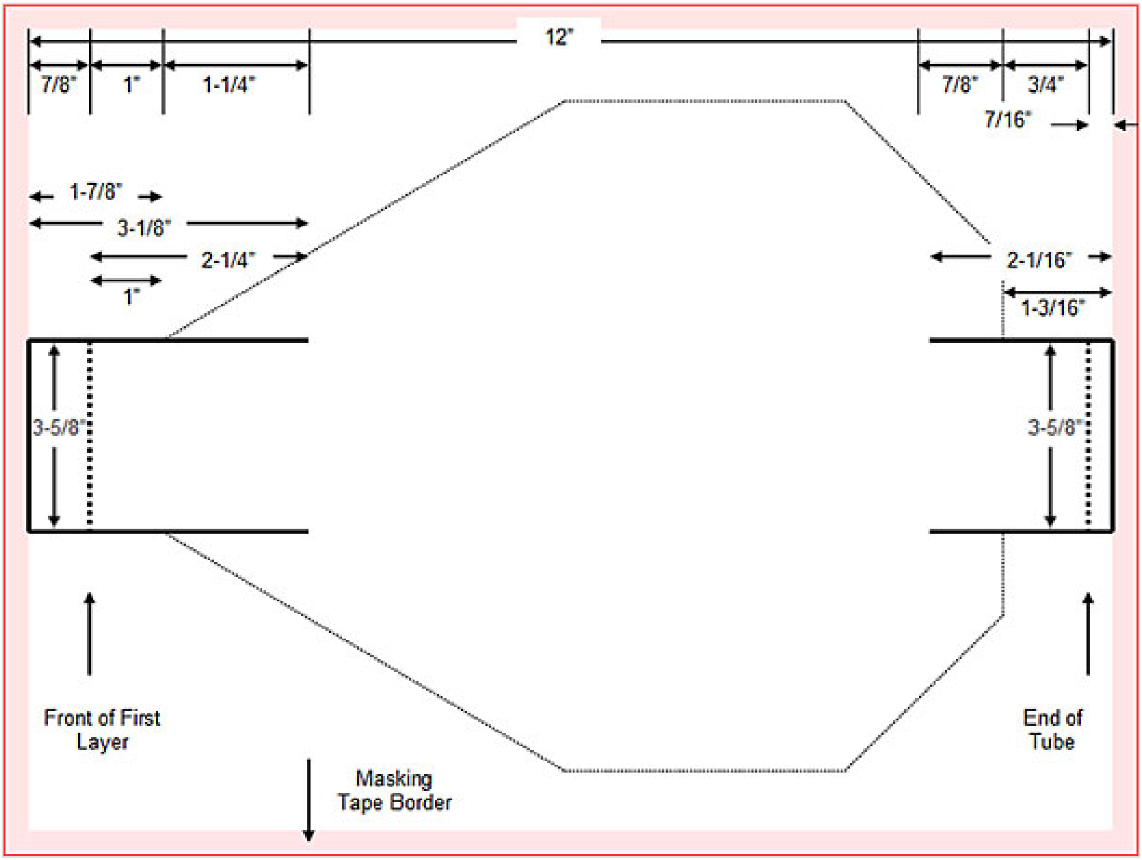
Here, I've marked the centerline at the aft end of the tube and I've applied some tape pieces (with a centerline) just ahead of the point where each of the tip-to-tip carbon pieces will end.

The last preparation step is to add some supports under the fins. These will help support the carbon while I am trying to get it lined up.

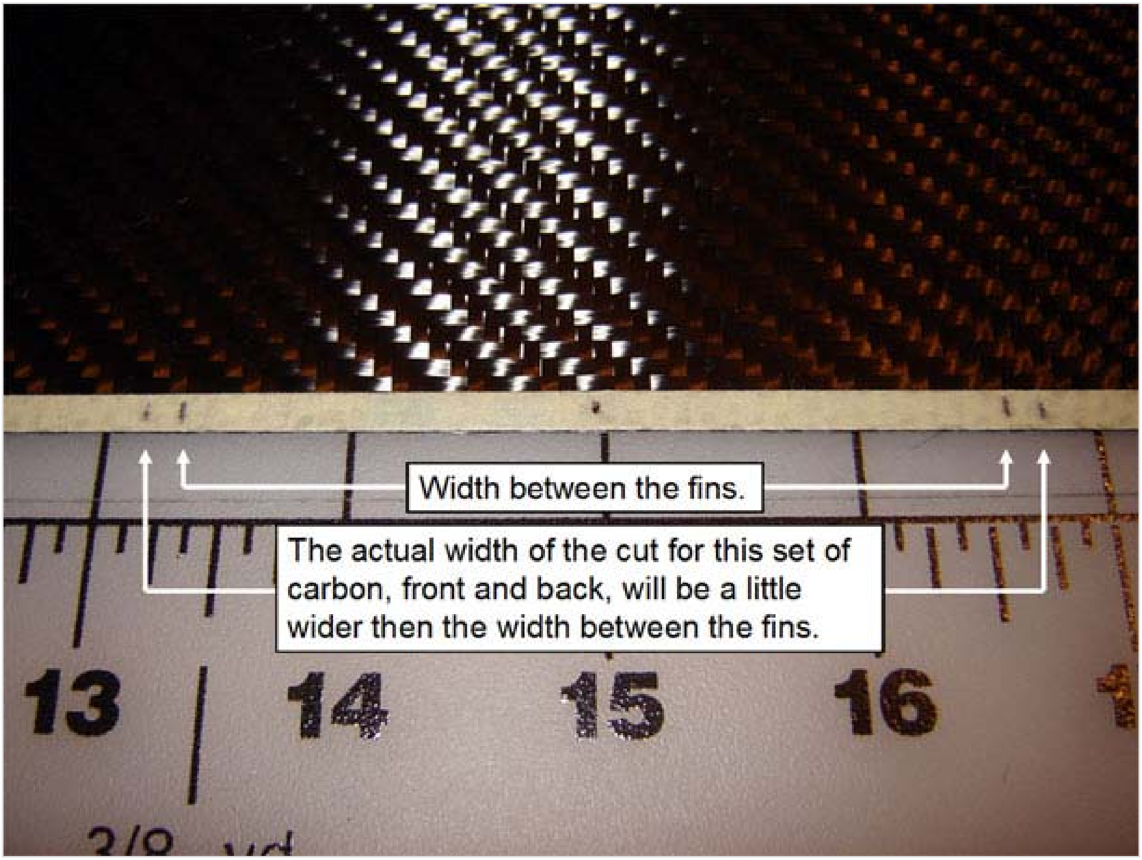
I made a template drawing that shows the dimensions of the cuts that will be required. One cut in particular is a slit that is cut at the points where the cloth passes over the tapered portions of the fillets. It isn't possible for a single layer of cloth to cover the whole tip-to-tip area because of the compound curves over these tapered areas. However, I believe it is better to have a large-radius fillet, and slit the tapered areas than to have a small-radius fillet that is continuous. Note that the compound curves over the tapered edges of the fins can be covered with no problems.

One strategy I use is to cut the cloth a little wider in the areas where the seams will meet on the tubes. Then, I trim these to an exact fit before the epoxy gets too hard. This process really improves the appearance of the seams.

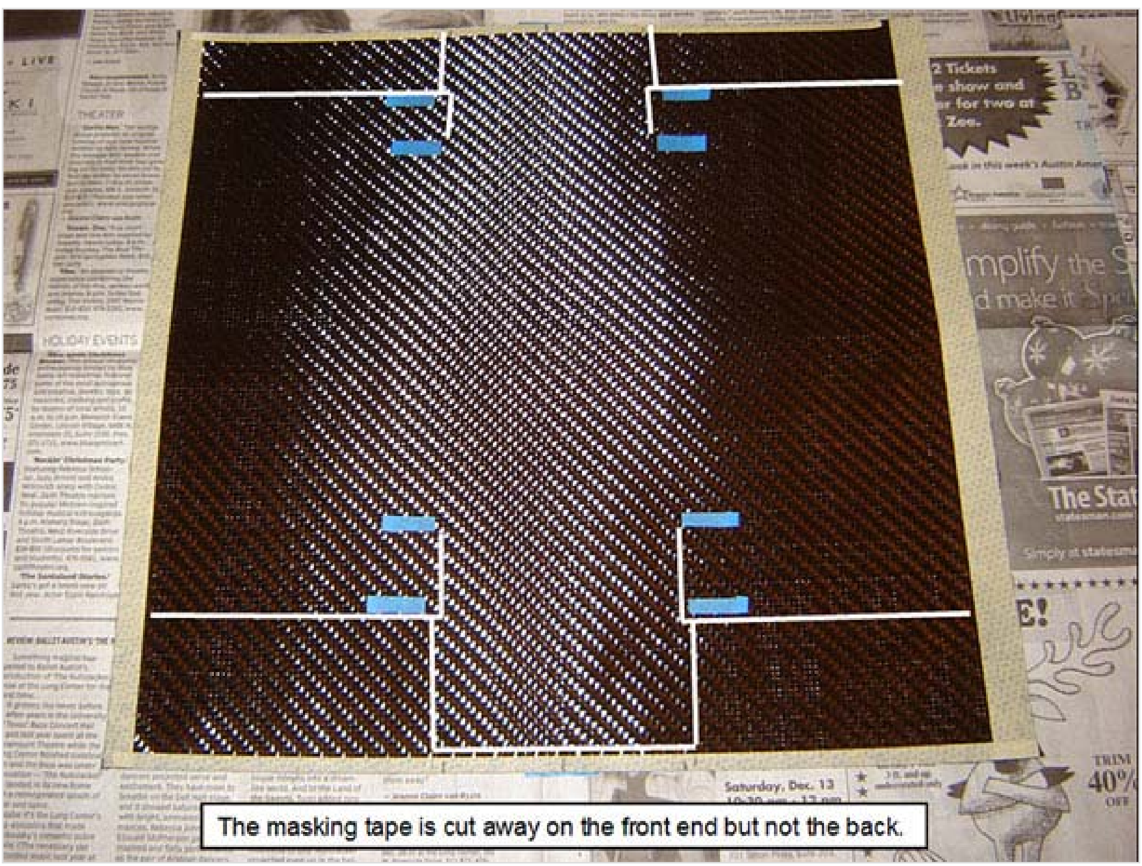
I use a little of the 3M 77 spray adhesive in the areas where I will cut the front seam and the fillet slits. This helps to keep the carbon from fraying. The adhesive can make it more difficult to wet out the carbon, and it probably reduces the quality of the bond. Therefore, I use as little adhesive as possible and I only apply it to the areas that can fray.



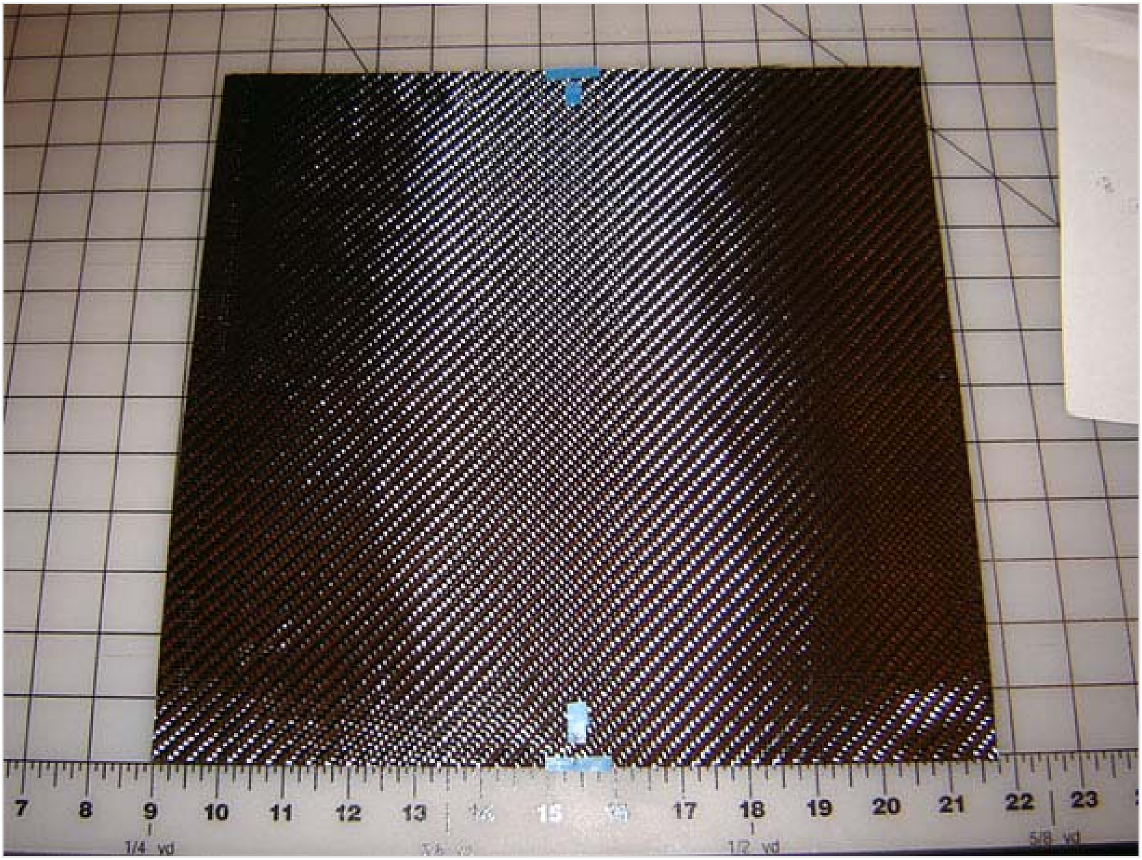
Here is a drawing of how the carbon will be cut. Note the slits, which are unfortunately necessary to fit the front and back of the fillets. The slits are 1/8” longer on each end than the fillet.



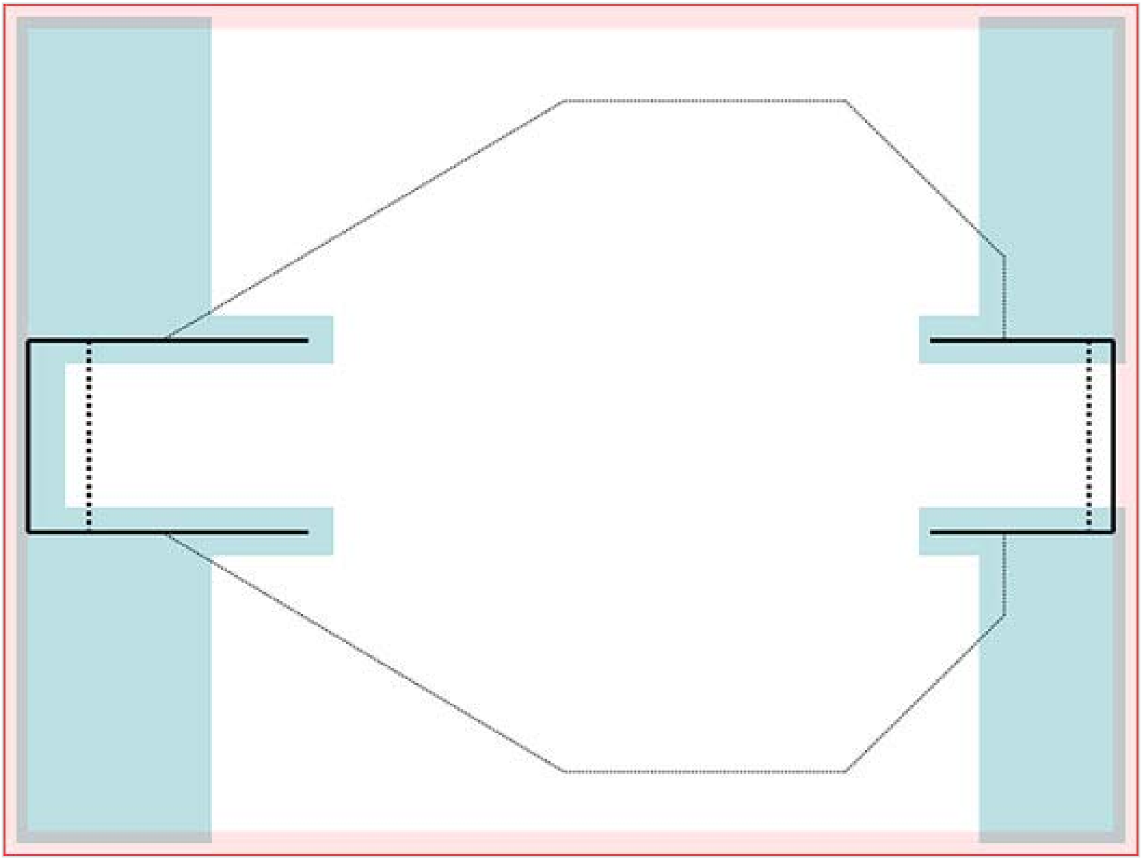
After marking the center location, I mark the width between the fins. For this first (of three) carbon applications, however, I'm going to cut the carbon that falls ahead and behind the fins a little wider and then trim it down to an exact fit later.



I'm using "sensitive surface" blue tape to mark how far up (or down) that I need to cut. Note that this is the underside of the carbon piece. I've drawn in the actual cuts that will be made here, just to illustrate where they will fall.

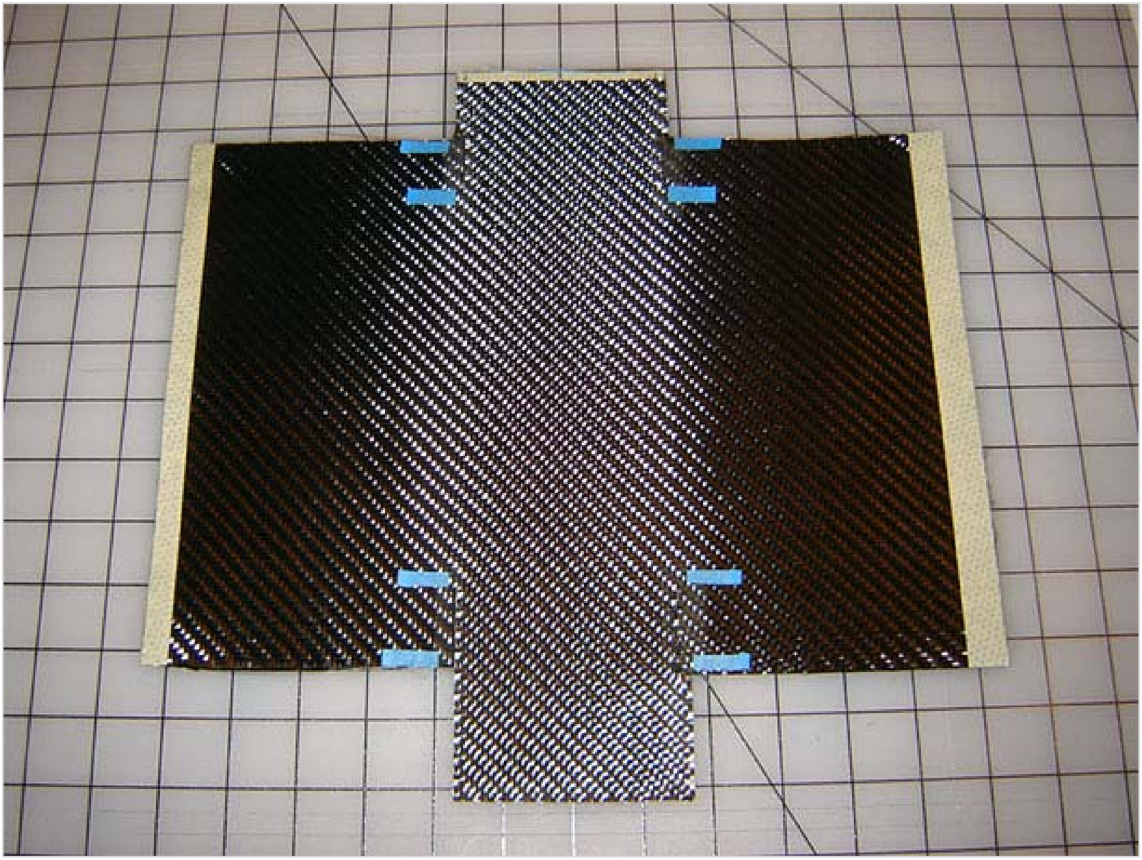


This is the top of the carbon piece. I'm marking the centerline so that I can position the piece.



When I cut the cloth, it will tend to fray. I use a very light coat of 3M 77 spray adhesive to minimize the fray. The shaded areas are the areas that I want to cover with the adhesive.

Here, I've used some newspaper pieces to block off the areas that I don't want sprayed with the adhesive. The approximate areas to be cut are marked.

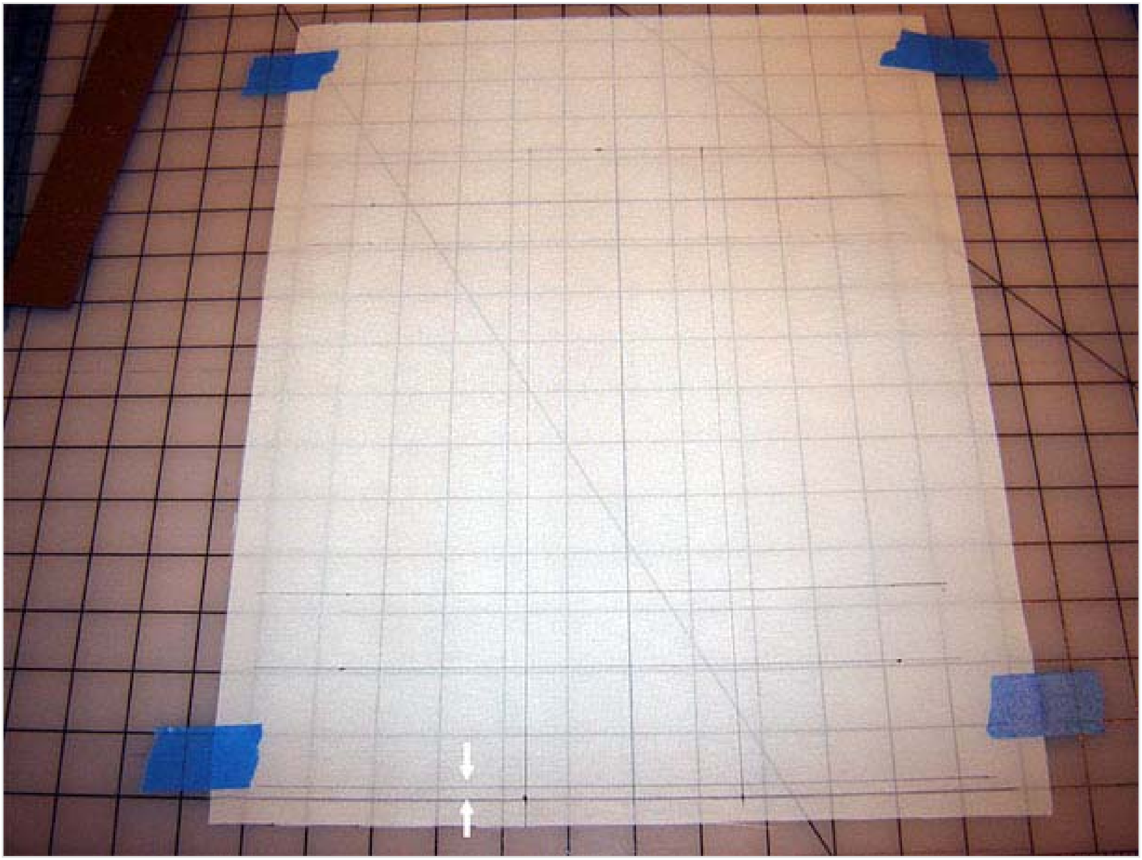


Here is the final piece ready to apply (after I remove the blue tape). The piece shown is actually the second of the two pieces, with the first just being a bit shorter.

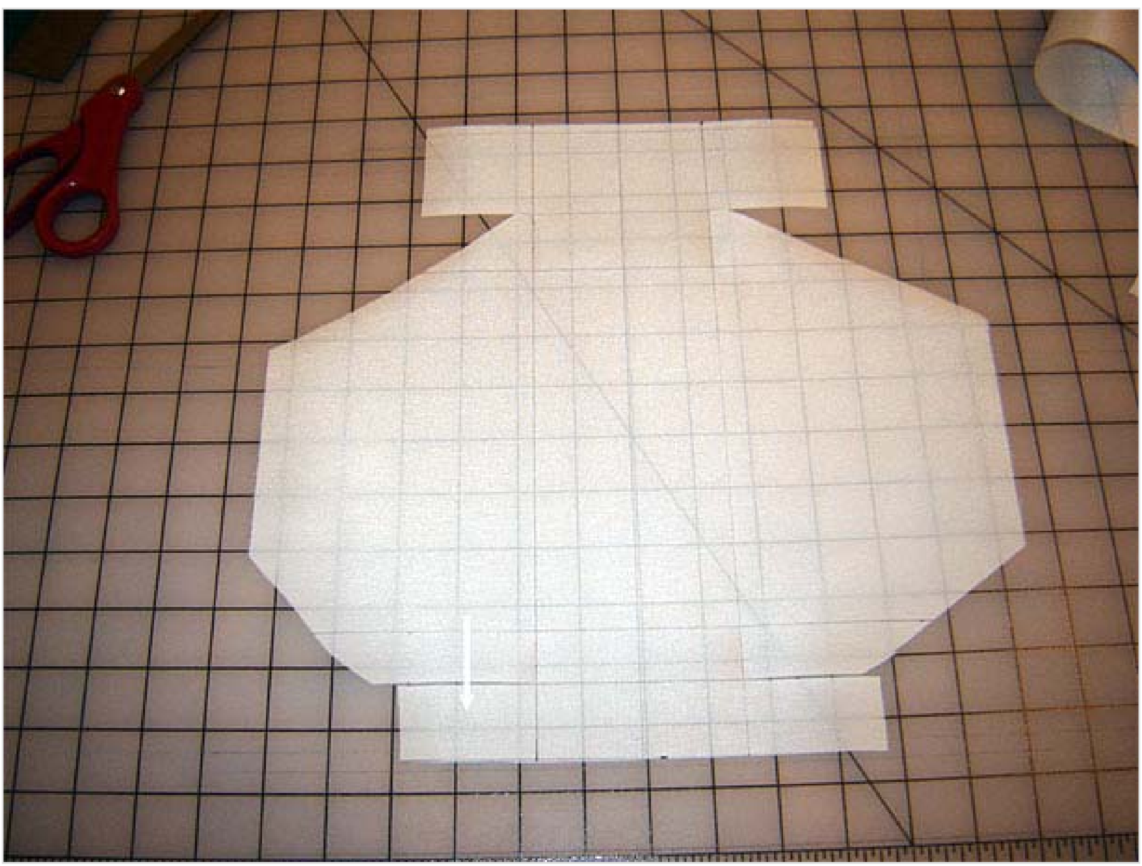
As was the case with the airframes, peel ply is the secret that makes the application successful. For this rocket, the peel ply is cut the same as the larger piece of carbon, except in two areas. First, I cut the peel ply about 1/4" longer at the top so that it overlaps the carbon onto the airframe itself. This will help to blend the tip-to-tip carbon into the airframe. Second, I leave "flaps" on the peel ply in the areas above and below the fins. These flaps will be used to hold down the carbon over the front and side seams. These flaps should be pulled firmly but not too tightly.

If the carbon and peel ply are cut accurately and centered on the tube, the actual application is easy. I usually have to work a bit to get the peel ply to lie down smoothly over the tapered portion of the fillet and around the tip of the fin. Sometimes, the peel ply has to be cut a little here and there. The tip of the brush is very helpful here.

As with the tubes, it is important to initially cure at low temperature (90F). If the temperature is above that, air bubbles can form below the peel ply that are very difficult to remediate.

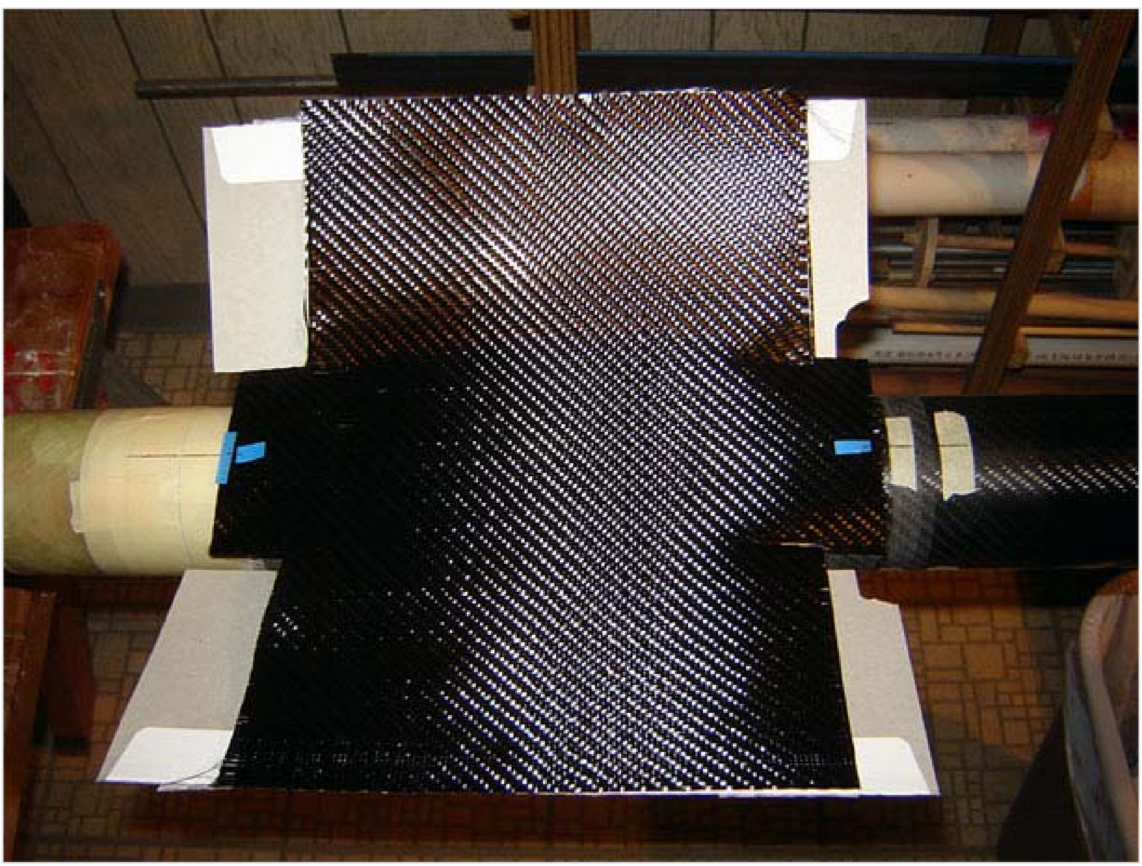


I will also cut the peel ply with the same general pattern. The peel ply is cut to extend about 1/4" past the top of the carbon.

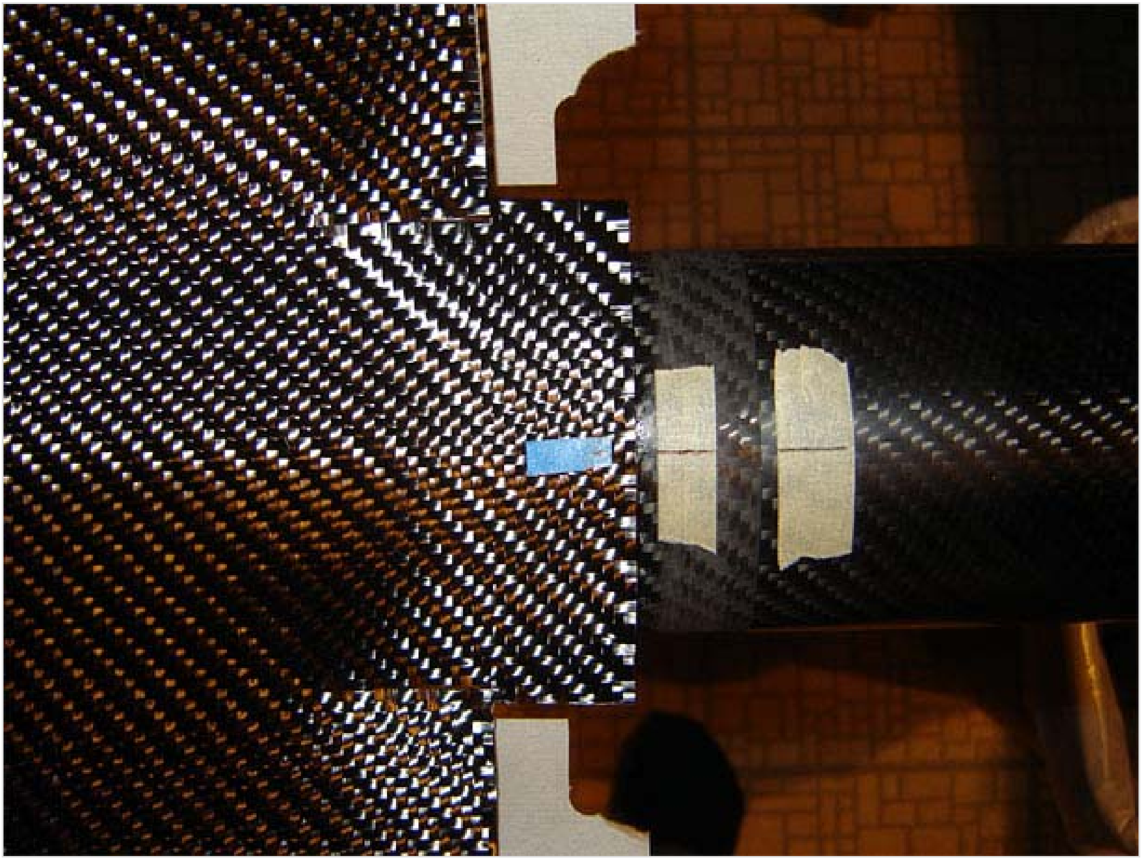


One additional difference is that I will leave this extra material ahead of and behind the fins. These "flaps" will hold down the carbon in these areas.

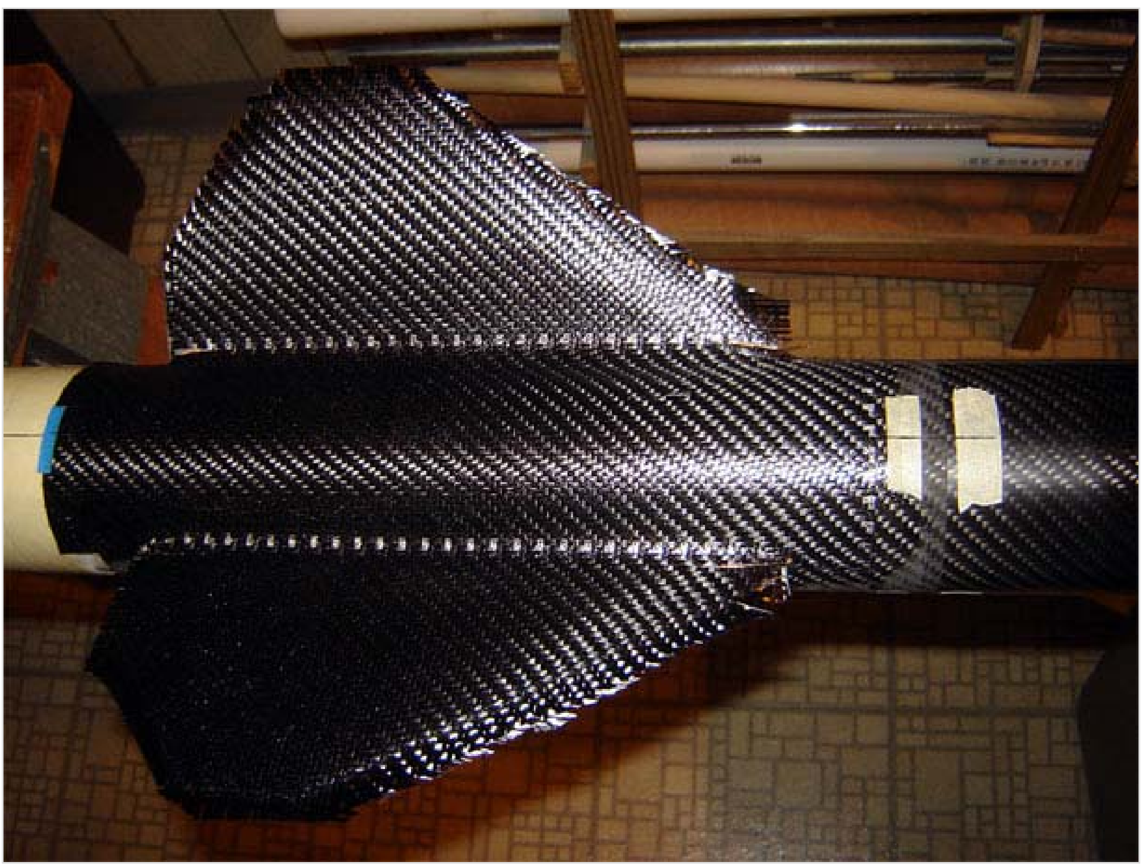
Here, I've applied the epoxy.



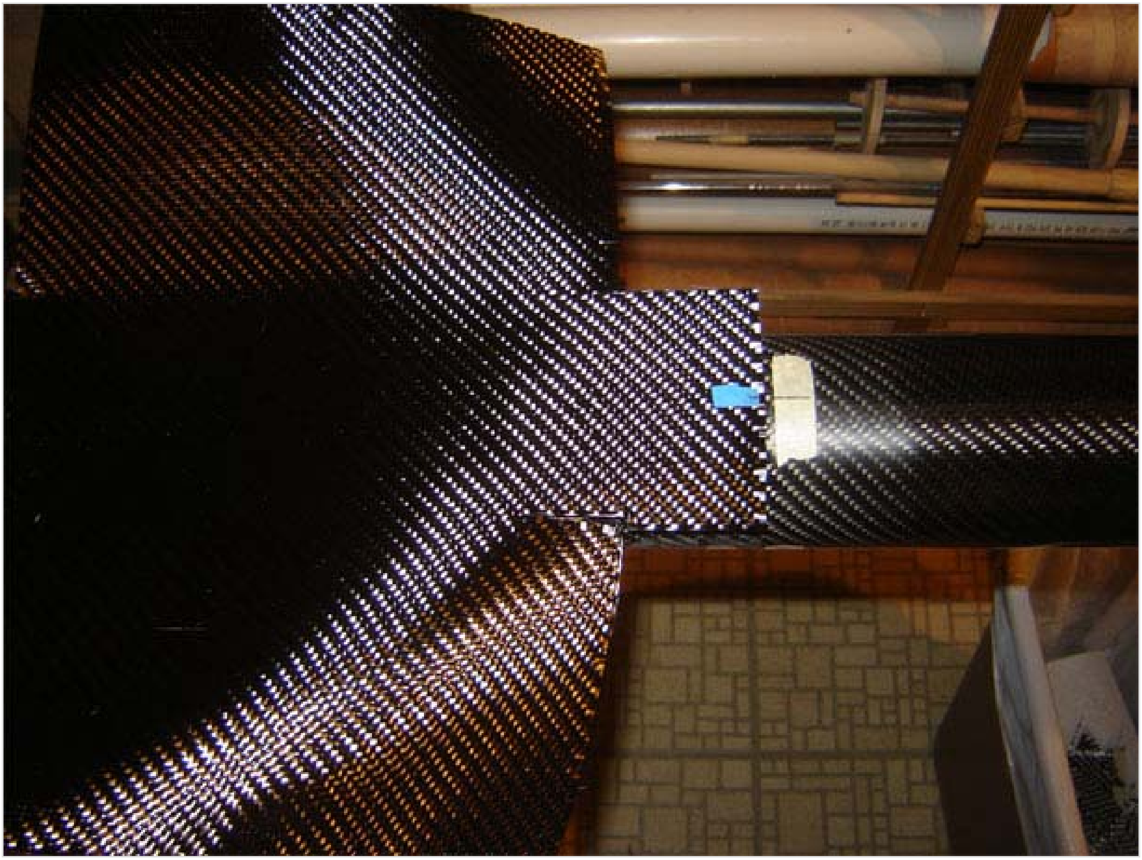
Here is the first piece. The front seam will go into the first groove that was cut before. The extra material makes it easier to keep the seam square.



Marking the centerline of the cloth and the tube is important for getting the cloth on straight.

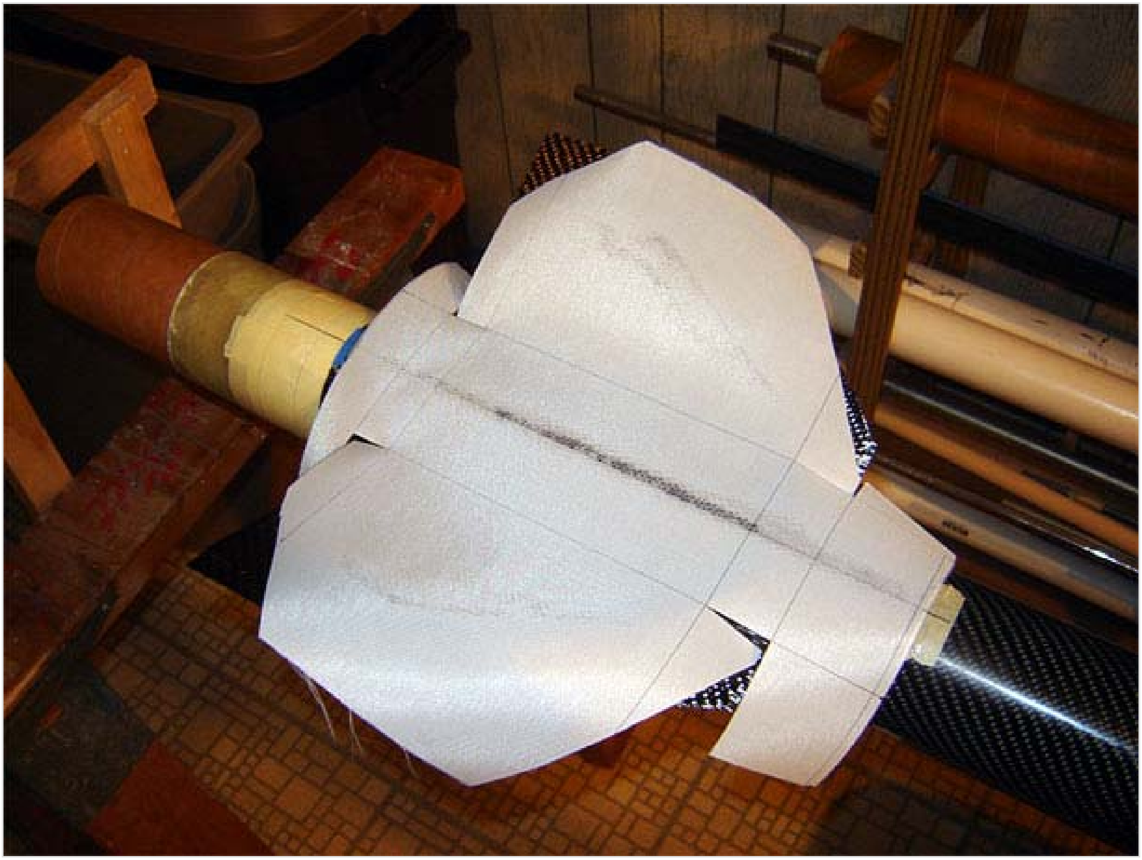


Here's the first piece glued into place.

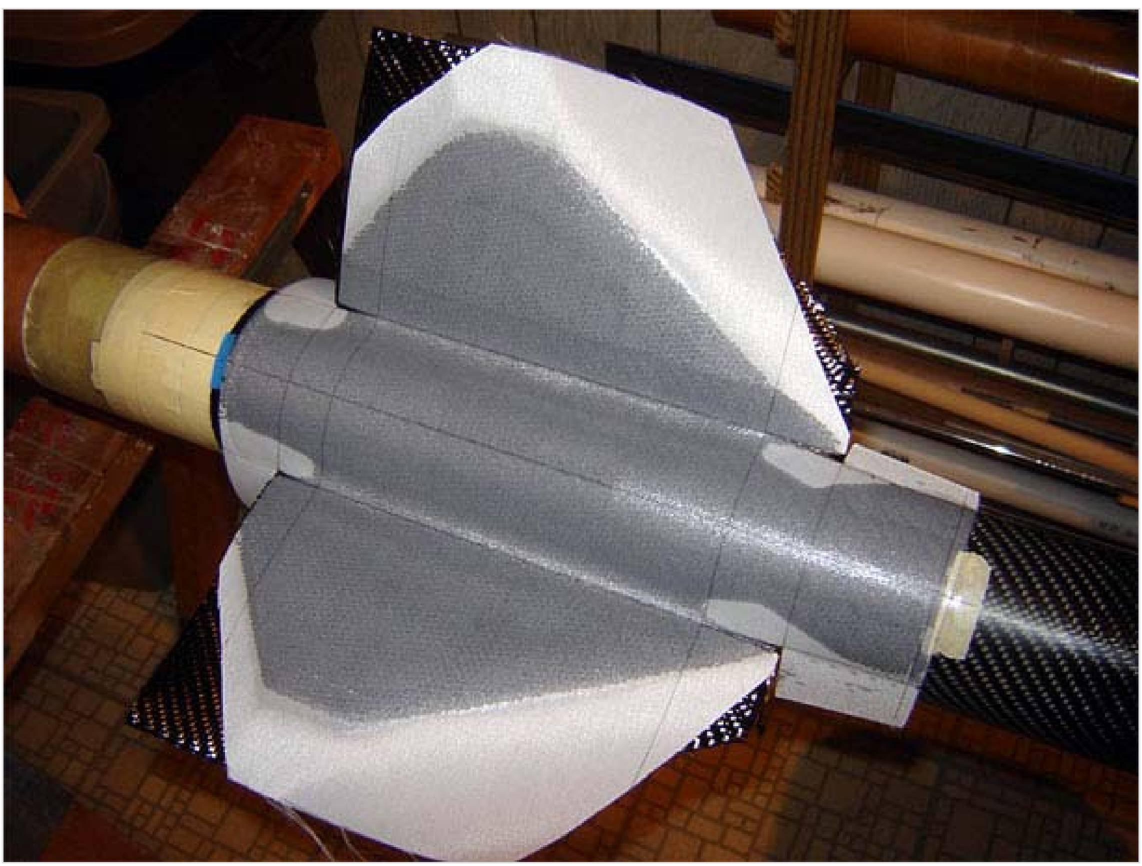


Here, I'm lining up the second piece of cloth. Again, the seam goes right up to the edge of the groove I cut previously.

I cut this first set of carbon a little wider at the top and the bottom. Here, the carbon extends a little beyond the tip of the fin.

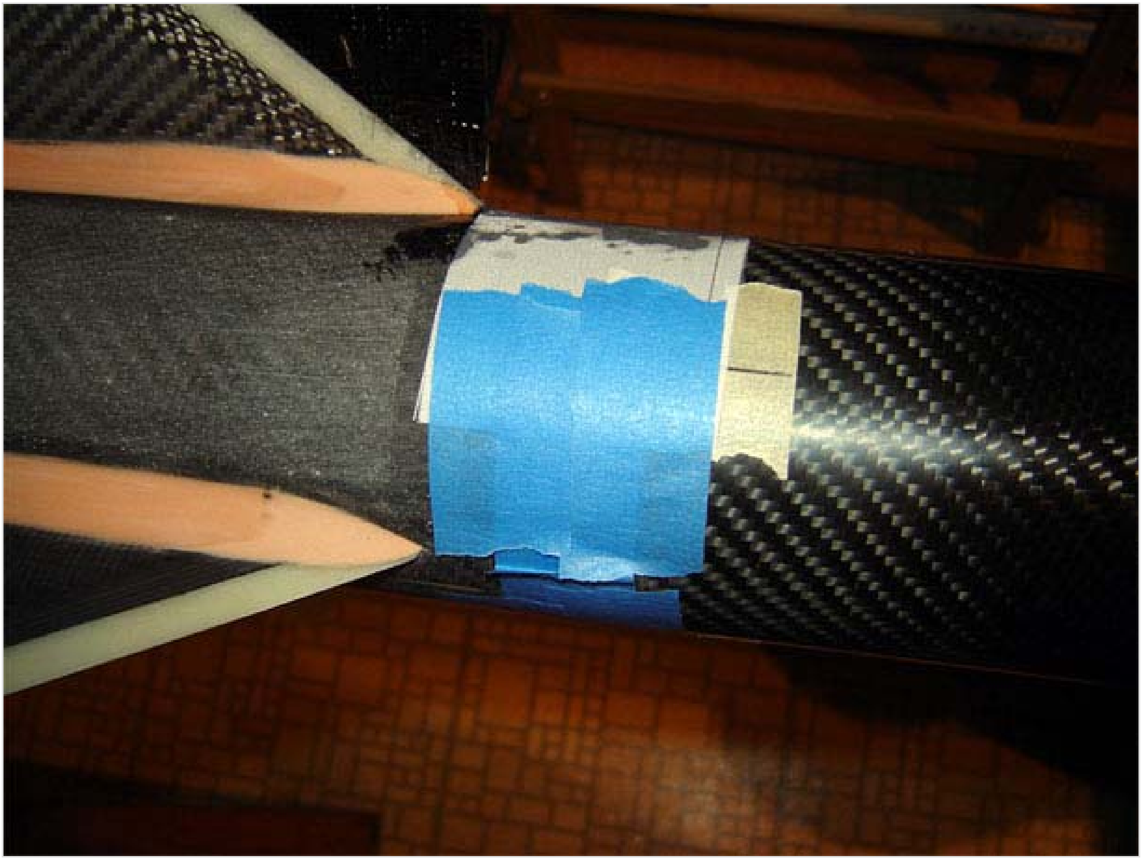


The peel ply is applied just as if it was a third layer of carbon. It extends 1/4” beyond the carbon at the top. Note the “flaps” on the peel ply that will help to hold the seams in place.



Here, I'm starting to wet out the peel ply. The areas around the front and back of the fillets always take a little work. The tip of the brush is useful here.

Here, I've taped the ends of the flaps around the tube to hold the seams down. Note how the slits are separated a little (which is why I had to slit the carbon and peel ply in the first place).

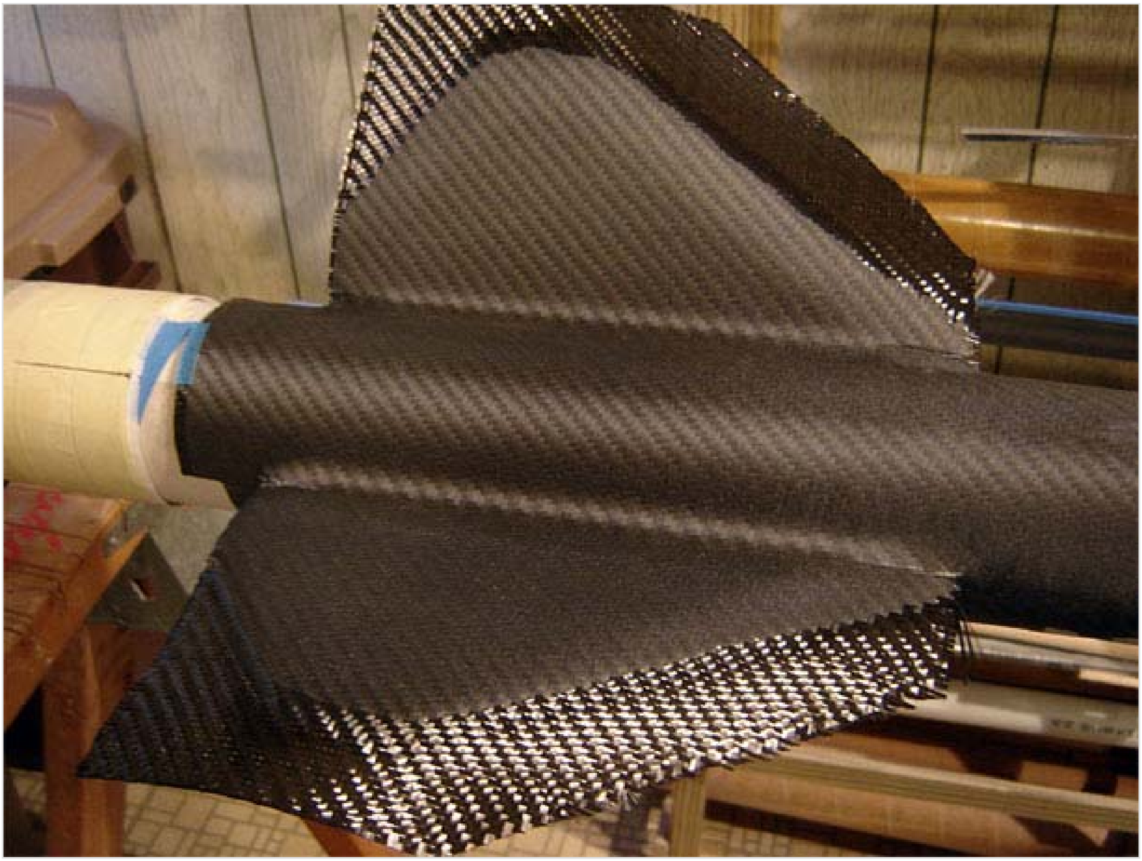


Here’s the tape holding the flaps tight. The idea is to have this hold the peel ply down firmly, but not too tight.

Here is the peel ply fully wetted out. As with the airframe itself, the idea is to remove the bubbles below the peel ply. This goes into the oven for an initial cure at no more than 90F.

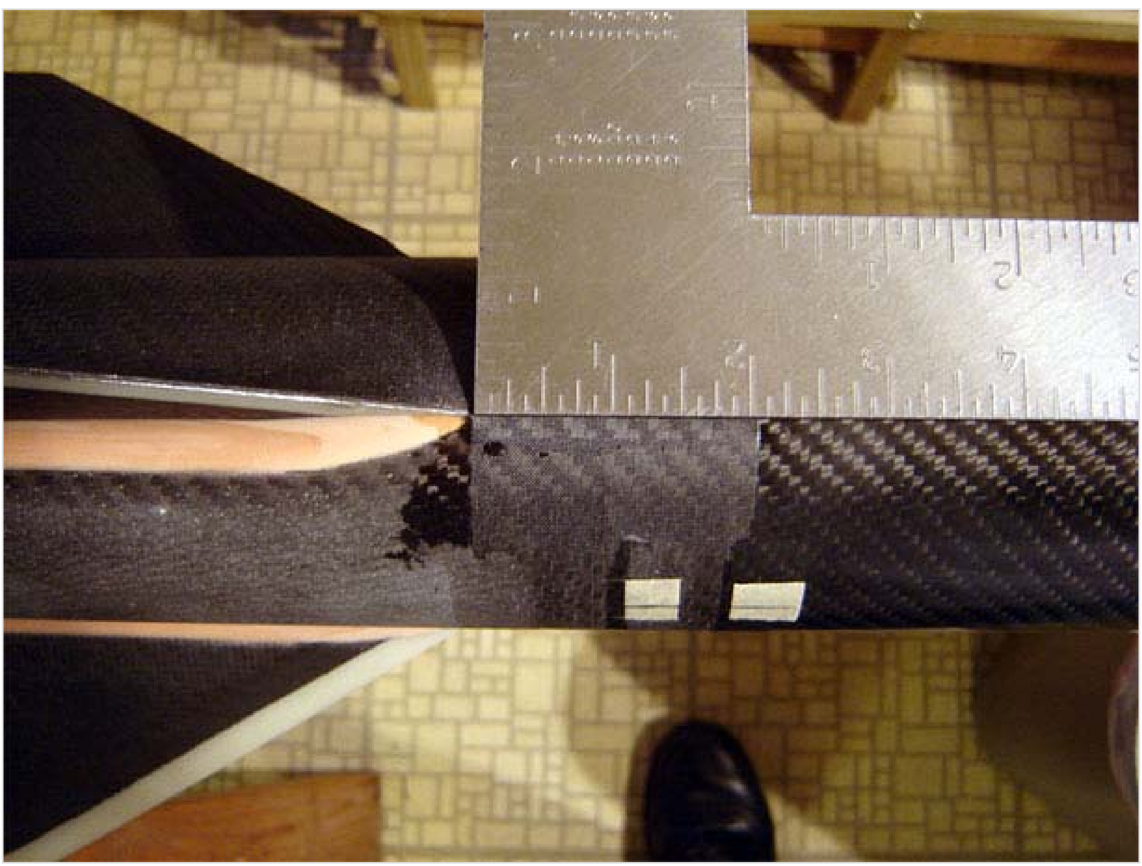
When I cut the first set of carbon pieces, I cut the portion that covered the airframe above and below the fins a little wider than the actual distance between the fins. I trim out the extra carbon while the epoxy is still a little soft. The idea is to restore this area to where it was before the first set of carbon was applied. Then, it's ready for the next set of carbon.

Once the seams are cleaned up, I like to apply a layer of epoxy over the peel ply finish as quickly as possible. As with the airframe, I don't sand the peel ply before I do this, because dust that gets into the peel ply finish won't come out. After that epoxy cures, I will clean up the edges of the fins in preparation for the next set of carbon pieces. For the side seams, this second set of cloth will be cut to match the seam from the first set of carbon. However, I'll cut the second set oversized on the other side and then trim it just as for the first set of carbon. For the third set of carbon, I'll cut it to fit the seams from the first and second sets and hope it fits!

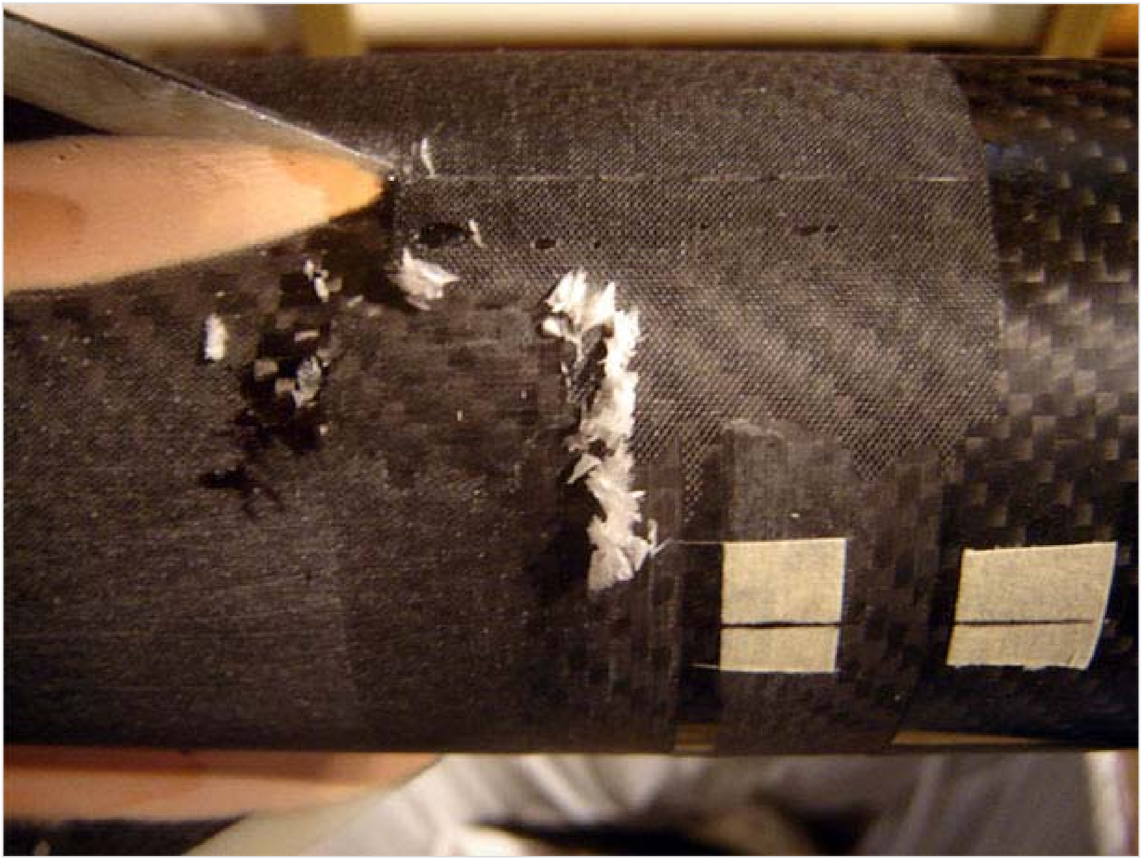


Here is the first section after removing the peel ply. Now is the time to remove extra glue and cloth before the epoxy gets really hard.

Here is one of the seams. Recall that the cloth extends past the end of the fin, and there is some extra epoxy below that. It's time to remove this extra material.

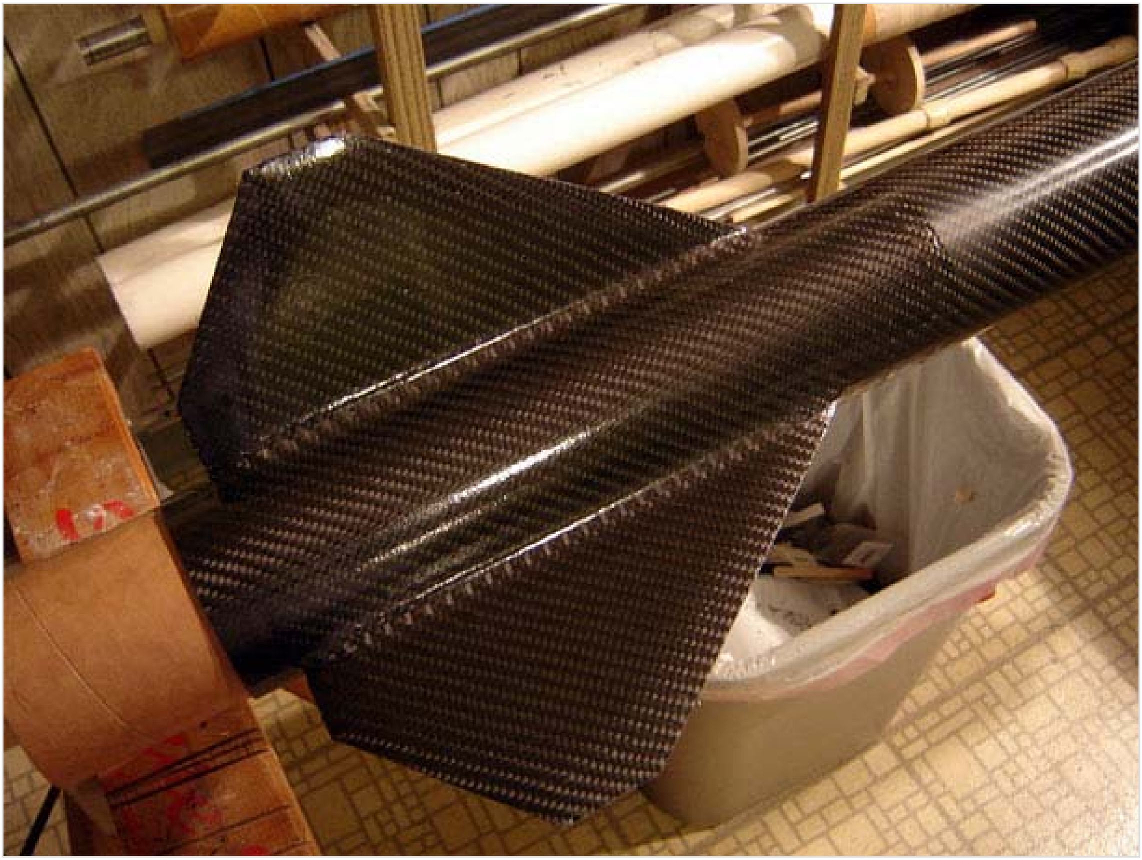


Here, I'm going to make a cut that is even with the end of the fin. A square will help to make this cut as even as possible.

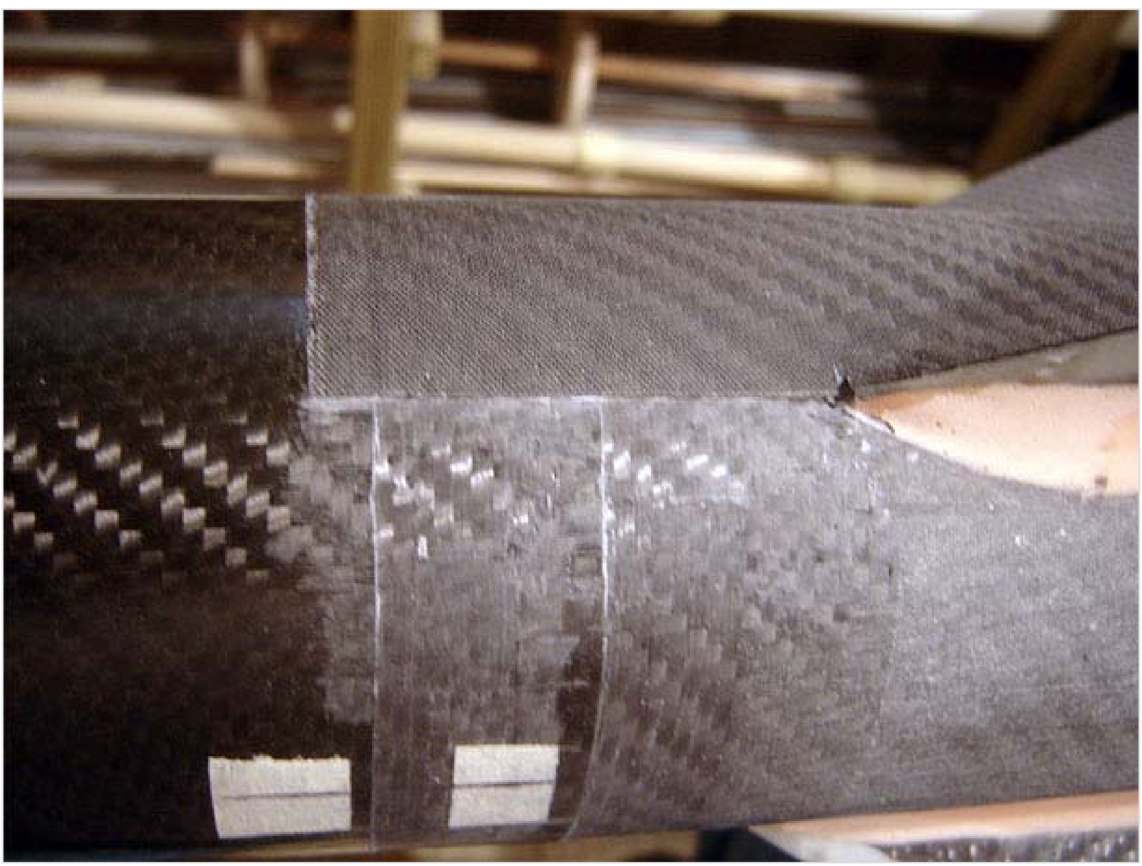


I just use the tip of a knife to remove the new epoxy and the one and two layers of carbon up to the cut point. This step is best done just after the epoxy is initially cured.

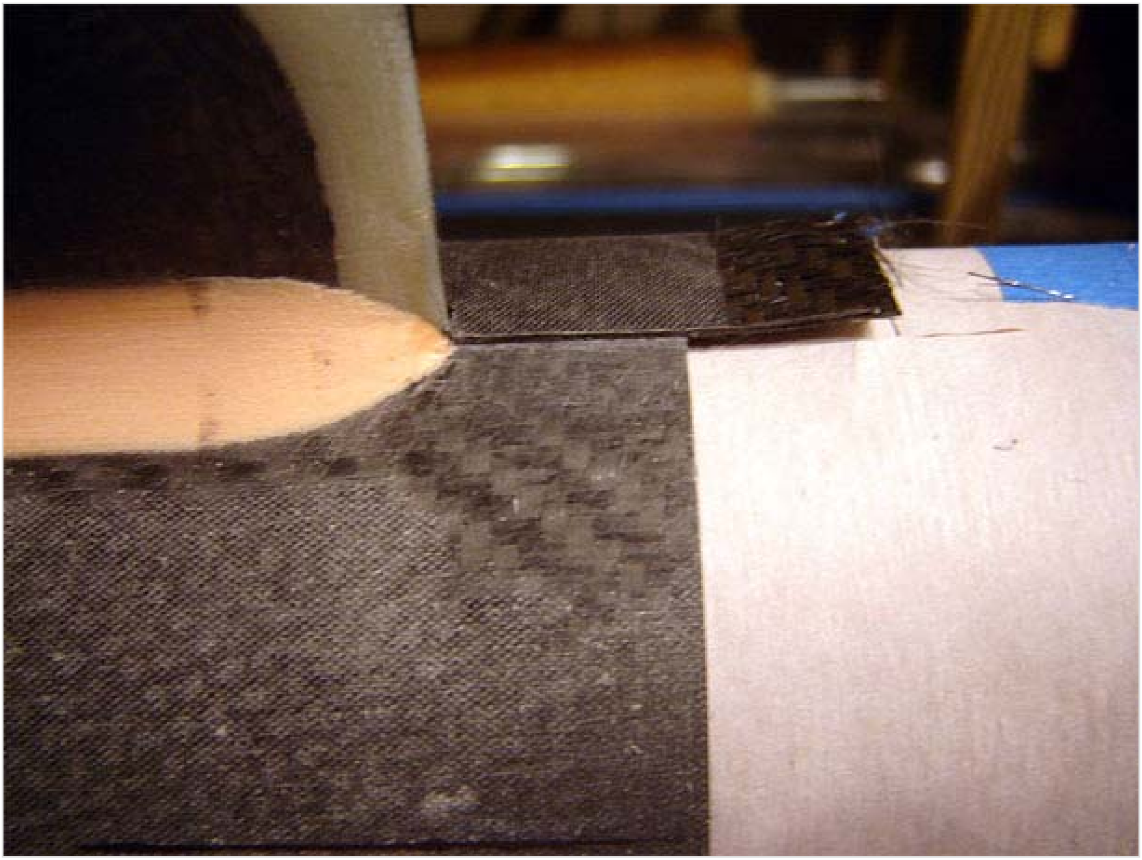
Here's the cleaned-out seam area. For the second set of carbon pieces, I will cut one edge to fit against this new seam, and I'll leave the other side a little over-sized and then trim it just like this.



With all four seams finished, I will apply a coat of epoxy to seal up the small holes in the peel ply.

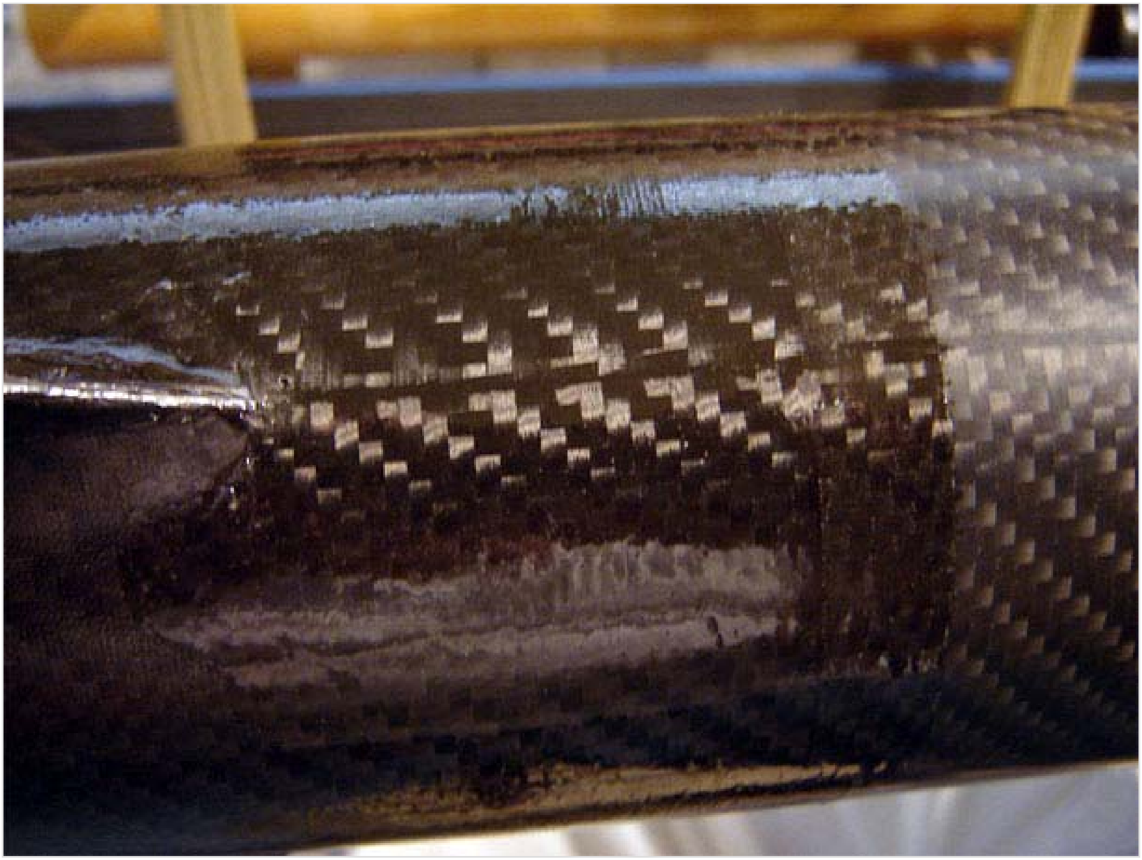


Here is the seam from the second set of carbon after cleaning out the glue. It's ready to accept the third set of carbon pieces.



And here is what the aft seam looks like.

Here, I'm measuring the exact distance between the seams for the third set of carbon pieces. These pieces must be an exact fit on both sides.



Here is the seam between the first and second sets of carbon. It turned out quite well (actually, all six seams, as well as the top seams, turned out well).

Final Steps

Well, all six of the tip-to-tip pieces are installed and they turned out great. As always, this is by far the most difficult part of the process. Now, it's time to finish the fin section to match the airframe. Most of the fin section will be finished using the same process that was used to finish the airframe. This involves applying six coats of epoxy (5 additional coats) and then sanding most of it off and ending with 320 grit sandpaper. Then, as with the airframe, two wipe-on coats of epoxy will be used to fill the scratches, and this will be followed by wet sanding to 1000 grit and polishing with 3M Finesse-It II polish. The wipe-on epoxy approach really saves a tremendous amount of work!

There are a few areas of the fin can that will take a little extra work. One area is where the carbon at the tapered parts of the fillets was slit. There are gaps in these locations (12 total) that simply need to be filled up with epoxy and then sanded smooth.

It is also necessary to blend in the top seam of the carbon to the airframe. As I apply the six coats of epoxy to the fin can, I'm going to go up a little higher on the airframe (about 1/4") with each coat. The first of the 5 remaining coats of epoxy will terminate about 1/2" above the top of the tip-to-tip carbon. Since I'm going to apply 5 coats of epoxy in total, the last coat of epoxy will end 1-1/2" above the carbon. Therefore, I'm going to lightly sand the airframe up to the point.

When the above process is completed, the tip-to-tip seams will be coated with quite a bit of epoxy, so it should be possible to just sand it flat without getting into the carbon at any point. In past efforts, some epoxy fill has been needed in this area to get things flat, either because the top seam is lying above the airframe or due to a bump resulting from the seam of the first layer of carbon. However, in this case, the seams worked out very well (the combination of the grooves and the application of the peel ply to a point above the top of the carbon pieces seemed to do the trick).

At this point, all of the tip-to-tip carbon has been applied and one coat of epoxy has been applied over the peel ply finish to fill the holes in the peel ply weave. Now I can go ahead and sand down the edges of the fins. They all turned out great with no areas where the cloth was separated from the edge.

I'll also go ahead and lightly sand the entire area after the first epoxy coat. Note how I've sanded 1.5" above the seam area so that I can taper the seam into the body tube.

All 12 of the slit areas will need just a little epoxy fill.

And here is how things look after applying the second of six epoxy coats.

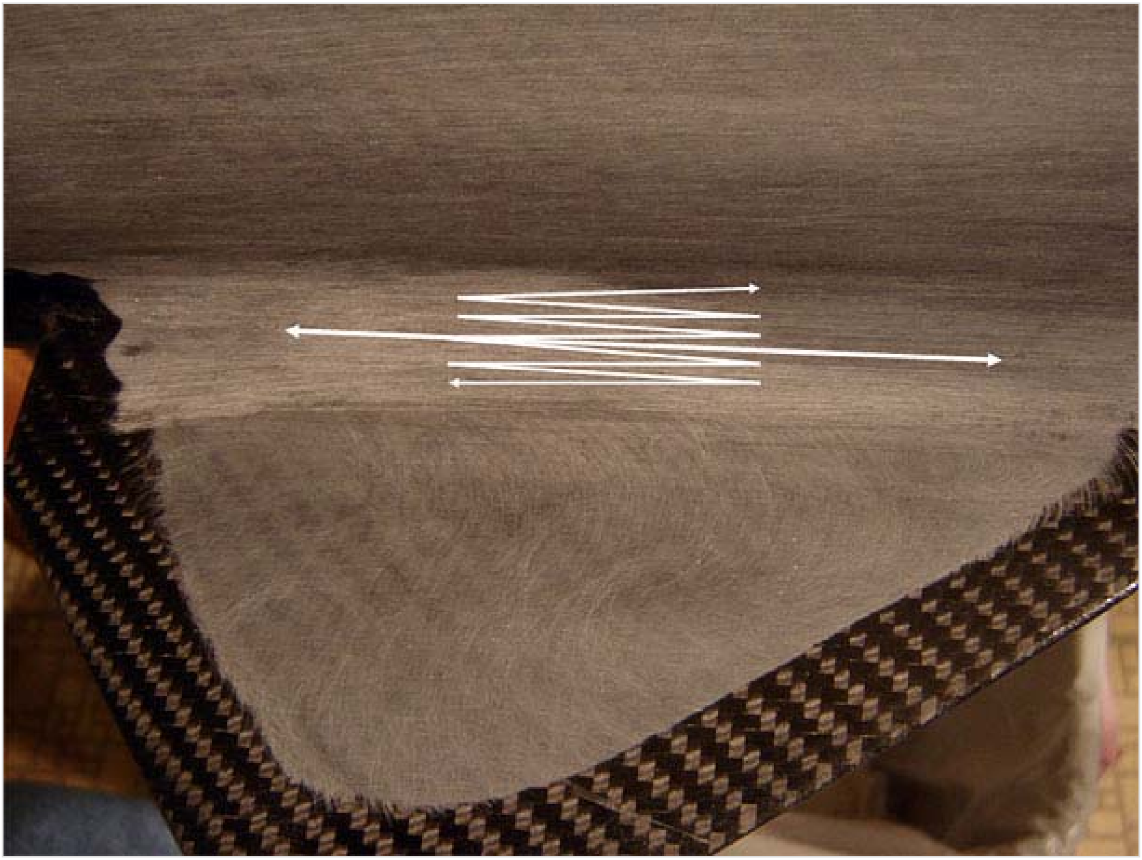
And here is how things look after applying all six epoxy coats. Note that each coat finished higher on the airframe, and the last coat finished just above the sanded area.

I start the sanding process by sanding the main area of each fin flat. I go far enough to remove most of the low spots on the fins (i.e., no shiny areas). Typically, there is an area near the fillet that is low for some reason.

I do not try to sand this area flat along with the fin area – that just results in sanding into the carbon.

Here, I sanded the body tube using a sanding block. It turned out completely flat. The secret to this was the light sanding of the original airframe (see pages 102 and 103).

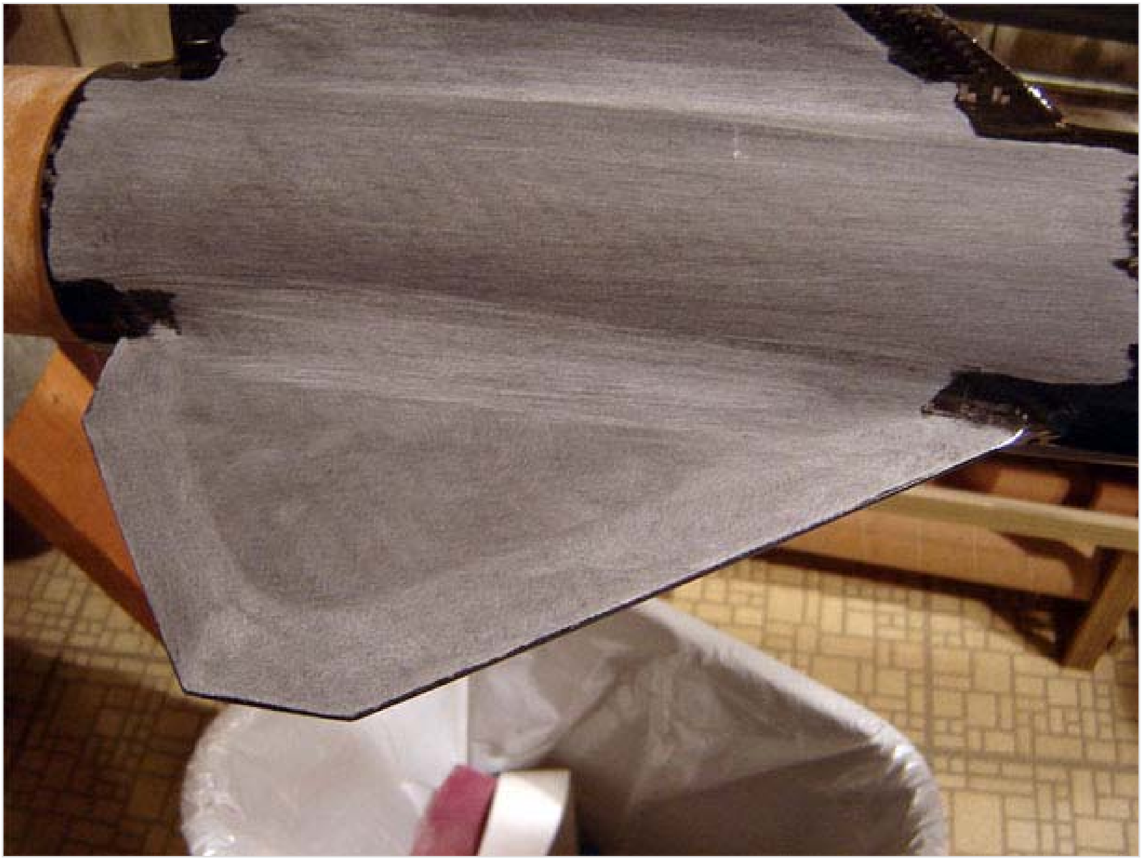
To sand out the fillet area, I used a 0.80” dowel. Recall that the original Aeropoxy light fillet was sanded with a 0.93” dowel, so that 0.80” dowel is slightly undersized. The technique is to sand in the “crotch” of the fillet and then use the dowel to sand outward to the fin and to the body tube. The approach creates a smooth transition in each direction.



The drawing illustrates the dowel sanding motion that I have found works the best (i.e., sand the fillet area itself and then work outward in both directions). I don't worry about the scratches in the finish. As with the airframe, these will be filled with thin coats of epoxy later on.

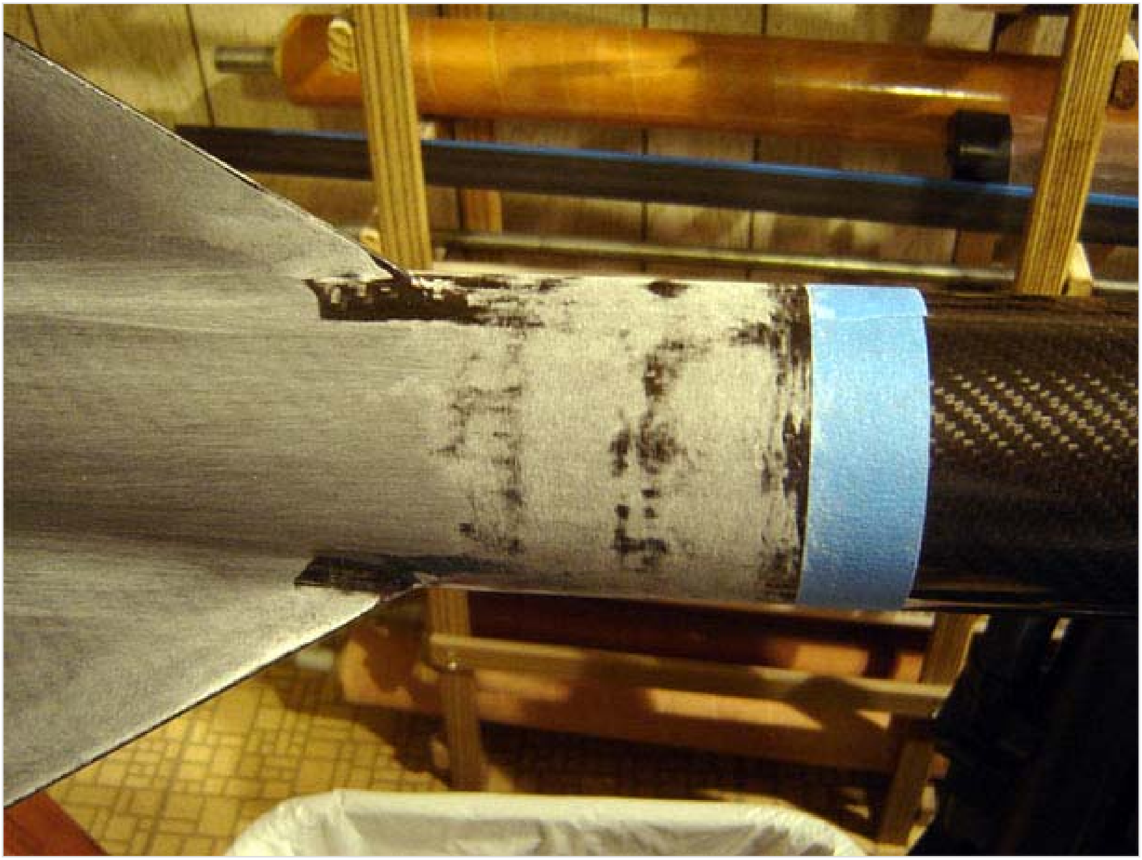
Sometimes, there are some low areas that can't be sanded flat with the dowel. It is easy to accidentally sand into the carbon in the fillet, particularly at the point where the slits terminated. It is better to spot sand rather than continue to sand the entire fillet.

I spot sanded the low areas in the previous picture using the end of a slightly smaller dowel. It is better to do this then to take a chance of sanding into the carbon.

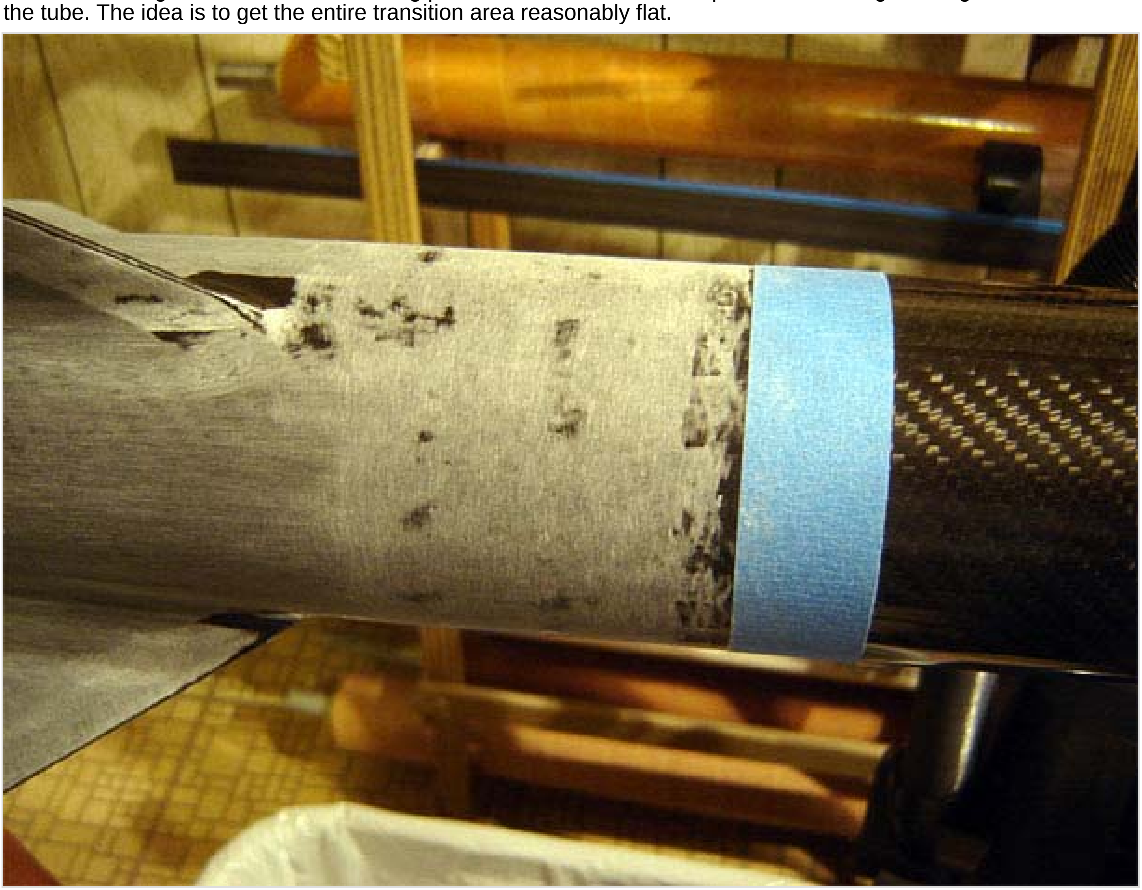


Next, I sanded the tapered areas around the perimeter of the fins. This was very easy to do and went quickly.

At this point, it's time to sand down the seam areas above the fins. The application of the tip-to-tip carbon went pretty well, so with the six layers of epoxy added, I should be able to sand this area flat.

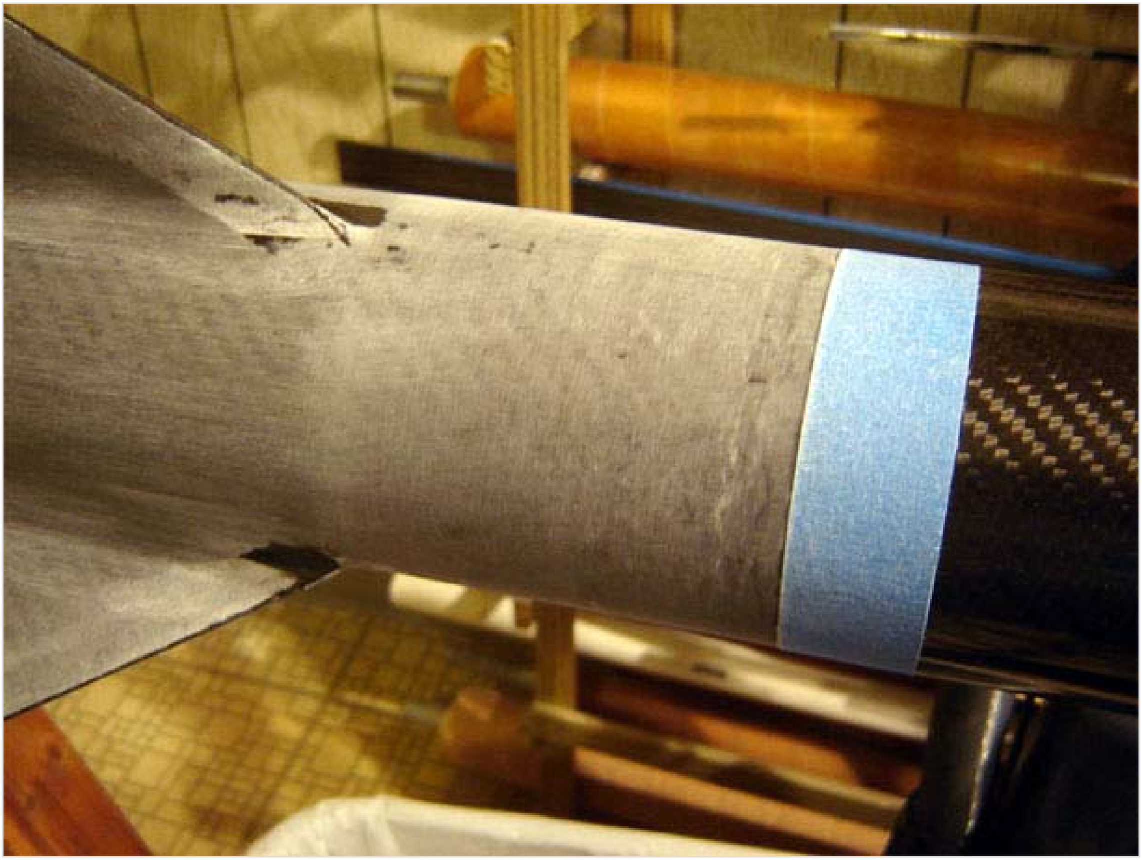


I used a sanding block to start the sanding process. I moved the block up and down using a rolling motion around the tube. The idea is to get the entire transition area reasonably flat.

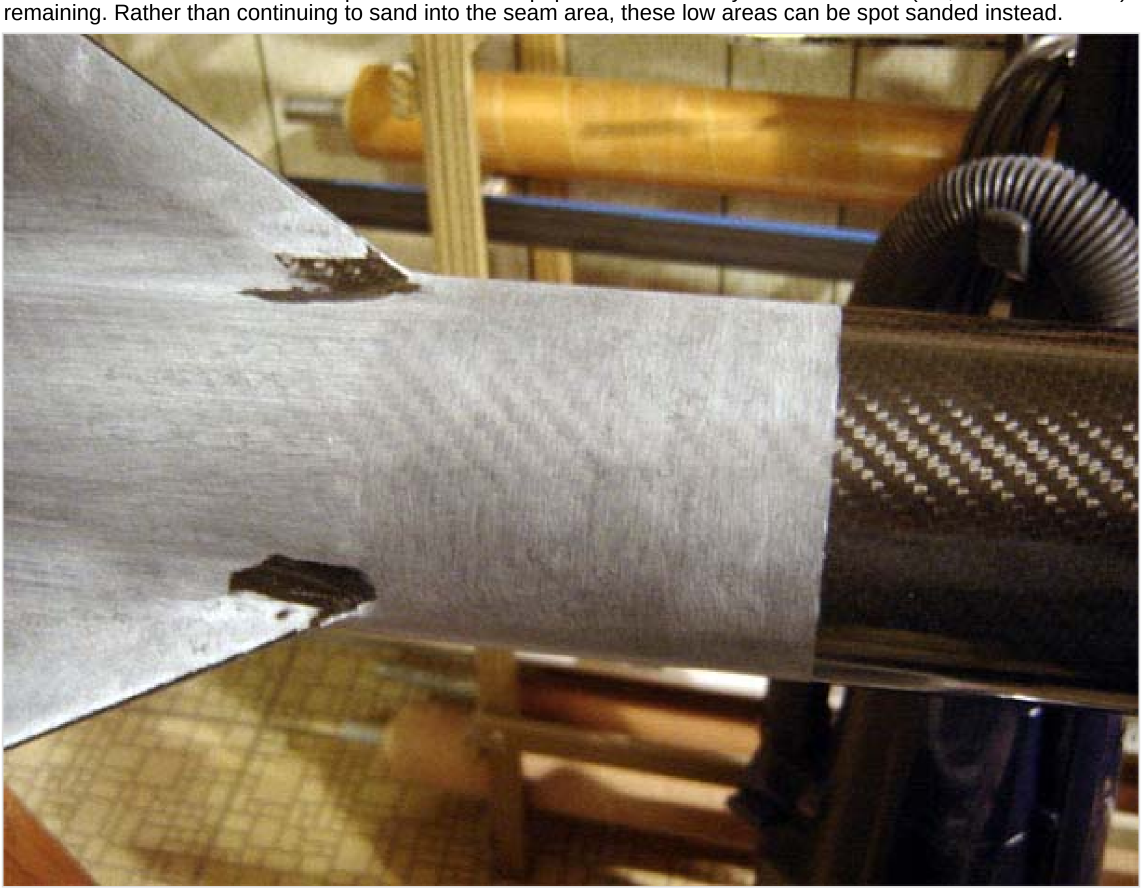


Here is the result after a second pass with the sanding block. This is by far my best effort!. It's the result of the grooves that were sanded into the tube, the use of the peel ply in the tip-to-tip procedure, and layering the six layers of epoxy up the airframe.

I got the tube sanded as flat as I was willing to do with the sanding block. Now, I’m going to use a thin piece of sand paper to sand out the remaining low areas.

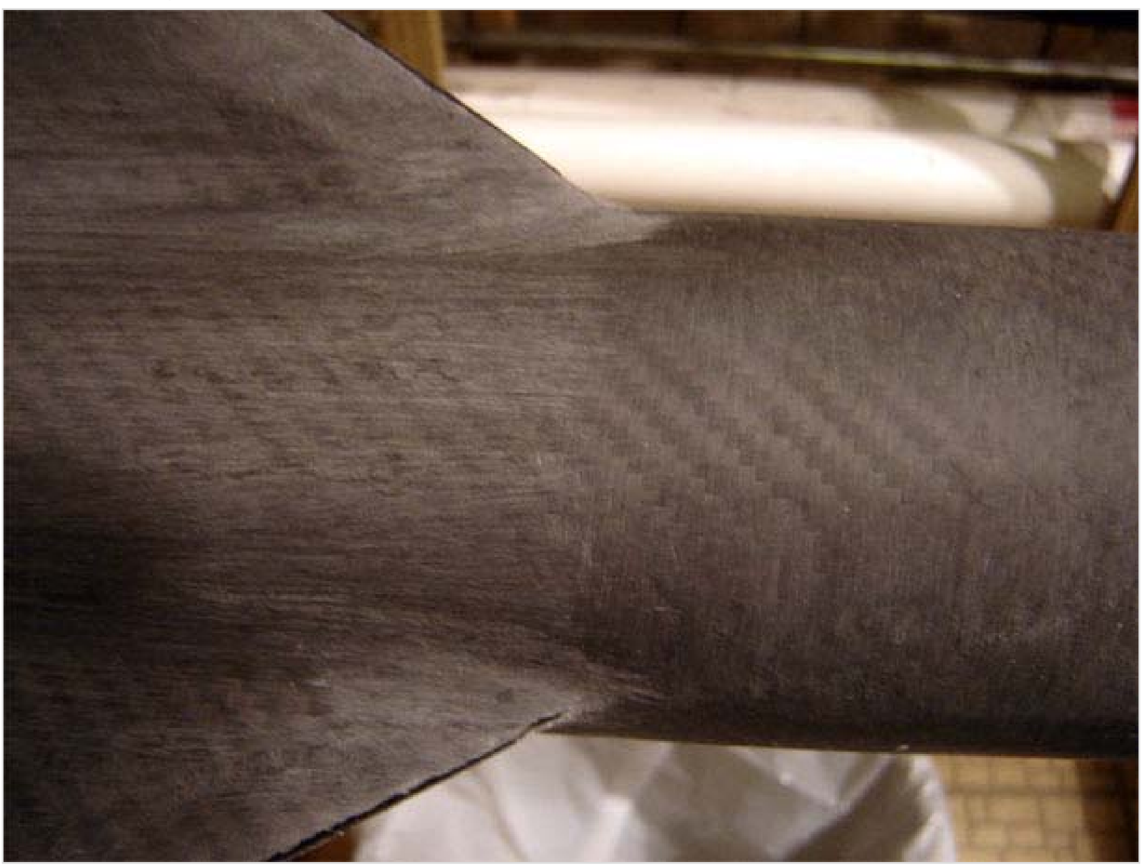


Here is the result after the second pass with the sandpaper. There are only a few low areas (i.e., unsanded areas) remaining. Rather than continuing to sand into the seam area, these low areas can be spot sanded instead.



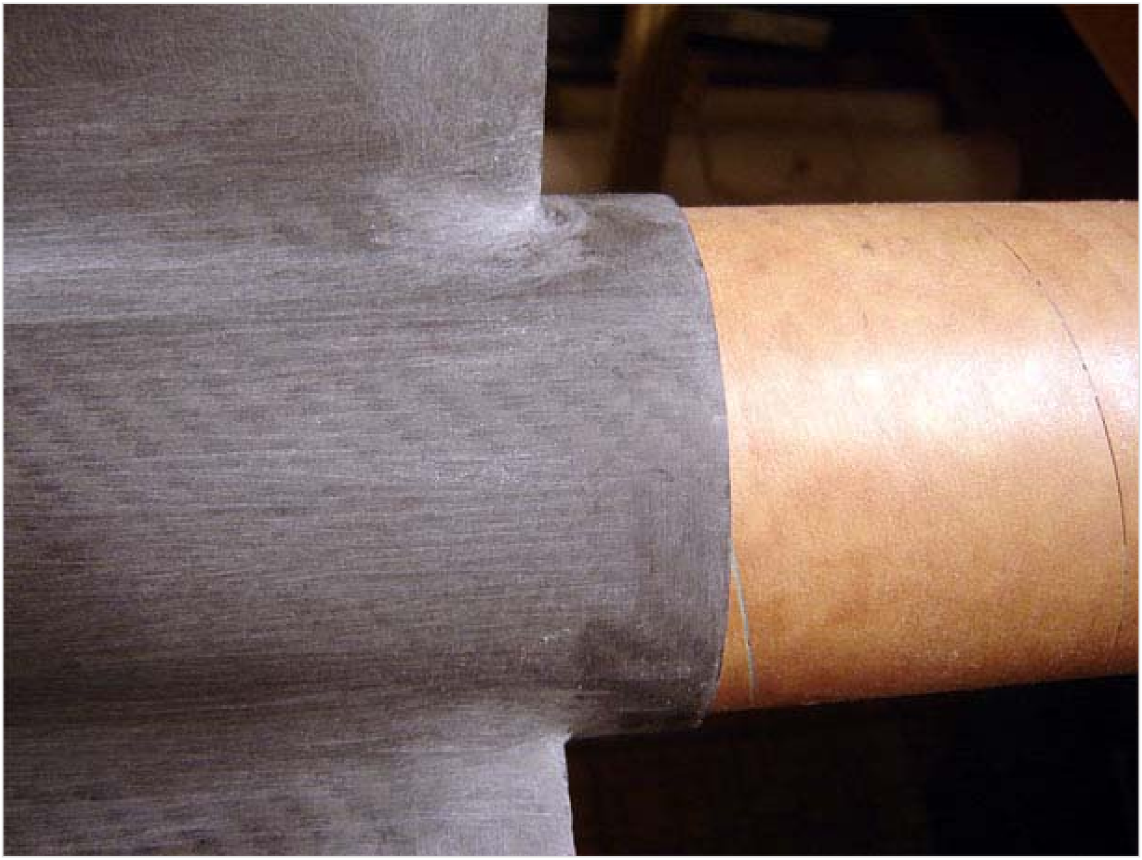
After a little spot sanding, there are no imperfections remaining. This is as good as I can do.

The same basic process is used to sand the aft end of the airframe below the fins.

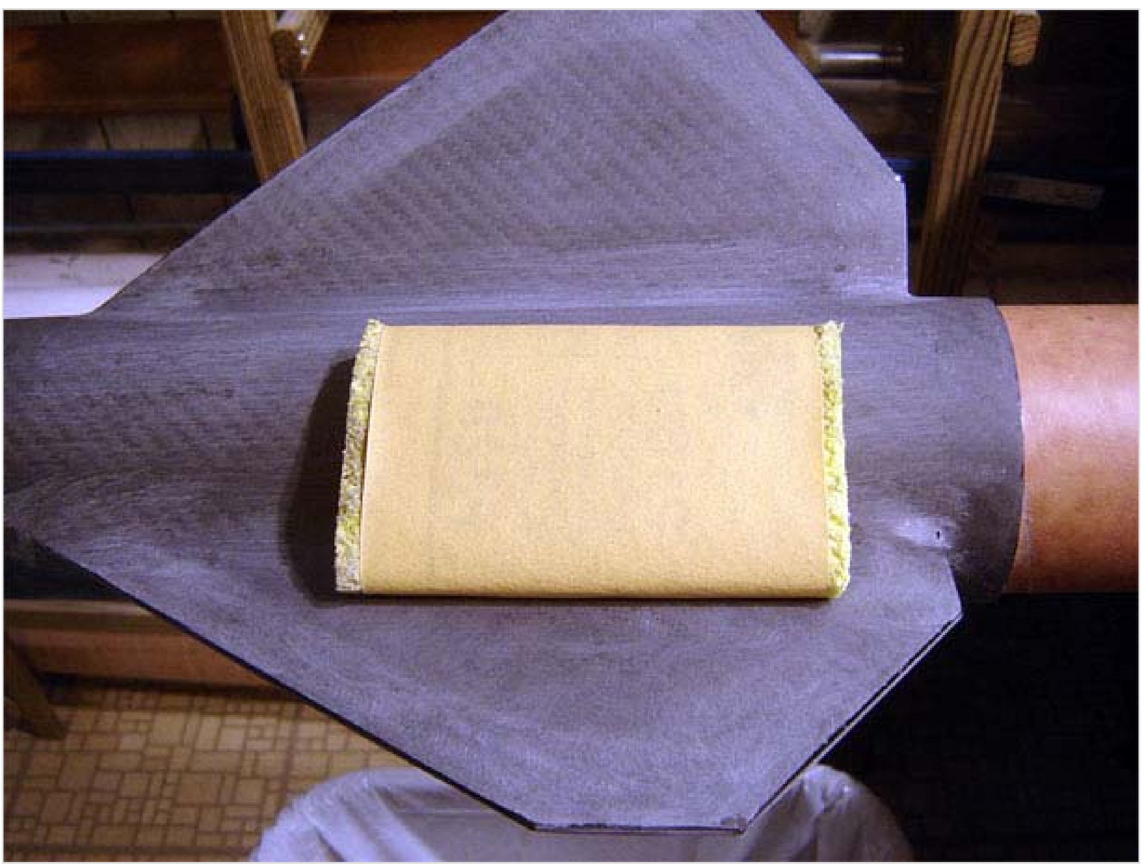


Last, the fillet transitions need to be sanded. I used a set of dowels with 180-grit sand paper. The smallest dowel was about 1/8”. This turned out to be very easy

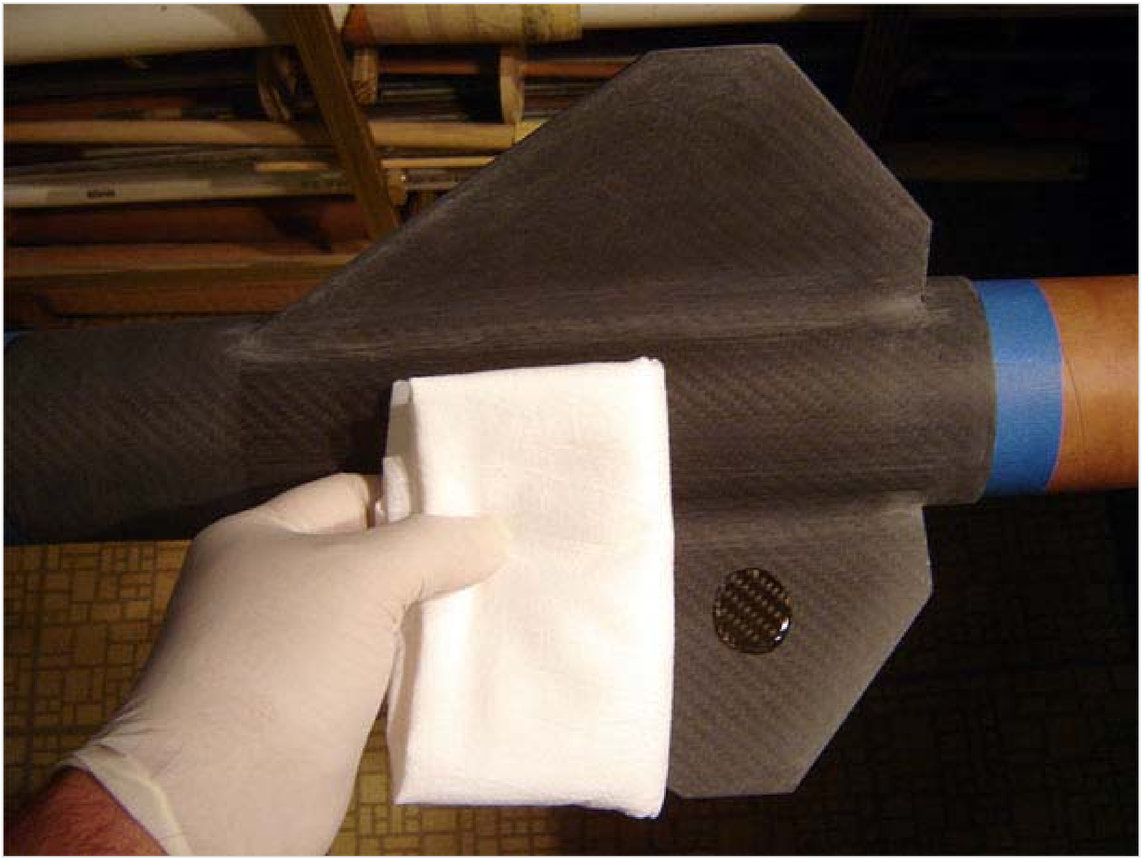
The secret to making the fillets easy to sand down is accurate sanding of the Aeropoxy Light fillets and accurate cutting and positioning of the tip-to-tip carbon and the peel ply. If everything is positioned correctly, it is then easy to sand flat. Here, I’ve lightly sanded the fin edges flat to help in smoothing out the transitions around the fin. This doesn’t need to be perfect because the fin edges and the transition area will later be covered with Contronics epoxy.



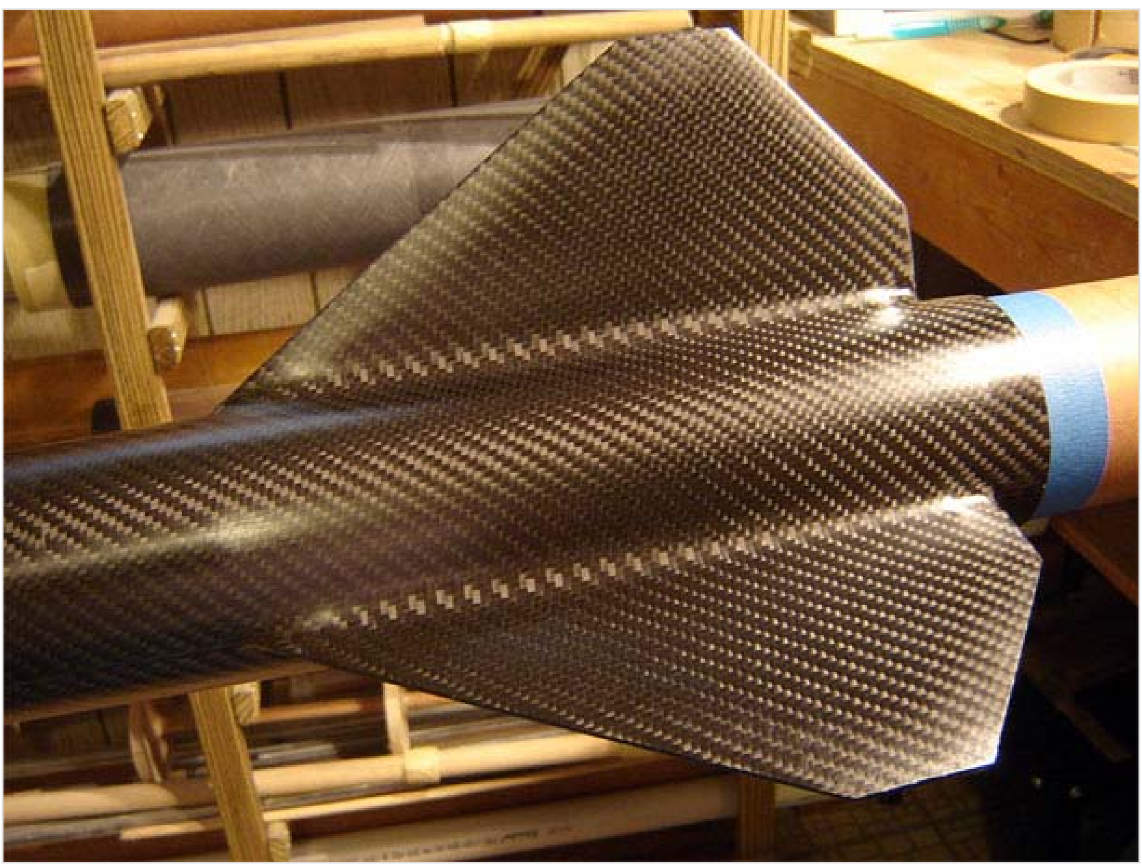
The same basic process is then used to sand the fillet transitions behind the fins.



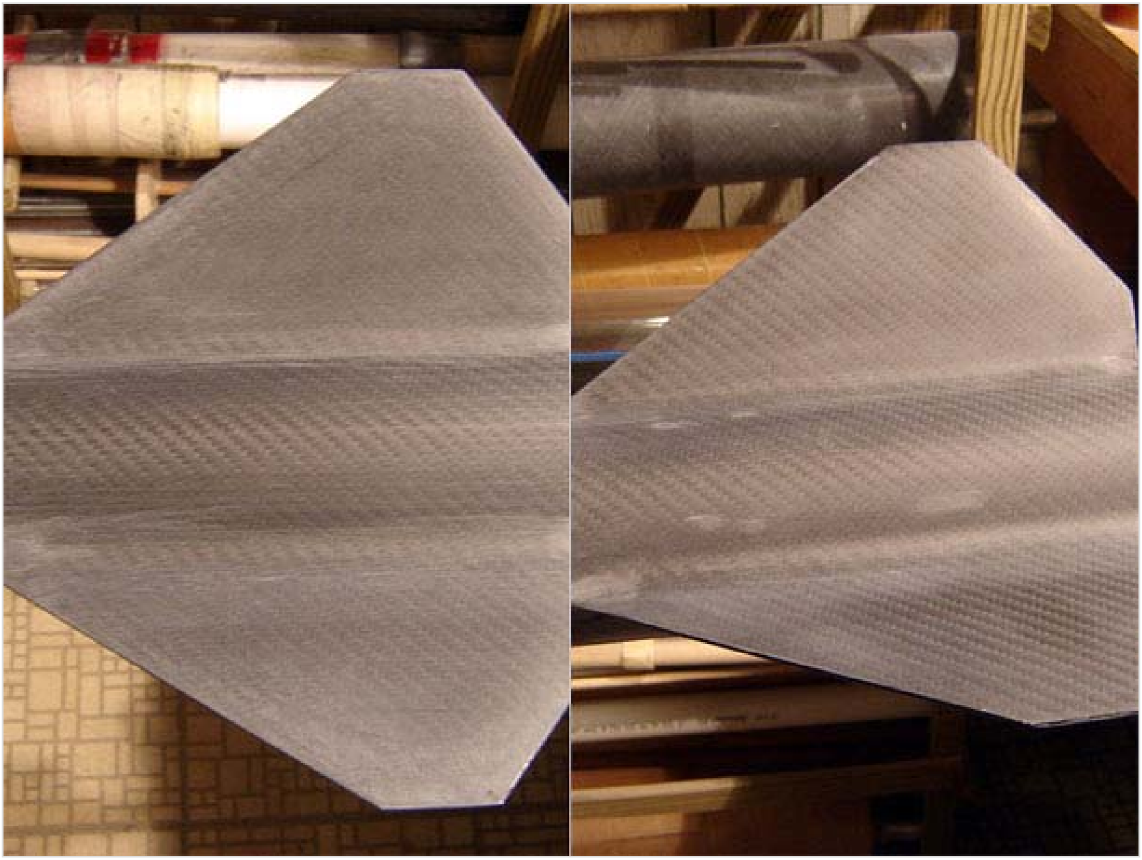
The entire fin can was first sanded with 180 grit paper using a sanding board for the fins, fin taper and body tube and dowels for the fillet and fillet transitions. In retrospect, I should have used 320 grit with the dowels, as some of the scratches later proved difficult to remove. Here, I am sanding everything with 320-grit paper over a sponge.



Here, I'm covering everything with a very thin coat of epoxy. I tried to wipe off as much of this as I could using lint-free towels. This fills the scratches from the dry sanding, and I applied two coats.

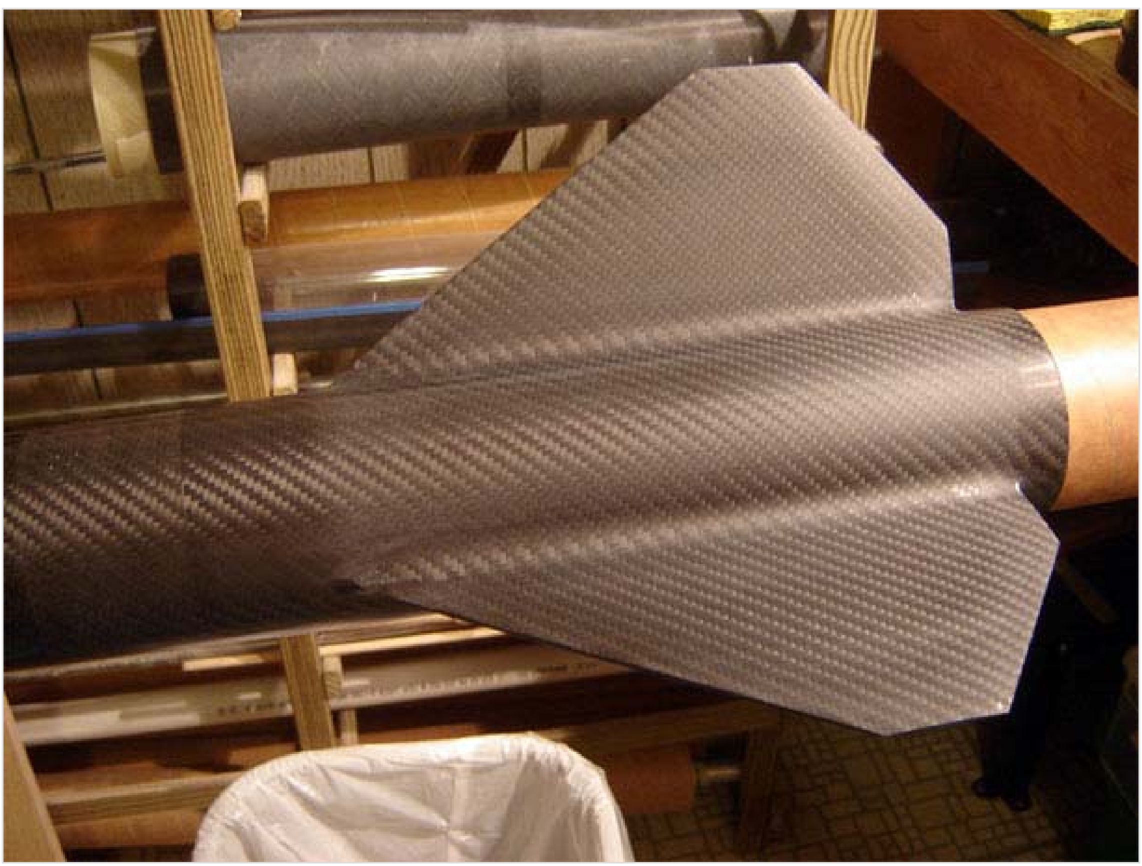


Here is how things look after applying the two thin coats of epoxy.

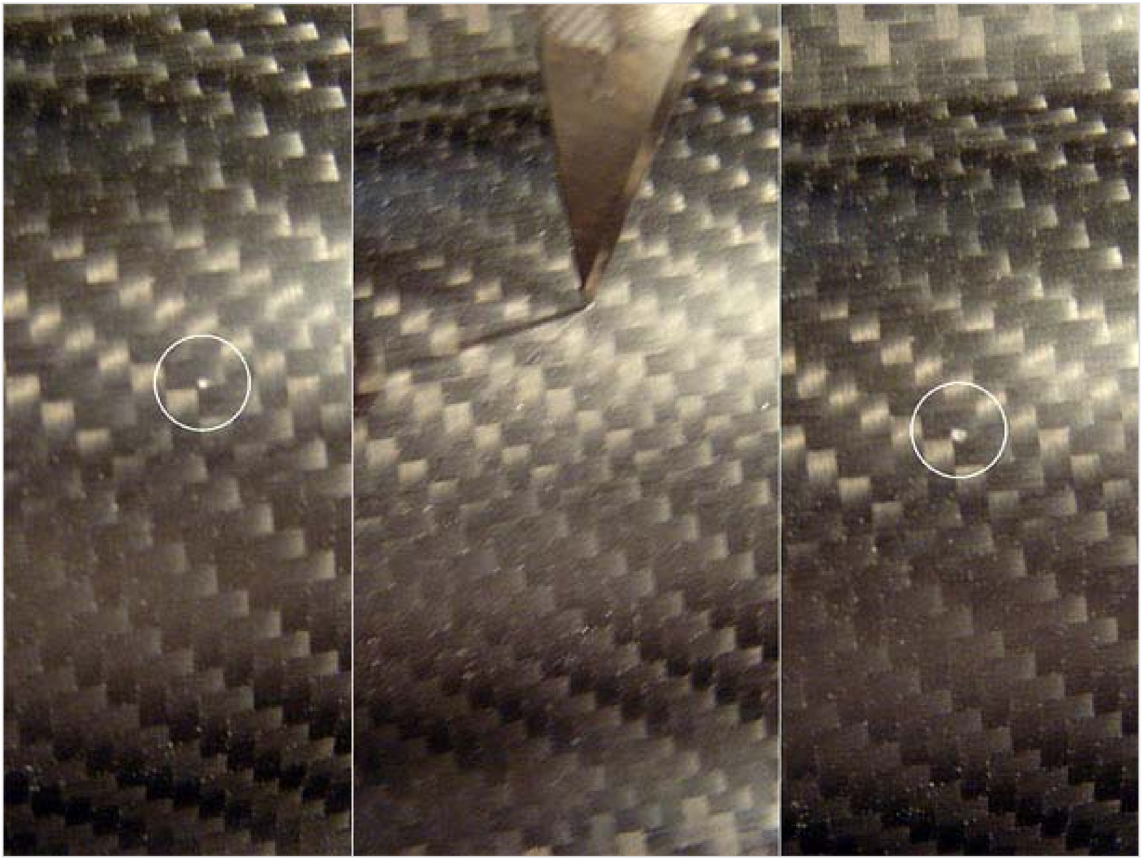


My intent was to go to wet sanding after the two layers of epoxy. However, it became apparent that more dry sanding with 320 grit would be required to remove some of the scratches. This figure shows the improvement with the two coats of epoxy followed by more 320 dry sanding.

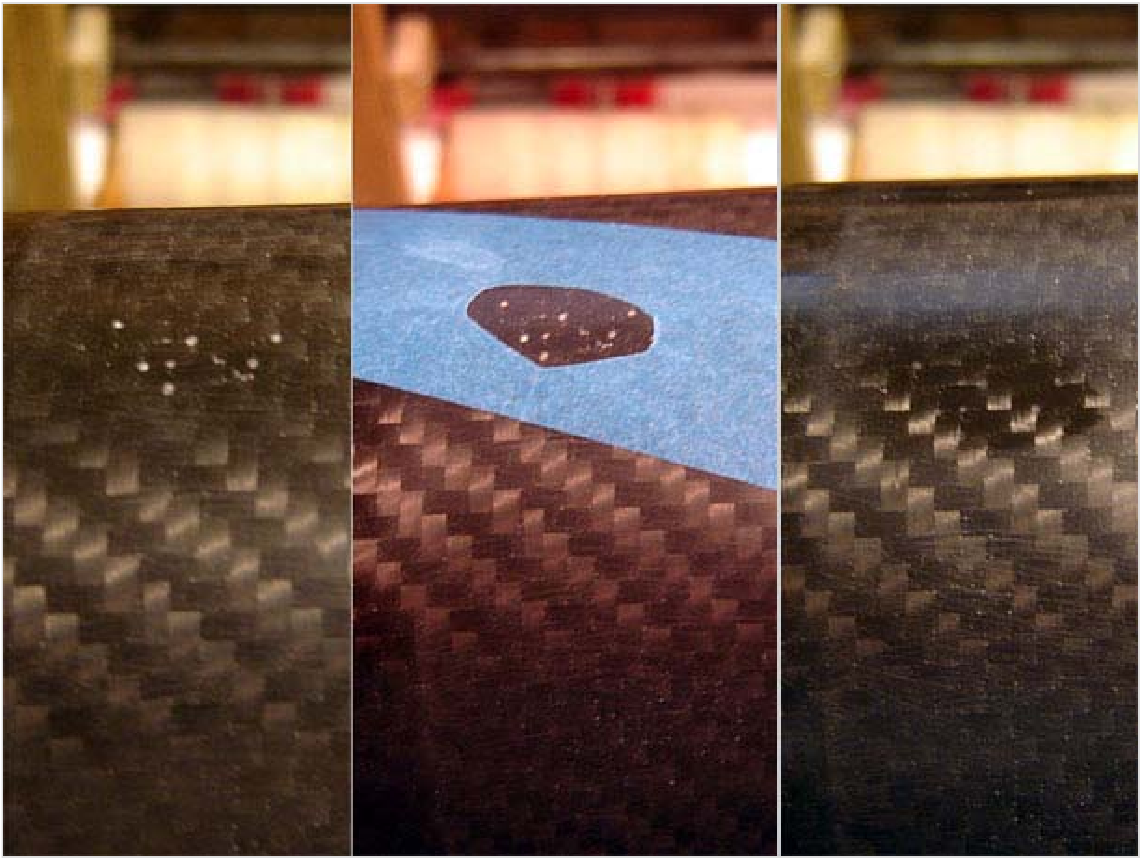
After the 320 dry sanding, I switched to 600 grit wet sanding. I used the sponge approach for the fins and between the fins, and a thin strip of paper for the body tube above the fins. I did not use a wider strip of paper because the transition area above the fins is not completely flat.



Here is the fin can after wet sanding with 1000 grit paper.



At this point, it's time to do some final touchups. In the process of sanding, small bubbles within the epoxy are encountered. When you sand into them, they turn white. I'm going to give them a wipe of epoxy so that they turn clear. First, I open them up a little with the tip of a knife.



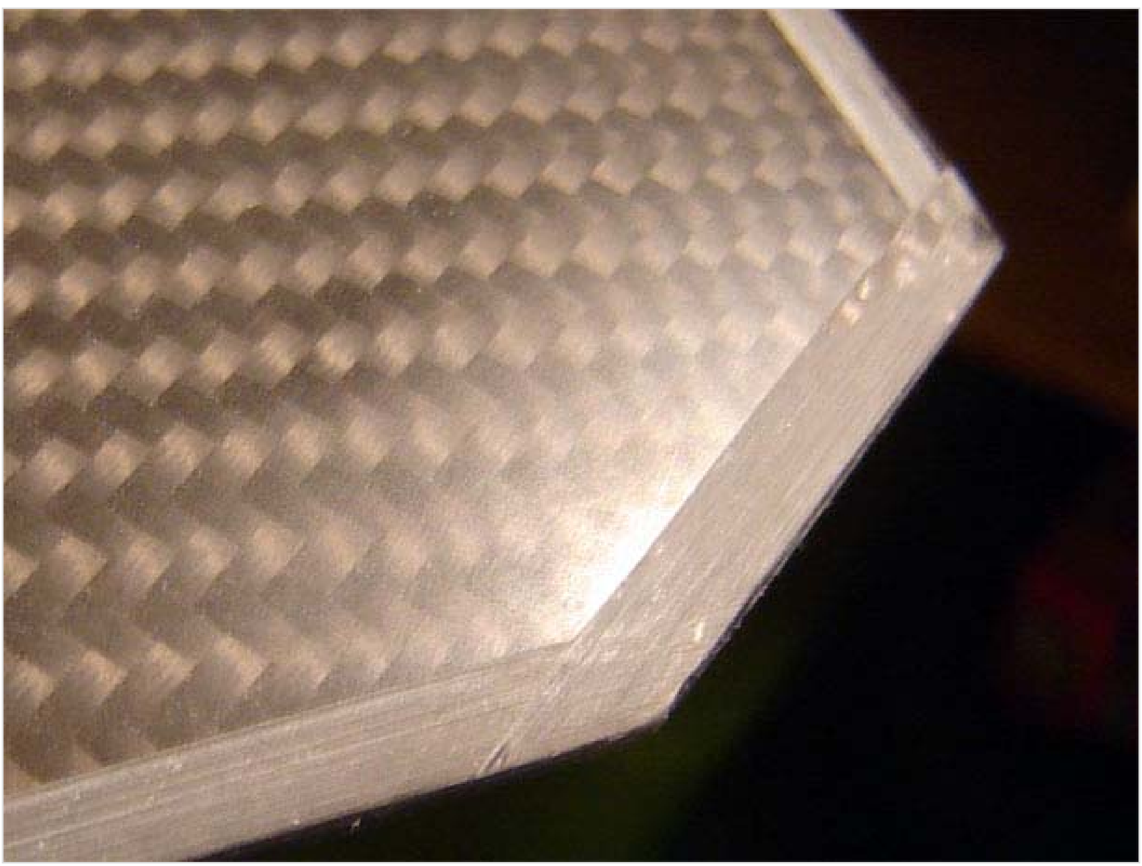
Here is another area that needs a little fixing. After opening up the bubbles a little, I outline the area with tape and then wipe on the epoxy. I then try to wipe off as much of it as possible. This doesn't fill the bubble depressions, but they aren't white anymore. This same technique can be used if there are places where you accidentally sand into the carbon.

The final step in completing the surface finish is to polish the surface with the 3M Finesse-It II. This will really improve the gloss and appearance of the epoxy. However, as I have done in previous rockets, I also want to coat the edges of the fins with Cotronics epoxy. Since solvents in the Finesse-It II could affect the Cotronics bond, I will apply the Cotronics first and then polish with the Finesse-It II.

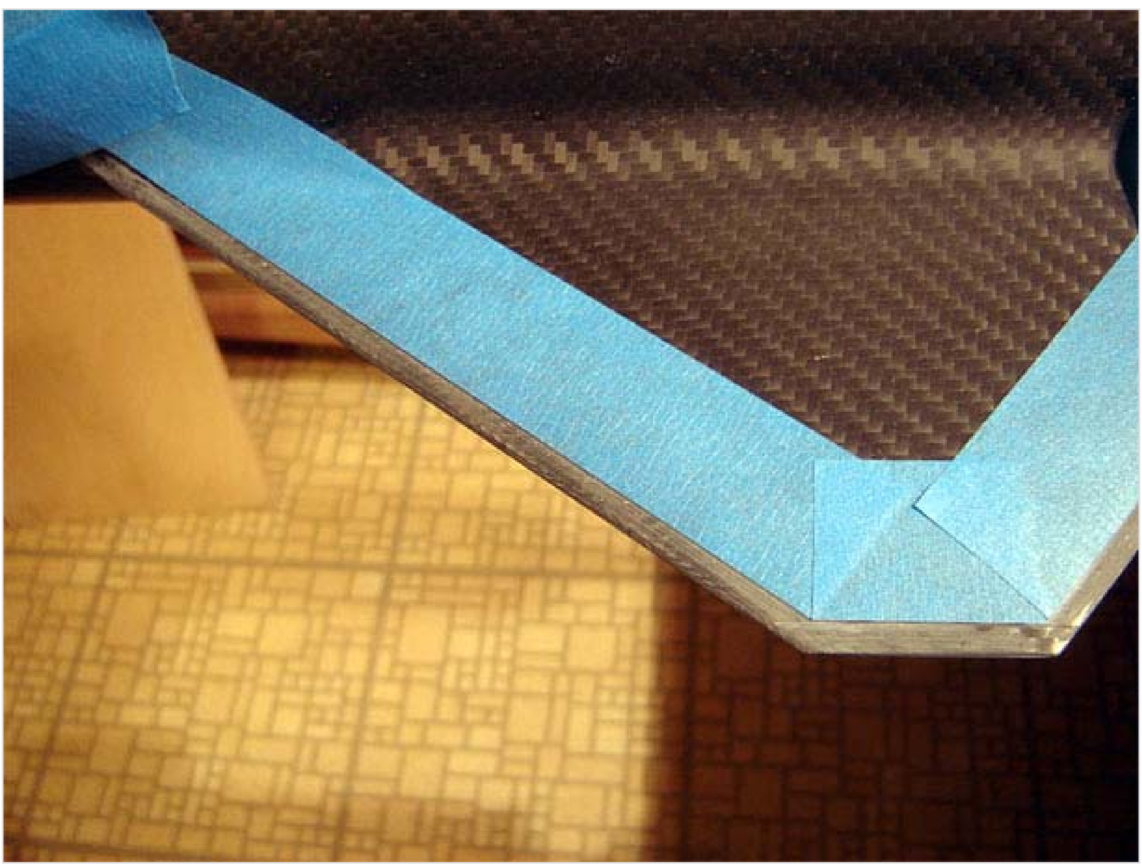
I am applying the Cotronics to improve the heat resistance of the edges of the fins (and the leading edge in particular). This rocket design has flown up to Mach 2.3, and I expect to fly this particular rocket at least that fast. Although the leading edges of the fins are encased in Aeropoxy, it is possible that the Aeropoxy could fail due to heat generation at high speed. This would result in delamination of the tip-to-tip carbon, and then more bad things would happen. The Cotronics 4525 epoxy has a much higher heat-handling capability than Aeropoxy. I have used Aeropoxy to cover the edges of the fins on a number of rockets, and none of them have ever suffered a problem due to leading edge heating.

Cotronics epoxy is not particularly well suited as a finish material. It doesn't go on very smoothly, and the buildup around the fin probably causes a fair amount of drag. So, I try to improve on the technique of applying this material on each fin can. This time, I'm going to sand in a groove around the perimeter of the fin, and then I'm going to try to fill in the groove with the Cotronics. If this works, I'll get a smoother transition between the Cotronics and the fin itself. I am also going to try to sharpen the leading edges of the fins because, at this point, they are relatively blunt. We'll see how it goes...

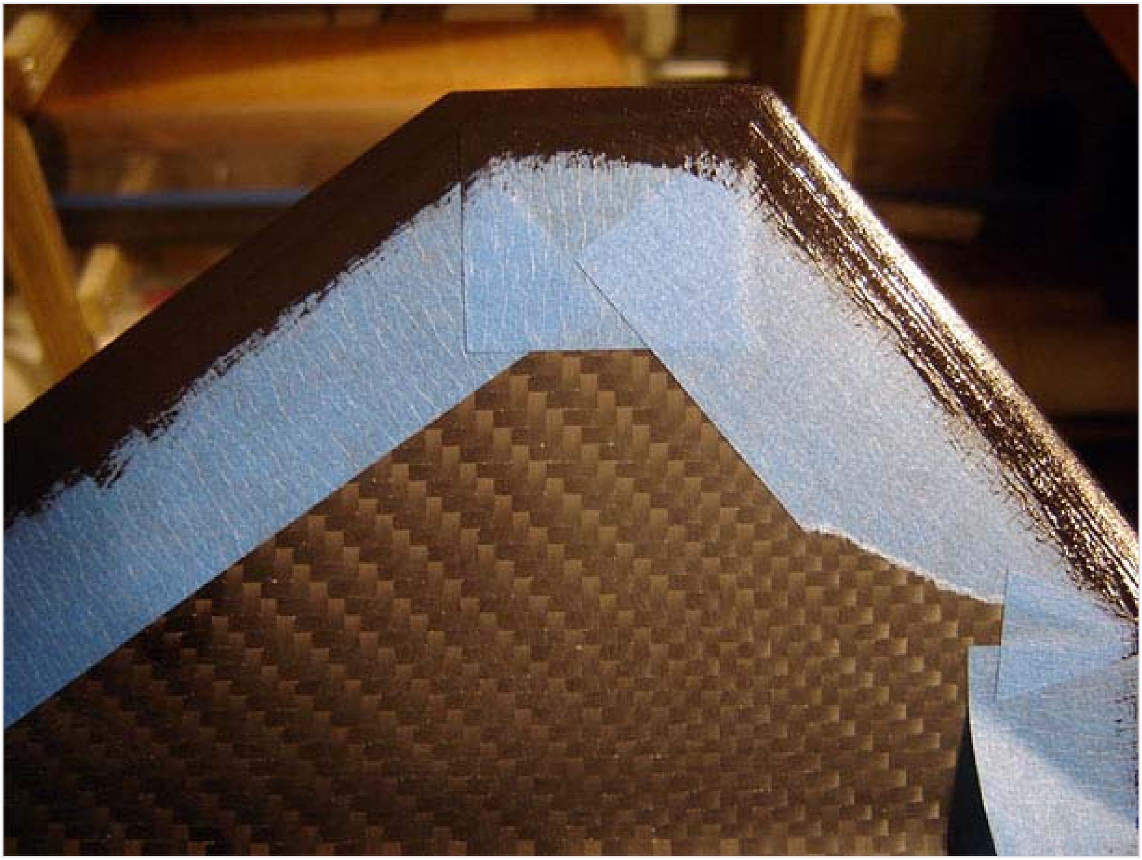

Here is a little right-angle jig that I made to sand the edge of the fin to a consistent depth.


I sanded far enough to leave a little lip. I did this so that the Cotronics wouldn't build up too high on the flat part of the fin.

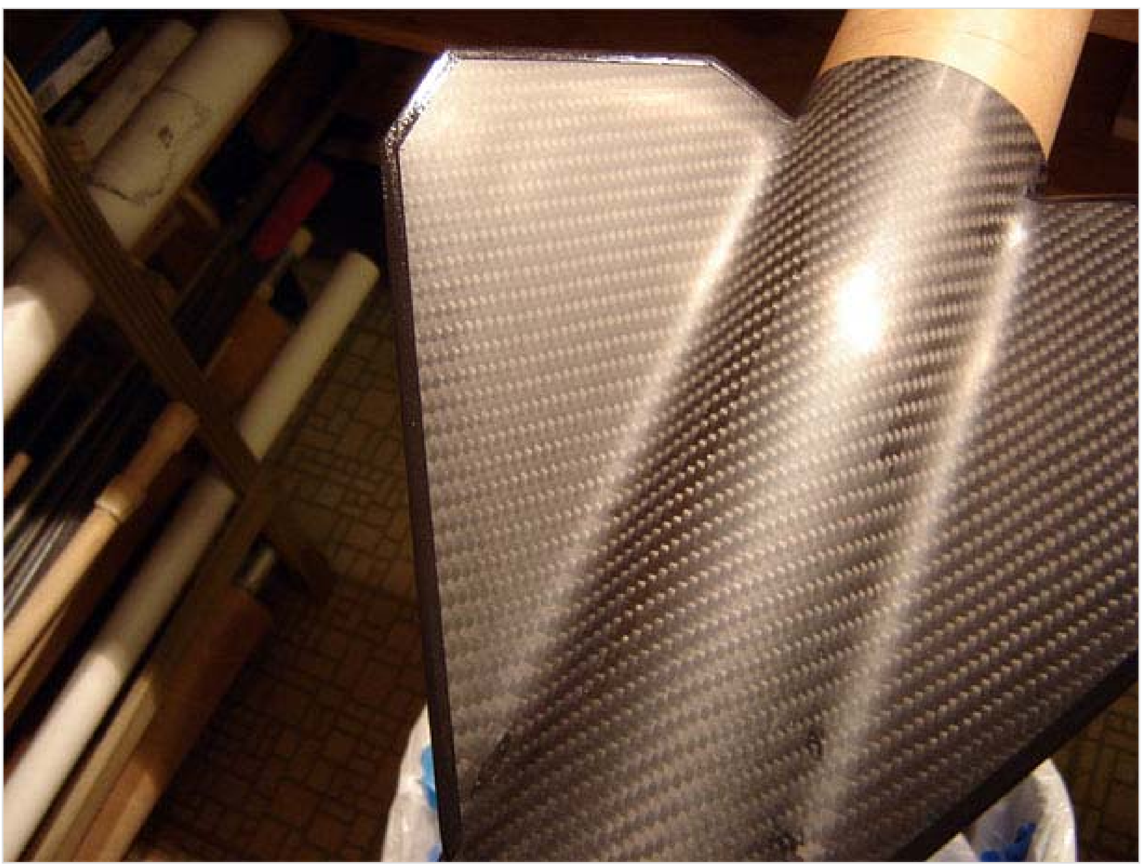
After sanding in the lip, I sanded the leading edge (only) to a relatively sharp tip. The other edges were just rounded a little.



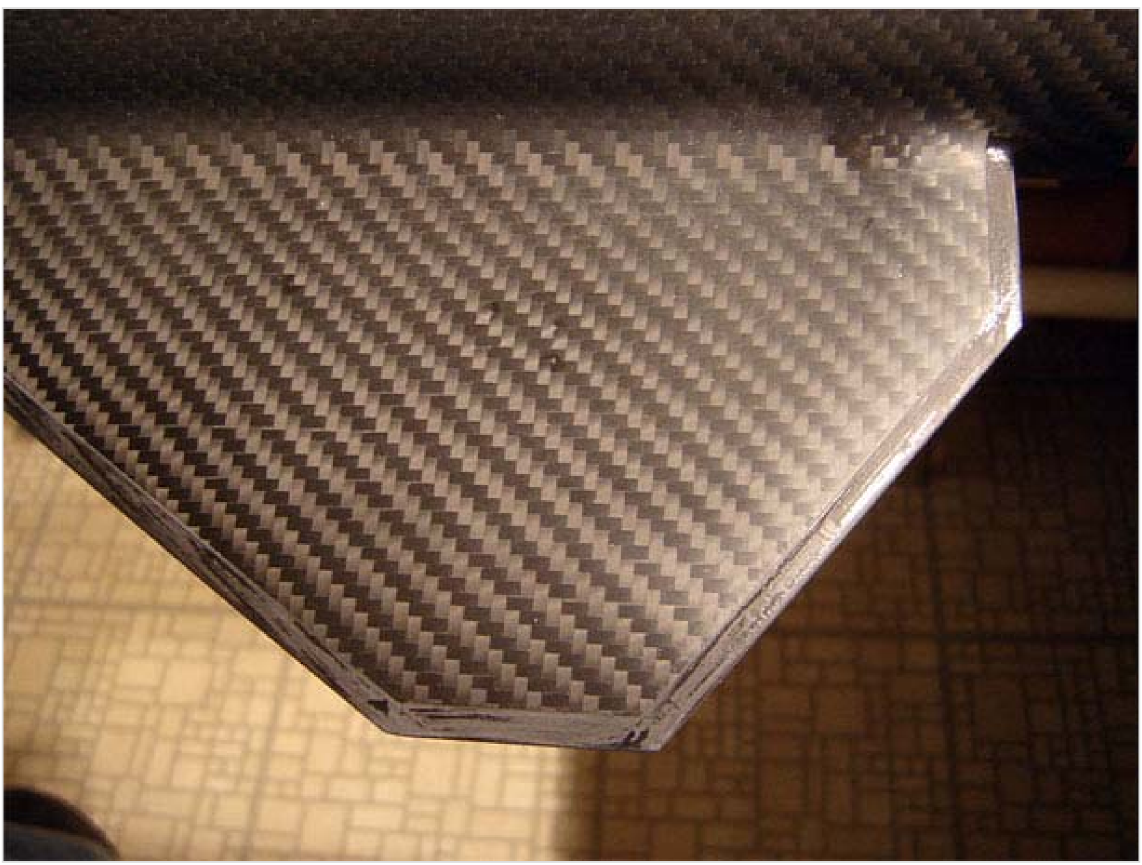
With the edges sanded, it's time to apply the Cotronics. The first step is to tape off the portions of the fin that won't be coated.

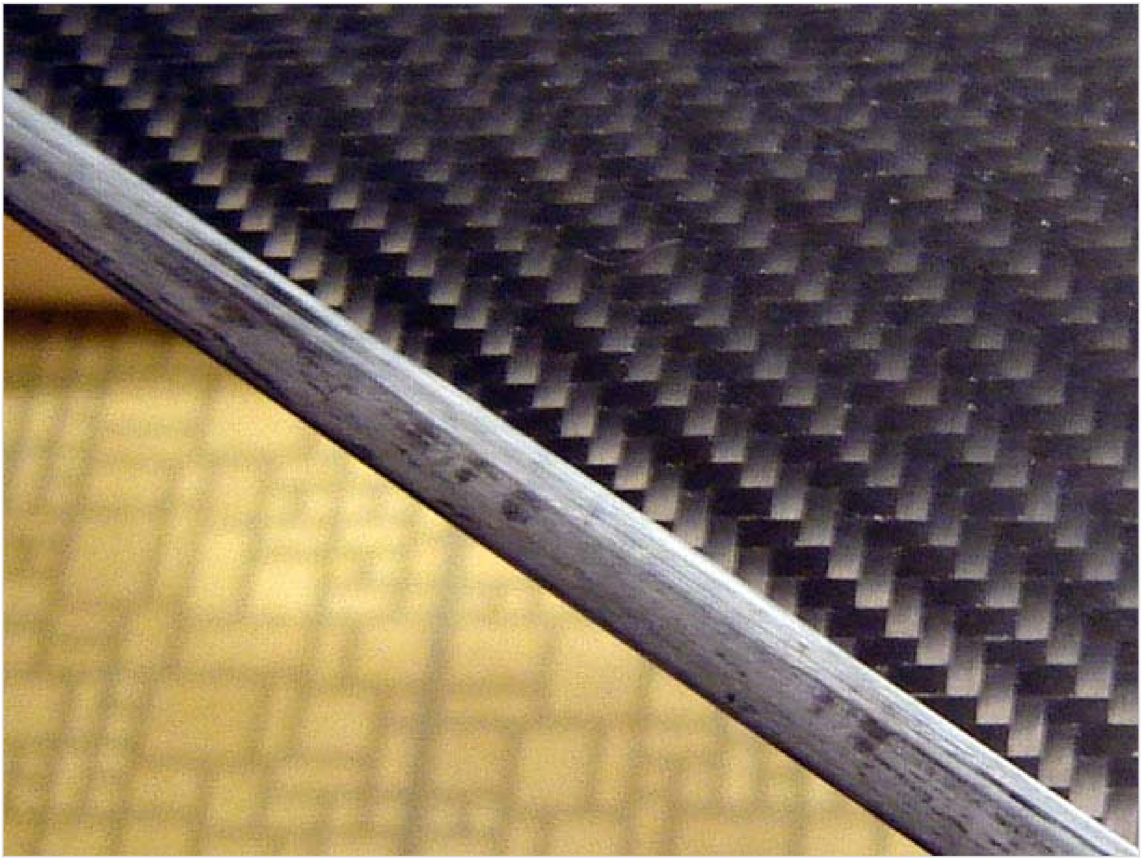


I applied the Cotronics with a small brush and then smoothed it out and removed the excess with a foam brush.

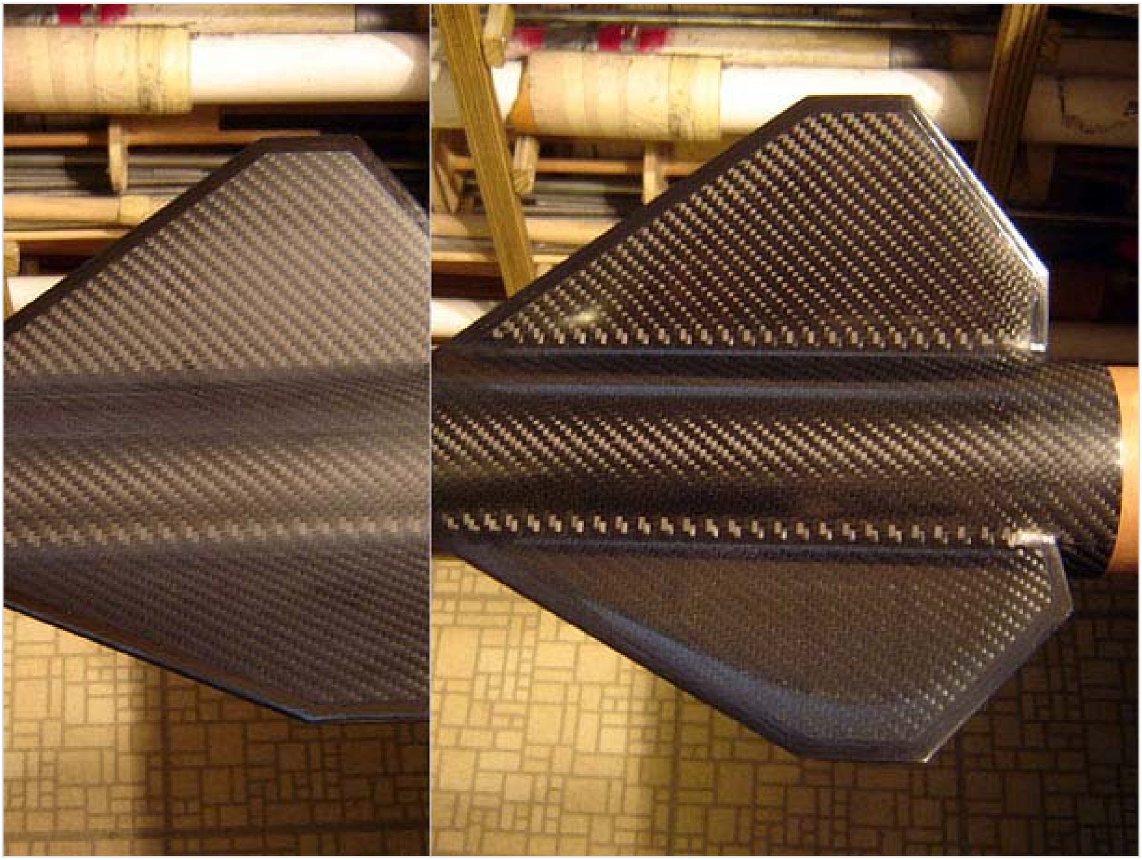


Here’s how the edges look after the first coat of Cotronics.


And here’s how I terminate the Cotronics on top of the fins.

After the first coat was partly cured, I used a knife to shave off any epoxy above the groove. After it cured, I sanded the first coat and applied a second coat.

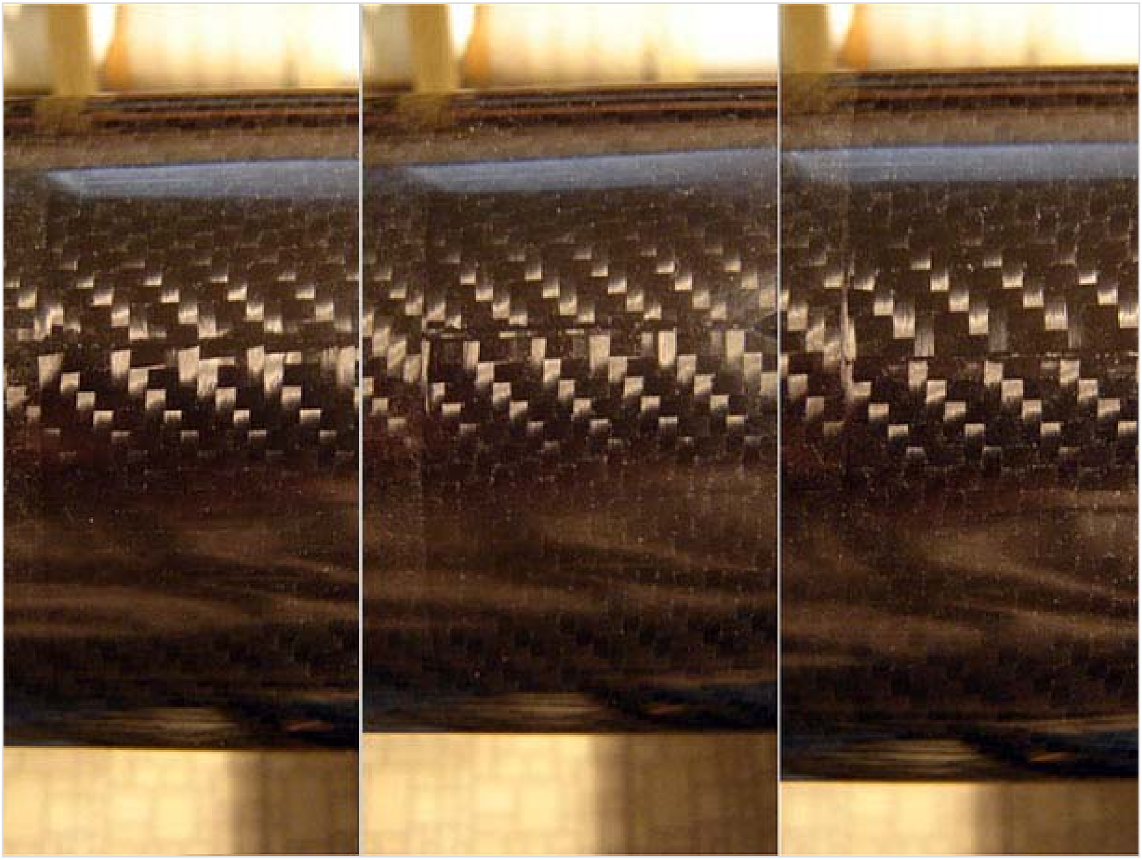

I again shaved off any epoxy above the groove and then sanded the second coat after it cured. But this time, I sanded a little further into the fin (1/4” instead of 3/16”) in preparation for a third and final coat.

Here is the third and final coat.



The final finishing step is to polish the fin can with the 3M Finesse-It II. Here's the before and after pictures. This stuff is amazing!

Remember that area that had some bubbles? I cleared out the bubbles a little with a knife point and then rubbed epoxy on the area. Here is how it looks after the polish.



Here are the three seams ahead of the fins. In each case, the seams at the top against the airframe are, well, seamless. There is no hint of the first layer of the tip-to-tip carbon. There's a slight gap between the side seams on the 2nd and 3rd seams, but all things considered, this worked out very well.

Just a couple of shots of the final appearance.

All that is missing is a 7600 Ns motor!

Jim Jarvis is a high power rocketeer who resides in Austin, Texas, and flies with the Austin Area Rocketry Group. Jim holds a degree in Chemical Engineering from the University of Wisconsin and works as a project manager for a large engineering company, managing environmental control system projects on coal-fired power plants for the electric utility industry. For Jim's contribution of this article, he will receive a free Rocketry Planet T-shirt. This sponsorship is made possible by our friends at Graphix & Stuff, producers of high quality hobby apparel and vinyl signage. Want your own free gifts? Read the program details page *for complete information.*