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N E W S L E T T E R

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## Fabricating Carbon Fiber Airframes

### Part 1: Preparation & Layup

By Alex Laraway

#### What is carbon fiber?

Carbon fiber is comprised of a polymer resin and extremely small fibers of carbon atoms. These tiny fibers are bundled into strands and woven into cloth. The polymer provides the compressive strength and the carbon fiber provides the tensile strength. Carbon fiber is a composite material combining two different materials with different properties. These form a new material with properties exceeding the performance of the original materials on their own. Composite materials can be found all around us. Papier maché, concrete, and fiberglass are examples of common, household composite materials. Carbon fiber is in some ways similar to fiberglass: fibers are laminated with a resin (usually epoxy) to form a tough, durable fiber/epoxy matrix. The advantage of carbon fiber is its incredible strength-to-weight ratio, so it is well suited for the automobile, the aircraft, the recreation and, of course, the aerospace industry.

#### How is carbon fiber applied in rocketry?

Carbon fiber is an extremely versatile airframe material. It can be used to build the lightest of low-power rockets or the sturdiest of high-power rockets. Carbon fiber is often used in applications where weight and strength are critical. Many large minimum diameter rockets use carbon fiber instead of other airframe materials because of its stiffness and low weight. Many lightweight competition rockets similarly take advantage of carbon fiber's light weight. However, carbon fiber does have certain drawbacks. Commercially available carbon fiber tubing is costly and the preparation of home-made carbon fiber tubing can be time-consuming. For these reasons, I'd recommend only using carbon fiber for applications where it is necessary. It costs time and money, the two things rocketeers seem to never have enough of! This article will discuss the process used in rolling and finishing lightweight and rugged carbon fiber tubing that is suitable for both high-stress situations and low-weight situations.

The creation of carbon fiber tubes can be divided into four stages:

1. Preparation
2. Layup
3. Mandrel Removal
4. Finishing

If this is your first time working with carbon fiber, be ready for those first few tubes to be hard on your wallet. The start-up costs of working with composites can be painful, but once you buy that first gallon of epoxy and the first few yards of carbon fiber, things will get easier.

What you will need (Figure 1):

- A full-length coupler or other mandrel
- Mylar film (.005" thick)
- Carbon fiber cloth
- Peel ply
- Chip brushes
- Epoxy resin
- Scotch tape



**Figure 1: The Supplies Needed for Making a Tube**

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## Fabricating Carbon Fiber Airframes Part 1

### Selecting Materials:

Each builder is different and has different needs, so it would be impossible to identify materials that would be perfect for everyone. However, I can help you to select an epoxy that meets your needs. When selecting an epoxy, always consider your specific project. Will this component be subject to high temperatures? Will this component take a long time to lay up? How much are you willing to spend? Fortunately, epoxy manufacturers generally provide all the necessary information for you to select the epoxy that suits your application best. If your project will be subject to high temperatures (such as on high-speed minimum-diameter rockets), select an epoxy with a high TG. TG is the "glass transition" temperature of the epoxy in degrees Fahrenheit. It's the temperature where the epoxy turns from a hard material into a soft rubber-like material. Exceeding the TG of epoxy for long periods of time will result in a rapid loss of strength in the cured composite.

Another important factor to consider is the epoxy's pot life. Pot life is the amount of time you will have to work with the epoxy until it becomes unusable. If you are building large components that will require a long lay-up time, selecting an epoxy with a long pot life is best. Generally, I find that a one-

hour pot life will cover most of the applications necessary for rocketry. Different hardeners will be available with different pot lives.

You should also consider the viscosity of the epoxy. Viscosity is a measure of how thick or thin the epoxy is. Thinner epoxies generally laminate (or "wet out") carbon fiber much easier. A viscosity of 400-1000 cps is normal. Choose an epoxy that states explicitly that it is for the lamination of carbon fiber and fiberglass. Regular "construction" epoxies will fail to properly saturate the carbon fiber and will prevent you



Figure 2: A few epoxy systems

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## **Fabricating Carbon Fiber Airframes Part 1**

from taking advantage of the full strength of the carbon fiber. With the above-mentioned factors in mind, carefully choose an appropriate epoxy. Commonly used epoxy systems include West Systems 105, US Composites 365, Aeropoxy 2032, and Fiberglast 2000.

Selecting carbon fiber is a much more simple process. Generally, carbon fiber is selected based on aesthetics, cloth thickness, weave type, and price. Thinner cloth can be made to contour more easily to tight curves and edges; however, thin carbon fiber will require more layers to equal the strength of a thicker cloth. Different weave types can also affect the carbon fiber's ability to contour. A harness satin weave is ideal for tight curves and edges but you should be aware that as flexibility increases, cloth stability decreases. A harness satin will tend to fray at the edges when cut and can be easily damaged. A good all-around cloth is 3K 2x2 twill carbon fiber. The "3K" denotes the number of fibers in a strand and the "2x2 twill" denotes the twill-weave style. It is readily available, cheap, conforms well and has the classic twill carbon fiber appearance.

Although peel ply isn't an absolute necessity for rolling tubing, it helps tremendously. Peel ply is a fabric that is laminated over the carbon fiber like another layer. It is porous, so epoxy can soak both in and out of it. It will help you to remove excess epoxy, hold the carbon fiber seam down, and give you a better surface texture than bare carbon fiber. After the epoxy is cured, the peel ply can be removed. The weave of the fabric will leave the surface with a slightly rough texture. In the following discussion, we will be working extensively with peel ply, and even though it isn't absolutely necessary, it will make finishing much easier.

All of these above materials are available from a number of online distributors. Often you can purchase epoxy, peel ply and carbon fiber cloth all from one online vendor and save money on shipping.

## **Selecting A Mandrel:**

The mandrel is the guide that determines the inner diameter of the tube. Your mandrel should have the same outer diameter as the desired inner diameter of the tube you are making. For example, if you are making a tube to fit standard 3.1" components you will need a mandrel with a diameter of 2.98". Generally, the best option is to purchase a full-length coupler. These come in most high power airframe sizes from 29mm through 4". Full length Blue Tube couplers are available through Apogee Components. Since I'm making a 54mm airframe, I will be using a 54mm phenolic coupler as my mandrel.

## **Mandrel Preparation:**

We need to properly prepare our mandrel before we lay up our airframe. Without proper preparation, we would have trouble separating the finished airframe from the mandrel. To insure a clean release we need to wrap our mandrel in mylar film. Mylar is a kind of plastic to which epoxy does not adhere (it is available from Hobby Lobby under the name "DuraLar"). A wrap of mylar prevents the epoxy from sticking to our mandrel. Once we've completed the layup, we will slide the tube off of the mandrel and remove the mylar. We need to remember to cut enough mylar for a wrap around the tube, leaving a little bit of overlap. This overlap offers some cushion to make sure that no epoxy makes its way onto the mandrel. We also need to cut it several inches longer than the desired tube length. This will give us some wiggle room on either side of the layup. Since I am working with a 54mm x 24in. tube, I will need about 8.5in x 30in of mylar. This can be attached to the mandrel using scotch tape. Scotch tape is excellent for this application because epoxy will not adhere to it and it will come off when the mylar is removed. Wrap the mylar film tightly around the airframe and tape it to itself

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## Fabricating Carbon Fiber Airframes Part 1

with small strips of scotch tape. I like to begin at one end and work my way slowly toward the other, taping every 2 inches or so. Once finished, the mylar should be snug on the mandrel. If you encounter a wrinkle or air bubble, pull the tape off and start again. It may take a few tries to get it perfect, but it is worth taking your time. This is an essential part of the layup. Loose mylar will alter the inner diameter of the tubing, so it won't be true to the mandrel size. Wrinkles will provide an uneven surface for the carbon to lay on and cause problems later in the layup. Once completed, the mylar should be snug on the mandrel, but not tight. Remember, you will need to remove it once you complete the layup. Once you are satisfied, set your mandrel aside and move onto layup preparation.



**Figure 3: Mylar attached with scotch tape**

### Layup Preparation:

With our mylar cut and on our mandrel, we can begin preparing other materials for use. It is now time to cut our carbon fiber and peel ply. We'll need to do a bit of math to find out

how much cloth to use. To determine the length of the cloth, we can use this formula:

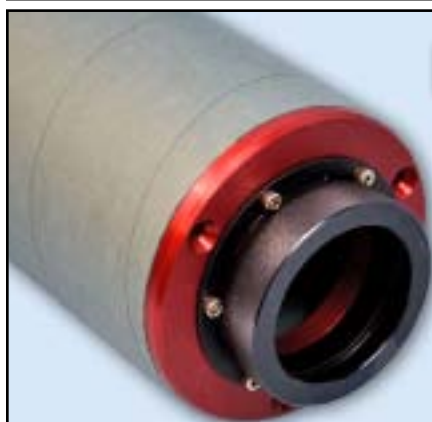
$$L = D \times W \times \pi$$

D is the average diameter of the airframe [(Outer Diameter + Inner Diameter)/2]; "W" is the number of wraps needed and pi is used to find the circumference of the tube. Since I'm making a 54 mm tube (ID: 2.14, OD~2.26) with 4 wraps of carbon fiber, I can plug those variables into the equation and get  $((2.14+2.26)/2) \times 4 \times 3.14 = 27.632$ . It will take exactly 27.6 inches of carbon fiber cloth to get 4 wraps. Now that I've found the length of the cloth, I need to find the width. This part is easy. Take the desired length of tube and add 2 inches. These two inches allow for cutoff at both ends of the tube. Since I want a 24-inch tube, the width of the cloth will be 26 inches. The size of cloth I'll need is 27.6in x 26in.

With the carbon taken care of, we can move on to the peel ply. To find the exact length of the peel ply needed we can use a similar equation to the carbon fiber (OD x 1.1 x 3.14). This time, we use the outer diameter of the tubing since the peel ply will go over the carbon fiber. Ideally, we would only need one wrap but since we aren't perfect we will be using 1.1 wraps. This excess peel ply isn't ideal, but it is a good safety cushion to have. We can plug the variables from my 54mm tube into the equation to get  $(2.26 \times 1.1 \times 3.14) = 8.51$ in. The width should be equal to the width of our carbon fiber (in this case, 26in). Now that I have the proper dimensions of both my carbon fiber and my peel ply, I can cut them both out with a pair of regular scissors. Be very careful when cutting the carbon: it has a tendency to fray very easily. Trim all stray fibers immediately or else they will continue to unravel the cloth.

Now that we have our cloth prepared, we need to find the weight of epoxy to mix. A general rule of thumb is to mix the weight of the carbon fiber in epoxy, plus a little more. If the

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weight of our carbon is 3.5 ounces, we'll need to mix about 4 ounces of epoxy. That excess allows for the epoxy that stays behind in the mixing container and on the brush. It never hurts to mix too much epoxy, just too little.

Now we need to prepare the space needed for the layup. This varies from builder to builder, based on personal resources. I work at a table with the mandrel supported off the table and the carbon fiber resting directly beneath it. Make sure you are comfortable with your working area. Support your mandrel by setting it between a long strip of flat material such as a 2x4. Flat supports are easiest because the mandrel won't roll as you are working with it. Support the mandrel off the table a few inches with the carbon fiber and peel ply resting directly beneath it. This is so any epoxy that spills off the tube will drip onto the carbon fiber beneath and won't be wasted. Shop temperatures should be from 60-80 degrees for most epoxies. Please read your specific epoxy instructions for ideal working temperatures. An increase in temperature may cause an accelerated epoxy cure. Temperatures above the stated working temperature may dramatically reduce the pot life of your epoxy and prevent you from completing the layup or completing it faster than you'd like to. Take shop temperature very seriously. This may mean moving where you build inside or waiting a month or two for the perfect temperature. A decrease in temperature may cause the epoxy to not cure fast enough or not cure at all. Working below the recommended working temperature may also cause the epoxy to thicken, leaving a slow-curing, epoxy-rich layup. Keep an eye on that thermometer!



**Figure 4: Ready to Begin!**

### Beginning the layup:

You are now ready to begin the layup. Before doing anything else, put on a pair of nitrile gloves. A pair of gloves is essential for your safety whenever dealing with epoxy. Too much skin exposure to epoxy will result in sensitization and a nasty epoxy allergy. Begin by mixing the pre-determined amount of epoxy. Be extremely careful with the mixing process. Too much or too little hardener will alter the curing and the epoxy will never reach its full strength. It's always a good idea to mix with a flat tool, such as a popsicle stick, rather than a round one. A flat tool will insure a more even mix. Mix the epoxy thoroughly, but not vigorously. After about a minute of mixing, give the mandrel a thick coat of epoxy. I prefer

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to use a chip brush, but others use small foam rollers or even their gloved fingers. You can play around with what you like as long as it works well. This thick coat of epoxy will help the carbon stick to the tube and help us position it easier.



**Figure 5: A thick coat of epoxy**

Lift the carbon up and apply the first inch or two at the same time (Figure 6). Applying the first few inches at once will prevent the carbon from slipping around as opposed to just starting with the tip edge of the carbon.



**Figure 6: Apply the first 2 inches at once**

Slowly rotate the mandrel with your left hand while spreading epoxy with your right. Make sure all the carbon is wetted out before advancing to the next section. Properly saturated carbon will take on a glossy appearance. Unlike fiberglass and Kevlar, it will not change colors. This makes it much more difficult to distinguish between saturated carbon and unsaturated carbon. Constantly look for the gloss of saturated carbon. Continue applying and rotating the mandrel in 1/8 to 1/4-turn intervals. Don't be afraid to put down more epoxy than is necessary. The next layer of carbon or the peel

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ply will soak up excess epoxy.

Remember to be careful when beginning your second layer. The beginning of the first layer has a tendency to stick up and cause problems as the first layer meets the second. It may be beneficial to soak the area where the beginning of the carbon meets the mandrel. Keep an eye on this seam to make sure the second layer lays down properly. I've ruined my fair share of tubes because I didn't do this. From here on out, it's relatively smooth sailing. Keep slowly rotating, laminating as you go. Watch the edges of your carbon and keep an eye (and a hand) on your epoxy.



**Figure 7: Making sure the first layer lays flat**

Once you get the hang of it, this part is easy, but time consuming. Even though it is monotonous it's extremely important so pay attention to little details like stray bristles that stay behind in the layup. Any bits of brush, or any other contaminant should be removed immediately. I find it's easiest to do this with a toothpick or something similar.

The final layer of carbon fiber is a little trickier than the mid-

dle ones. This will be the cosmetic layer that determines how your final finish looks. As you reach the end of the cloth, the weave will grow more and more unstable and will have a tendency to fray. Make sure not to distort the weave. I find that I get best results when I switch my brush stroke techniques. I roll the majority of the tubes pulling the brush down but that tends to pull the final horizontal fibers out of place. I switch to a jabbing or dabbing motion for these last few inches to keep these final fibers from moving. After everything is laid down, give the tube one final thick coat of epoxy.



**Figure 8: Final layer**

You want to really oversaturate the carbon fiber. This final coat will help in filling the texture of the carbon fiber. You are now ready to apply the peel ply.

### Applying the Peel Ply

Like the carbon fiber, drape the peel ply over the tube. If you oversaturated the carbon fiber as suggested, the peel ply

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should wet out fairly quickly. Unlike carbon, the peel ply will darken, becoming clearer and giving you a good sense of what is saturated and what is not. Continue to wrap the peel ply along the tube, as if it were another layer of carbon fiber.



**Figure 9: Applying the peel ply**

It is critical to pay attention to air bubbles between the peel ply and the carbon fiber. Sometimes a white spot isn't unsaturated peel ply but a spot where the peel ply lifts off the carbon. Using your fingers or a brush try to pull the cloth

around the bubble to pull it tight. If you ironed the peel ply, large air bubbles shouldn't be much of a problem. With your peel ply wrapped, you need to start worrying about pinholes. Pinholes are small air bubbles that form between the weave in the carbon. They don't cause much structural harm but they are a major pain to deal with, cosmetically speaking. These pinholes will look like tiny white dots in your peel ply. They may be very hard to notice at a first glance so take your time to identify all possible pinholes before moving on. Although it's possible to fill these pinholes during the finishing stage, it is much easier to get rid of them now.



**Figure 10: The tiny white dots are pinholes**

To fill these now, use a sharp jabbing motion with your brush. You need to force epoxy through the peel ply and into the pinhole. Take your time with this step. I'd guess it will take ten times the time and effort to fill these after the epoxy has cured.



**Figure 11: Use a "jabbing" motion to get rid of pinholes.**

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After you are satisfied with the tube, that's it! You're done for now. Set it aside to cure in a warm, dry environment.



**Figure 12: A good, healthy tube!**

Some rocketeers construct "curing ovens" specifically to cure composite parts and boost the TG of the epoxy. See your epoxy for specific cure instructions.

Congratulations! You've made it through the most stressful part of composites fabrication. The sequel to this article will discuss techniques of getting a beautiful, polished, aerodynamic finish on these tubes.

## About the Author:



Alex Laraway has been making carbon fiber airframes and rockets for three years. He flies with UROC and occasionally AeroPac. He loves everything and anything that has to do with altitude, speed, and just about every kind of material. If you have questions regarding this article or about getting started with composites in general, he would love to answer them at [Aksrockets@gmail.com](mailto:Aksrockets@gmail.com).

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