Basics of Composite Construction

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Ron is currently president of Alexander SportAir Workshops, a series of "hands-on" workshops on building airplanes is presented throughout the country for education. For a schedule of locations and dates of upcoming workshops and information (prices, curriculum, etc.), call 800-967-5746 or visit their web site at www.sportair.com

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Basics of Composite Construction

By Ron Alexander

During the fall of 1997, I wrote a series of three articles on composite aircraft construction. These articles provide an overview of composites as they relate to aircraft building. The articles began with the October 1997 issue of Sport Aviation. I am going to again focus attention on this popular method of aircraft construction by discussing in more detail each step involved in building a composite aircraft. A certain amount of review will be necessary to achieve the goal of explaining the steps involved in this type of building.

Once you have made the decision to build a composite aircraft, either a kit aircraft or a plans-built, the first step is to set up your workshop space, purchase the necessary tools, and organize materials and parts.

WORKSHOP SPACE

To begin this discussion it is important to note that you do not need a pristine laboratory to build a composite airplane. Like most aircraft building projects, if you have a 2-car garage you have what is needed. It has been my experience that having your workshop in or near your home solves two problems. First of all, you will be much more likely to spend time on the project after getting home from work versus having to drive 30 minutes to another location. This equates to more hours on the actual project. Secondly, your family is more likely to become involved. This is very important if you are to successfully complete the project.

If you had an ideal composite shop you would have a "clean room" for doing layups, cutting cloth, etc. and a "dirty room" for sanding operations. Most of us do not have a partition in our garage so we must be careful during our sanding operations not to contaminate our work. Sanding should be accomplished after completed parts are cured and covered-not just after doing a fresh layup.

You will need a table on which to cut your reinforcement fabrics (usually fiberglass). Since most of your fabric will be cut on a 45-degree bias, it may be handy to have a table set up just for that. You can shape the table by cutting one end at a 45-degree angle to facilitate cutting on a bias. The table should be wide enough to handle the fabric you will be using (60 inches should be enough). You should be able to unroll about 4-5 feet of fabric on the table. You will want to place a hard plastic cutting surface on the top of the table to allow you to cut the fabric with a cutting blade. (More about cutting fiberglass later.) This material can be 1/8-inch thick high-density polyethylene or something similar.

Another table can be constructed to do your resin mixing and basic layups. This table should be roughly 3 feet x 8 feet depending upon the amount of space available. The length of the table needed will also vary with the aircraft you are building. The table should be placed in an area that will allow you to walk completely around it. In addition, some builders prefer to have another smaller table dedicated to mixing resins. After completing a part you should remove it from the area if at all possible or hang it from the ceiling.

A large thermometer should be placed where you can view it along with a humidity indicator. As you will learn, temperature and humidity control is very important when mixing and working with resins. Ideally, you should be able to control the temperature of your workshop. This, of course, is not always practical. Place a large clock with a sweep second hand on the wall where you can see it while working. The clock is always running on your resins after they have been mixed. You will have only a certain amount of time with which to apply the resin before it begins to gel. Of course, you need a first aid kit and an eye wash station. The eye wash station must be easily accessible.

Proper ventilation of the work area is necessary. When working with resins or when sanding you will want to move the air through the workshop space. A fan can be set up to move the air outside the workshop. If you really want to do it right mount an exhaust hood over your layup table. This is not that difficult to do and is very effective in removing fumes created from the resins when you are working with them.

Storage of materials, parts, etc. must be addressed. If you are building a composite kit aircraft the pre-molded parts must be carefully stored. Wing panels, as an example, can bend and adapt to any shape to which they are subjected. Warping can result from improper storage. The best way to store parts is to simply leave them in the shipping crate in which they arrived. You may also want to save the shipping materials from the crate to use as padding, etc. for completed parts.

Resins should be stored in a warm area if at all possible. When the temperature is less than about 65 degrees resins become thick. The colder the temperature the more thick the resin. That means you will have difficulty pouring the resins from their container. Several builders have designed heated areas within their shops to store resins if the shop itself is not maintained at a normal temperature. If resins are stored in extremely cold temperatures they are susceptible to crystallizing. This is not a major problem and can be corrected by placing the resin container in a pan of water and heating the water to about 160 degrees F or so until the crystals dissolve. Resins may be stored for several years prior to being used. This is termed their "shelf-life". However, with epoxy resins the accompanying hardener usually has a shelf life of less than one year. Vinyl ester resins often have even less time for shelf life especially if they have been promoted prior to shipment.

COMPOSITE TOOLS

Most of the tools you will need to build a composite airplane are readily available and somewhat inexpensive. The following is a partial list of tools you will need:

- Scales, mixing pump, or balance scales to mix resin
- Sanding blocks
- Saws hacksaw, coping saw, and pad saw
- Carpenter's level
- Carpenter's square
- Clamps
- Electric hand drill
- Fabric scissors
- Rotary cutter
- Grooved laminate rollers
- Knives-including utility knife and large serrated knife
- Respirator
- Rubber squeegees
- Straight edge
- Vacuum cleaner
- Hair dryer

Other tools that are nice to have consist of a Dremel tool with bits for shaping and cutting, a die grinder, drill press, band saw, rotary or orbital sander and the list can go on. The tools I have mentioned are specific to composite construction. You will also need basic tools and usually some sheet metal tools for a small amount of riveting, etc. The best way to determine the exact tools you will need is to read the kit manufacturer's assembly manual or the designer's plans. They will almost always provide you with a list of basic tools needed to construct their airplane.

Now that we have established what kind of workshop space you will need along with several of the tools that are required lets get down to the basics of construction. I will talk about each type of material used in composite construction and how to work with each separate one. After we have established a foundation, in up-coming issues I will discuss the proper methods of doing a composite layup, methods of bonding and tape glassing, forming hardpoints, post curing, and most of the activities you will become involved in if you decide to build a composite airplane.

If you want a complete review of basic composites I invite you to read the previous articles I mentioned in the beginning of this article. I do want to briefly review some of the materials used in composite construction with an emphasis on how to work with each one.

CORE MATERIALS

Let's begin with the core materials that usually consist of some type of foam. Polystyrene is the first core material that will be discussed. Polystyrene comes in large blocks and is normally used to form large structures such as wings, control surfaces, etc. If you are building a plans-built airplane you will build a large portion of the airplane out of this material. Polystyrene can be cut with a knife, saw, or it can be "hot-wired" into the shape of an airfoil. Usually the latter will be called for in the plans. You can find plans for a "hot-wire" device in the Rutan booklet called Moldless Composite Sandwich Homebuilt Aircraft Construction available from supply companies. This device is easily constructed from common materials. Templates are made from the aircraft plans you receive and are used as a guide in cutting the foam to proper shape. One thing in particular when working with all foams and especially with polystyrene foam, the cells or voids in the foam must be filled prior to applying the reinforcement material. This is accomplished by mixing a slurry compound or using a commercial filler manufactured by Poly-Fiber called "SuperFil". This is the first step in the layup process that will be discussed in detail later. It should also be noted that vinyl ester resins will dissolve polystyrene foams therefore they are not used with this type of core material.

Most of the kit aircraft use either polyurethane (urethane) or polyvinyl chloride (PVC) foam. These foams come in different densities and thickness. Usually the thickness will be from about one-quarter inch to two inches or so. With most kit aircraft the large airfoils will be partially completed and you will simply be required to construct ribs, bulkheads, etc. and glue them in place. These foams are easily cut with a knife or saw. DO NOT HOT-WIRE URETHANE FOAMS. They will emit poisonous gases if hot-wired. They are also flammable. Do not burn the scraps of material left over as the same gases are emitted. Sanding blocks are used to shape foams. Band saws and routers may also be used to cut and shape.

Honeycomb cores are used in several kit aircraft. You will usually not be required to work with this material, as the kit manufacturer will supply the completed parts that use a honeycomb core.

REINFORCEMENT MATERIALS

This is a term used for the fabric materials found in composite construction. We will find three different types of materials used in most composite aircraft. They are fiberglass, Kevlar, and carbon fiber (graphite). Fiberglass is the most commonly used material. It has the best physical characteristics at the lowest price.

Without going in to great detail, there are a few basic things you really should know about fabrics. Fiberglass is made up of filaments of glass that are twisted together to form a yarn. This yarn, or fiber as it is often called, is then woven into certain styles of fiberglass. When the weaver looms fiberglass they use terms such as "warp", "fill", and "selvage edge." See Figure 1. Warp defines the fibers that run the length of the fabric as it comes off the roll. The warp direction is designated as 0 degrees. Fill fibers run perpendicular to the warp fibers. They are designated as 90 degrees. The fill fibers or threads interweave with the warp fibers. Selvage edge is the woven edge produced by the weaver to prevent the edges from fraying. Some of the new fabrics today appear to not have a selvage edge. The edges have been stitched with a lightweight thread.

Unidirectional Fiberglass

With unidirectional fiberglass, all of the major fibers run in one direction. All of the strength of the fabric is found in that one direction. The fill often consists of threads designed to hold together the glass fibers. A common term for this glass is "uni". It is manufactured in both glass cloth and in tapes. A common style number used by many composite airplanes is designated as 7715. This cloth is typically used where the primary loads are in one direction such as a spar cap.

Bi-directional Fiberglass

In this glass, the major fibers run in two directions, both the warp and the fill. In other words, instead of using threads as a fill, glass fibers are used. Thus we have glass fibers in both 0 degrees and 90 degrees. In other words, the cloth has half of the fibers in one direction and half in the other direction at right angles. This means that the cloth has the same strength in both directions. This type of cloth is commonly called "bid". Of course, there are many different styles and weaves that are available. 7725 and 7781 are two very common cloths used in amateur-built aircraft. In your plans they will often be referred to as bid cloth.

Bid cloth can be stitched together in more than one layer to form what is known as biax cloth or triax cloth depending upon the number of layers involved. The most important thing for you to understand it that you must use the type and style of cloth called for in your plans. Do not experiment with cloths. The designer has specified the cloth to use based upon structural analysis. Use what they tell you to use.

Keeping it simple, I am not going to discuss all of the different weaves of cloth, etc. that are available. You can read Andrew Marshall's book, Composite Basics, for a good discussion of this. I want to concentrate on the basics you need to know to safely build your airplane.

Handling & Cutting Fiberglass

First of all, you must be careful when handling fiberglass. Remember to cut the glass in a clean area. Do not drop fiberglass on the floor. It will be contaminated with dirt and debris. If your fiberglass gets wet do not use it in the structure. Be careful when handling fiberglass as its shape can be easily distorted. Mark the cloth using a Sharpie marker. These marks will not show through the final finish. Your plans will usually require you to cut your cloth at a 45-degree angle. This is done to achieve maximum strength in the final structure. So we will usually be cutting the glass on what is referred to as a 45-degree bias. You need a sharpie marker, a straight edge, a measuring device, and a good pair of scissors or a rotary cutter. When you make a cut, allowance for small deviations is usually built into the dimensions. If you are within one-half inch or so that should be good. As you make a cut the cloth may slightly distort. If so, it can be carefully pulled back into its proper shape by pulling on an edge. Cutting can be done using a good pair of scissors or a rotary cutter or they are sometimes referred to as a roller blade. Many people call this a pizza cutter-which is a term for the rotary cutter-it is not a real pizza cutter. Get a rotary cutter from one of the supply companies.

After you have cut the cloth to the proper dimensions, carefully roll it into a fairly large roll. In other words, do not roll it tight. This is the best way to transport the fabric to your structure. We will see how to apply it later. If you pick it up by the ends it will distort and not fit the area of the part correctly. It is also important to note that the selvage edge must be removed prior to applying it to the structure. (Note: this will not apply when using the type of fiberglass without a selvage edge.) Cutting on a 45-degree bias will cause a certain amount of waste. However, it is necessary that you cut this way to achieve maximum strength. By the way, the angle is not critical. You do not have to measure it accurately. Eyeing it will work fine. Let me emphasize that you must cut the fabric in the orientation called for by your plans.

RESINS

To emphasize the importance of the resin matrix I would like to quote Andrew Marshall from his book Composite Basics. "Basically, the resin matrix is the key to the whole operation of producing composite structures. It was noted earlier that the resin matrix is the mass in which the fibers exist, but the resin does much more than just contain the fibers. Its primary job is to carry the load from one fiber to the next, and from the bundles of fibers or groups of reinforcements into an adjacent structure which may either be embedded in the composite during manufacture, or adhesively bonded to it at a later stage. The resin material thus distributes and transfers the load within the structure so that each reinforcing fiber carries a proportional share of the load."

There are two types of resins that are most commonly used on composite aircraft. They are vinyl ester resins and epoxy resins. I am not going to discuss polyester resins, as they should not be applied on aircraft except for very limited non-structural use.

Vinyl Ester Resin

This type of resin is used by several of the kit manufacturers. Vinyl esters are low in viscosity making them easy to use. The cure time can also be easily affected simply by adding more hardener thus speeding up the cure time. Despite the cure time, hardened vinyl ester usually exhibits consistent properties of strength and flexibility. Working time with vinyl ester resin is dependent upon the ambient temperature and the amount of catalyst that is added. Vinyl ester resin is less expensive than epoxy and it will withstand high temperatures without post curing.

The negative side of vinyl esters results from the mixing process. Vinyl ester resin must be "promoted" prior to mixing the catalyst. It is promoted using a chemical called cobalt napthenate (CONAP). This chemical must be added into the resin before catalyzing. Vinyl ester resin is catalyzed using a chemical called methyl ethyl ketone peroxide (MEKP). CONAP and MEKP mixed together prior to being placed in the resin can cause a fire or explosion. You will not encounter this hazard as long as you remember to place the CONAP into the vinyl ester resin prior to adding MEKP. Extreme care must also be taken when using MEKP. This chemical is very dangerous to the eye.

Overall, vinyl ester resins provide an easy to use, strong, high temperature, and inexpensive resin. Skin irritation problems are also less likely to occur than with epoxy resin. Just remember to take proper precautions when you are mixing vinyl ester resins. Be sure not to mix CONAP with MEKP and always wear a face shield when using MEKP.

Epoxy Resin

Epoxy resin has come to dominate the aerospace industry and it is widely used on custom-built aircraft. Epoxy resins differ from vinyl ester resins in that they harden through a process known as "crosslinking". Epoxies are packaged in two parts: a resin and a hardener. Unlike vinyl ester resin, the mixing ratio of resin to hardener is critical. Adding more hardener will not accelerate the cure time, in fact, it may seriously impede the curing of the resin resulting in less strength of the final cured part. Different types of epoxy resins are available. Again, use the type of epoxy called for by the designer. Working time may be varied using different types of epoxies. A 5-minute epoxy is commonly used to simply hold two pieces together for further bonding. These epoxies set up within 5 minutes and should not be used for structural purposes. Structural epoxies will have a working time of approximately 45 minutes depending upon the type of epoxy and the ambient temperature.

Proper skin protection is a must with epoxies due to skin dermatitis that can be caused by the chemical. In the next issue I will discuss how to properly protect your skin from this problem. How to mix fillers and the actual process of completing a composite layup will also be presented.

COMPOSITE FILLERS

Many applications of composite construction require a filler material to thicken and/or reduce the density of the resin mixture for various purposes. The resulting mixture of the filler plus the resin is used to form a fillet to provide a radius where two composite pieces are joined together. Fillers are also used to seal the cells of foam. The slurry coat is used to fill the cells with a lower density material than that of pure resin. Fillers are also used to thicken a mixture so it can be applied without running, to enhance the strength of resin material for structural bonding, and to fill the weave of fabric during the composite finishing process. Mixtures may also be used to fill any gouges or dents in the foam core. Corners are also constructed using a filler material. Several different filler materials are used with resins. The more popular ones will be discussed.

Microspheres

Microballoons as they are often called are nothing more than very minute spheres of glass, microscopic Christmas tree bulbs provide an accurate analogy. This material is very lightweight and very easily suspended in the air. Care must be taken when working with microballoons not to inhale any of these glass particles. Quartz "Q cells" is another type of microballoon called for in the plans of several kit aircraft. When either of these forms of filler is mixed with a resin material the resulting mixture becomes lighter in weight with less strength. This mixture is commonly referred to as "micro". Micro is usually mixed in three different thicknesses. First is a slurry consistency. This is usually a 1 to 1 mixture by volume of microballoons and resin. This provides a mixture that is almost the same viscosity as resin by itself. Slurry is used to fill the cells of the foam prior to applying the first layer of cloth. The second type of micro is usually termed "wet-micro". It is thicker than slurry and is used to join blocks of foam together. The mix ratio is approximately 2-3 parts of microballoons to 1 part of resin. The third type of micro is called "dry micro". This mixture requires about 5 parts of microballoons to 1 part of resin and it is used as a filler material.

Micro must NEVER be used between plies of a layup as the final strength will be severely decreased.

Flocked Cotton Fiber

This particular filler material, usually called cotton flox, is also mixed with resin. It consists of finely milled cotton fibers that provide an adhesive when properly mixed with a resin material. The mixture is termed "flox". Flox is usually mixed about 2 parts of filler to 1 part of resin. A popular use for flox is to reinforce a sharp corner to provide more strength within that area. It is used in filling sections that require structural strength. It has much higher shear qualities than micro but is much harder and heavier.

Milled Fiber

As the name implies, this filler material is made by milling fiberglass into a very fine consistency. Milled fibers have a higher strength than cotton flox. The mixture of milled fiber and resin is used as a structural filler. It is also often used to form a fillet that requires structural integrity. Milled fibers and resin are used to form a "hardpoint" on a fiberglass structure. The hardpoint is used to attach other structures to the fiberglass. Care must be taken when working with milled fiber due to the very fine particles of fiberglass that can penetrate the skin.

Chopped Fiber

This material is the same as milled fibers, except it is available in different lengths. This allows its use as a filler for very specific areas where greater strengths are needed.

Cab-O-Sil

Cab-O-Sil is fumed silica that acts as a material to thicken a resin. Small amounts should be used. Larger amounts can act to inhibit the curing agents of some epoxies when used in concentrations greater than 15% by weight. Using Cab-O-Sil simply keeps a resin from running when you are applying it to a difficult area.

SuperFil

Poly-Fiber manufactures a substitute for dry micro called SuperFil. This filler material is mixed to the exact same consistency with each batch. In addition, it has talc added that facilitates the sanding operation. SuperFil may be used as a filler for virtually any material including metal, wood, and fiberglass. The epoxy in SuperFil has been optimized for the filling process. Micro normally uses resin optimized for the laminating process.

An important point-when you are mixing filler materials, always mix the resin and hardener thoroughly prior to adding the filler substance.

SAFETY ISSUES

A review of the safety issues involving composite construction is in order. One of the most important issues regarding safety when working with composites is skin sensitization. Many people become sensitized to resins. This is more common with epoxy resin than with vinyl ester resin. Regardless of the type of resin you are using you must protect your skin. Wear long sleeve shirts and protect your hands using a form of glove. What type of glove to wear is controversial. Many people can simply use a latex type glove found in drug stores.

However, a number of people are allergic to the powder often found inside the latex glove. Vinyl gloves are available and provide a very good alternative to latex. Rubber gloves are used by many people who place a cotton liner inside the glove. Several builders use barrier creams such as Invisible Gloves with success. No matter what you use change gloves often or recoat with creams often. Never wash your hands with solvents. Use soap and water.

Have adequate ventilation so you are not breathing the fumes from resins. A small fan will assist in moving the air out of the area. You also should wear a respirator. This is important when doing layups and also when mixing fillers. Those tiny spheres of glass called microballoons will do a number on your lungs if inhaled. Particles of fiberglass resulting from sanding operations should not be inhaled.

Vinyl ester resins pose a different type of problem. They have chemicals that should not be mixed together outside of the basic resin chemical. The catalyst used with vinyl ester, MEKP, is destructive to the eye. A face shield is preferable to use when mixing MEKP with the vinyl ester resin. Again, skin sensitization is not as common when working with vinyl ester as when working with epoxies.

Always acquire and read the Material Safety Data Sheet for the material you are using. These MSDS sheets will explain the hazards of each type of resin or solvent you are using.

Finally, mixing too large a quantity of a resin can cause a problem known as exotherming. The exotherm process is a consequence of the chemical reaction that takes place as a resin hardens or cures. This chemical reaction causes heat to be generated which in turn speeds up the chemical reaction causing even more heat to be generated. If you mix a large batch of resin you can create an "out-of-control exotherm." The container holding the resin will get so hot from the chemical reaction that you cannot hold it. The resin may actually bubble or boil and you will see smoke rise from the substance. You can prevent this by mixing small quantities of resin (8-10 ounces by volume). If you see that you are getting an out-of-control exotherm you should immediately pour the resin onto a sheet of plastic. This will allow the heat to more readily dissipate into the air. The exotherm process can actually cause a fire if the container is thrown into the wrong place.

A similar type problem can occur when putting foam blocks together if too large a micro joint is allowed. The foam is a good insulator and the heat will build without escaping. This can melt the foam and cause a core void.

BASIC LAYUPS

Now that we have set the stage and we understand some of the basics, let's get to the fun part-doing an actual layup. First of all, what is a layup? It is probably more accurately defined as a laminate. A laminate is one layer of reinforcement material impregnated with resin and usually added to a core material or to another layer of reinforcement material. This process is commonly referred to as a layup. If you are building a plans-built airplane you will become very proficient in doing layups. In a plans-built composite airplane you actually build most of the parts of the airplane and then bond them together. Building parts requires a lot of layup work. On the other hand, if you are building a kit aircraft you usually will only be required to bond the already completed parts together. However, you will still use the layup procedure for many activities on a kit aircraft.

The most important thing I want to recommend prior to our discussion is for you to do practice layups before doing the real thing. Any experience you can acquire doing basic layups will enhance the quality of your work on the actual airplane. Attend one of the EAA/SportAir composite workshops and make all of your mistakes while learning in a classroom setting. No matter what-practice.

Preparation

Before you actually begin the layup procedure you must be prepared. You should have everything on hand before you begin. This means gloves, respirator, mixing cups and sticks, scales or pump, squeegees, brushes, rollers, etc. Be sure the squeegees you are using have a smooth edge. If not, pass the squeegee over a sanding block to smooth it. The actual part itself must be ready for the layup. The cloth should be cut and ready to apply. The foam should be vacuumed clean of any debris. Temperature and humidity control is important. Begin by heating the shop, if necessary, and ensure the resin is warm (ideally 90 degrees F. or higher). The shop should be cleaned if you have been doing a sanding operation. Control of cleanliness is essential. If you are working on a large surface you may want to have someone to assist you. This is a good way to involve a member of your family. They can mix resins and maintain clean hands to move parts or do other activities that require cleanliness.

If you are bonding parts together you may encounter peel ply that was left in place by the kit manufacturer. Peel ply on a completed part is often difficult to see. You must remove this peel ply material prior to proceeding. The parts will not bond together if done over peel ply. The parts that are supplied with a kit have usually been manufactured in a mold and by the time you receive the part the resin has fully cured. This is important to the builder because the surface of a cured part must be prepared differently for an additional layup or bonding. This type of bond is called a secondary bond. Secondary bonding is the process of bonding together previously cured composite parts using a wet layup process. You should prepare the part according to the instructions provided by the kit manufacturer. This usually involves some type of sanding of the surface to remove any glossy areas. 180 grit sandpaper is often recommended to abrade the surface. Care must be taken to not damage any fibers.

Filling Cells of Foam

If you are doing a layup on a new piece of foam the cells of that foam must be filled to provide enough surface area for the cloth to stay in place and to achieve a strong bond. This also prevents excess resin from flowing into the core material and adding unnecessary weight. Polystyrene foam must be filled prior to application of the first layer of cloth. Some of the high-density foams do not require this filling step. Again, follow the directions of the designer. A slurry mixture of microballoons and resin is generally used to apply this first coat of material. SuperFil may be used very successfully to fill the cells on polystyrene foams. We will discuss the mixing procedure for slurry later in the article.

Cutting the Cloth

This subject was discussed in the previous article. As a quick review, you should use a Sharpie pen to mark cloth. Cut the cloth according to the directions provided by the manufacturer. Usually this will involve cutting on a 45-degree angle. Remember to be very careful with the cloth as you are cutting it and while applying it to the structure. It is easily damaged or distorted.

Mixing Resins

Now that we have everything ready to go we will mix the resin material. Use only non-waxed cups usually the 8-ounce or 16-ounce size. Remember that you are only going to mix small quantities. If you do mix any large quantities the resin should be immediately poured into smaller containers. A large amount of resin will create an acceleration of the chemical reaction-hence an exotherm. Exotherm temperatures can easily exceed 200 degrees F. and may actually damage the foam core itself.

The total amount of resin to mix depends upon the weight of the cloth that you are applying. You should try for a 1 to 1 ratio by weight of cloth to resin. In other words, weigh the cloth you are applying and mix a corresponding amount of resin. You will usually mix somewhere between 50-100 grams of resin at a time. If the kit manufacturer states that you should use a resin pump then use that method to mix your resins. Be aware that you should be careful of clogging or air bubbles that sometimes can occur with a pump. Balance scales are also used to mix resins. The important fact to remember is that you must be accurate in your mixing. This is particularly true with epoxy resins. Do not adjust hardeners to change cure rates in epoxies. The cure rate of vinyl ester resins is easily adjusted during the mixing phase. Again, refer to the directions for the specific resin material.

(I want to clarify a procedure mentioned in last month's article. If you encounter a resin that has crystallized you can use the following procedure to solve the problem. Put the can of resin in a container that will not melt. Remove the cap of the resin can and place the can in heated water to about 160 degrees for the length of time required to dissolve the crystals. You can then safely use the resin after it has cooled.)

Back to mixing. After you have carefully measured the resin and hardener, mix the two together for a minimum of 2 minutes. Take a mixing stick and cut the end at a 90-degree angle so it will reach the corners of the mixing cup. You must use a non-waxed mixing cup. Otherwise the wax from cups will mix with the resin. Stir the mixture spending about 20% of the time scraping the sides and corners of the cup to ensure adequate mixing. Do not mix too aggressively, as air bubbles will form. If any air bubbles form allow the resin to sit until the bubbles dissipate. Placing resin with bubbles in suspension on a layup can create a void of resin in the laminate. After you have completed mixing your resin leave a small amount in a cup so it can cure. This will provide a good test to see if the resin is curing properly. After a couple of days scratch the resin in the cup with a knife. It should leave a white mark if it is suitably cured.

Layup Procedure

After the resin is completely mixed pour some of the resin over the surface you are working on. Use your squeegee and spread the resin over the surface. Then place the reinforcement cloth in place at the proper orientation called for in the plans. Be very careful not to distort the cloth. Use a squeegee and your protected hands to ensure the cloth is in the proper place. Then, using a squeegee begin to press gently from the center of the cloth making sure you move the squeegee in the same directions as the fibers of the cloth. Keep the fibers straight and press the fabric into the resin while working the resin up through the cloth. Be careful not to distort the fibers. You can use a brush and a roller to assist in this process. After you have worked most of the resin through the cloth pour on the remaining resin over the top of the cloth and work it into the fibers. When the layer appears to have a nice even sheen that is flat you have a good layup. You do not want any air bubbles. Work air bubbles to the edge of the laminate to make them disappear. You can also use a brush that has been trimmed to stipple resin into areas that do not appear to have proper coverage or into problem areas.

If white spots appear in the laminate the cloth has not been properly wet out. A lighter color could also indicate an air bubble. Careful use of an ordinary hair dryer will change the viscosity of the resin enough to allow it to flow into certain areas. Do not hold the air dryer in one place for any length of time-keep the hair dryer moving. Otherwise, it can create a void if you leave it in one place.

When pulling the squeegee, excess resin will accumulate in front of it. Scrape this off into the mixing cup. Pressure applied to the squeegee varies with the type of resin, temperature, etc. Also, holding the squeegee at a 45-degree angle or less will move less resin. Holding it at 90 degrees or more will move more resin. Remember that the clock is running all the time on the working time of the resin. Normally, you will have 30 minutes or so to work until the resin begins to gel. This of course is dependent upon the type of resin, temperature, etc. Practice will make this entire process easy and understandable. Again, do several practice laminates prior to beginning on the actual structure. After doing this you will easily perfect your own technique of doing quality layups.

Inspection of Laminate

The laminate should be thoroughly inspected for air bubbles, any trapped air, excess resin, and of course dry areas or resin starved areas. Hold a light at different angles to observe any problems such as resin starved areas (not enough resin indicated by lighter color) or resin rich areas (too much resin indicated by darker or more glossy areas). When complete the laminate should have a nice even sheen. Have someone else inspect your work. They may see something you have overlooked. Inspect carefully for any delamination problems.

I am attempting to convey to potential builders the very basic knowledge necessary to construct a composite airplane. Composite building is not difficult. It simply requires a fundamental knowledge of the basics. When you undertake the building of a composite aircraft, the plans or assembly manual will guide you through the process. The basic skills needed for this type of construction consist of 2 primary items: knowledge of how to do a basic layup and knowledge of how to bond pieces of material together. Building a composite airplane from a kit is similar to building a model airplane. You glue the pieces together. Now, obviously the gluing procedure for an aircraft is much more critical and sophisticated than with a model but the basic principles are very similar.

Peel Ply

Peel ply is a polyester or nylon cloth material applied to the completed laminate while the resin is still wet. This cloth will not adhere to the layup thus allowing it to be peeled off at a later time, hence the words "peel ply". The application of peel ply is suggested when you are going to complete another laminate at a later time. If you are immediately going to apply another layer of cloth this step is not necessary. Peel ply provides an added benefit of absorbing excess resin from the composite skins.

Assuming you are going to apply another laminate later, or you are completing the final laminate, you will want to place peel ply onto the completed surface. Cut the peel ply to the proper size and lay it over the laminate while the resin is still wet. One layer of peel ply is all you will need. Use a squeegee and a brush to work the resin up through the peel ply. You may have to add a small amount of resin to get the peel ply to bond adequately to the laminate and to completely impregnate the peel ply and thus fill the weave. After ensuring the peel ply is saturated onto the layup, set the piece aside to cure. After the resin has cured you must then remove the peel ply. This is very important! Failure to remove peel ply will result in an unsafe bond of the next layer of reinforcement material. (Note that a number of kit manufacturers will ship pre-molded parts that still have peel ply attached. It is imperative this be removed prior to bonding the pieces together.)

After removal of the peel ply you will see that the laminate is very smooth and requires little preparation for the next layer of cloth or for the finishing process. The resulting surface is actually fractured somewhat leaving it better prepared for additional bonding or painting. Small glossy areas will be present on the peel-plied surface requiring abrading with 180 grit sandpaper or Scotchbrite pads. Without using peel ply, the composite surface will require extensive sanding or filling to prepare it for bonding or painting.

BONDING

Definition

Bonding is not a new process in aircraft building. In fact, bonding has been used in aircraft construction since the very beginning. The technique of gluing wood structures together has been used for years. Many of the same gluing elements found in wood is also found in composites. The term bonding, as applied to composites, is used to describe a common method for joining composite structures. Bonding is the process in which previously manufactured component parts are attached together during assembly of the airplane. Bonding composites can also be compared to welding metal. It is designed to be a permanent joining method. Several important points must be considered in bonding. We must know how much strength is needed in the joint, the bonding area required, what type of material must be used to provide the adhesion, and the procedure used to apply the bonding material. Preparing the surfaces that are to be bonded together is also crucial. As stated earlier, the majority of composite kit aircraft require some type of bonding procedure.

The first method of bonding used in amateur-built aircraft involves a four-step process. The first step is to cut and trim the component parts to get the proper shape and fit. The second step is to position the two pieces together. This can be accomplished by using temporary jigs or by temporarily gluing them together with a non-structural adhesive. Third, we must fill any gaps that may exist as a result of butting the two pieces together. The final step consists of actually creating the structural joint using wet (resin laden) strips of reinforcement material (usually fiberglass) bonded over the area connecting the two components together. (See figure 1.) If we are bonding together two pieces that are perpendicular to each other as in figure 1, then we must create a fillet.

The strength of a joint that is joined by a fillet is derived from the reinforcement material and not the fillet itself. The fillet is needed to prevent the reinforcement fibers from making a direct 90-degree bend without any radius. Composite materials must have a bending radius just like sheet metal. The number of strips of reinforcement material laid down over the fillet determines the strength of the bond.

An example of the type of construction explained is found in mating a wing rib to the wing skin. Another example is placing a bulkhead into a fuselage. Both of these are common types of construction techniques used when building a kit composite airplane.

The second method of composite bonding is termed "adhesive bonding". Adhesive bonding involves assembling component parts together using a structural adhesive in place of resins and fiberglass. Structural adhesives range from pre-formulated, two part mixtures that are in paste form to structural laminating resins that are mixed with flocked cotton or milled fiber to provide the necessary strength. The first method of bonding discussed uses laminating resins and reinforcement material to create a bonding overlap. Adhesive bonding requires the bonding area to be formed into the part when it is molded. This is usually accomplished by lowering one side of a part and raising a side of the second part. This allows the two pieces that will be bonded to slide over each other providing a precise fit. The joint that is formed when the pieces are joined in this manner is referred to as a "joggle." (See figure 2) With this type of overlap the builder is required to lay down the structural adhesive and apply some clamping pressure.

Some kit manufacturers prefer to combine both bonding methods to achieve the greatest possible strength. The key to achieving strength in any joint is to properly prepare the surfaces that will be joined. The laminating resin or structural adhesive must bond well to the surfaces. The surfaces must be cleaned properly and sanded.

You will often hear the term "secondary bonding" used in composite construction. This type of bonding simply refers to the bonding together of previously cured composite parts using the methods outlined above. Secondary bonding is commonly found in most composite kit aircraft. It requires proper surface preparation. Prepare the surfaces according to the instructions provided by the kit manufacturer. Usually, the surface will be abraded using 180-grit sandpaper or a Scotchbrite pad. Each of these will provide the proper surface preparation without cutting or damaging underlying fibers.

Steps of Bonding

When you receive your kit it will usually consist of many pre-molded parts that need to be bonded together. Sounds relatively simple-and it is-providing you carefully follow instructions. You must first of all remove any peel ply, prepare the surfaces, and then the pieces must be properly jigged to maintain an accurate alignment. Then the actual process begins. So, let's take the steps one at a time. We will use a simple "T" bond of 2 pieces of material to illustrate the steps.

Preparation

Most of the construction process of a kit aircraft involves secondary bonding. This means it is critical to properly prepare the surface. With a plans-built airplane or a kit airplane where you have just completed building a part, the piece is already prepared for the bonding step.

Assuming you are working with pre-molded parts, you must abrade the surface to ensure an adequate bond. Failure to do so will result in an unsafe bond. We have discussed this process earlier. Prepare the piece according to the instructions of the kit manufacturer. They will usually have you use sandpaper or Scotchbrite pads to scratch up the surface. 3M Rol-loc disks also work very quickly to prepare glass surfaces for bonding. You will want to make sure you have the proper fit between the pieces. A certain amount of sanding may be necessary to ensure this fit. You do not want any gaps between the pieces that are to be bonded together. The pieces must then be thoroughly cleaned to remove any contaminants. Often, residue from a mold release compound will be present on the piece. This must be removed. Acetone is often recommended for the initial cleaning followed immediately by a dry rag. The part should then be cleaned with soap and water to remove any solvents and then dried. Again, follow the directions of the kit manufacturer. I will amplify on the cleaning process in the next article.

Tack the Parts Together

The next step in the bonding process is to mate the pieces together and glue them in place using a non-structural glue. (Figure 3). This simply allows you to begin the bonding process. You can use 5-minute epoxy, hot glue, or instant glue to hold the pieces together. The parts only need to be tacked in just enough areas to hold them in place. This is not the final bonding of the pieces-it is simply a method of holding them together while we actually complete the bonding operation. None of the glues mentioned should be considered as structurally sound. Hold the pieces together until the glue sets up. Figure 2 shows our 2 pieces glued together using 5-minute epoxy. Assembly instructions will often require the use of clecos, screws, or clamps to attach the pieces together for the bonding process.

Note: As a reminder, remember to remove any peel ply that may be present on the component parts prior to bonding.

Create a Fillet

Once the temporary bond has hardened, a fillet needs to be made. This fillet provides a radius for the reinforcement material that will be bonded on next. The fillet alone is not strong enough to bond the parts together. Dry micro or SuperFil is used to make a non-structural fillet. Structural fillets, if required, are made by substituting microballoons with cotton flox.

Creating a fillet is relatively simple. Mix the SuperFil or micro and place it in a sandwich bag or in the middle of a piece of plastic. Close it up and snip a small hole in the bottom of the bag. (See Figure 4). This is similar to a cake-icing dispenser. Now squeeze the mixture from the bag along the corner area where the pieces are joined. A small amount is sufficient. An optimal fillet will have about a 3/16-inch to 5/16-inch radius.

After placing the SuperFil along the fillet area, take a tongue depressor and smooth the mixture into the corner area. Rounding the end of a tongue depressor with a pair of scissors will provide the exact size fillet you desire. Use the tongue depressor holding it perpendicular to the fillet and not leaned fore or aft. (See Figure 5). Remove any excess material that may have formed near the fillet along the sides of the pieces. This can be done using the tongue depressor. You do not want any micro or SuperFil where the glass will be applied except at the fillet itself. The completed piece should have the appearance of a smooth fillet. You are now ready to bond the pieces using reinforcement material.

Tape Glassing

In our example, we are going to use fiberglass to complete the bonding process of our two parts. This is often referred to as "tape glassing." On your project, you will complete this process according to the manufacturer's instructions. Usually at least 2-3 layers of cloth will be placed between the two pieces. Once the glass tapes are in place, the load path between the two pieces will be complete.

Wet layup strips of fiberglass cut at plus/minus 45 degrees are used for bonding nearly all components together. The most simple and clean way to make the layups is to pre-impregnate the material with resin while it is between two sheets of plastic. Clean 1 or 2-mil plastic drop cloth material works well for this. First, determine the total size for all pieces you will need. Obtain a piece of fiberglass slightly larger than this total size. Next obtain two pieces of plastic and cut them 3-4 inches larger than the fiberglass both in length and in width. Draw lines, using a Sharpie marker, on the plastic to form the necessary strips of cloth that will be the exact length and width needed. Flip the plastic over so the resin is not placed on the marks. Mix the required amount of resin necessary to saturate the cloth. Pour the resin over the plastic and place the fiberglass on top of the resin. Next place the second piece of plastic over the resin.

Using a squeegee, work the resin into the fibers through the plastic. In other words, you will be placing the squeegee on the plastic, not on the cloth. This enables you to keep everything clean and neat. Wet out the fibers completely just like any other layup. You can now pick up the entire piece of material and handle it without getting resin everywhere.

The next step is to use standard scissors and cut out the tapes you will need along the lines on the plastic. (See Figure 6). As you cut the strips, draw the scissors slightly toward you. This will enable you to make neat, easy cuts.

Next, lightly moisten the area to be laminated (on our "T") with resin using a brush. This will ensure that the bond is not resin-starved. Remove the plastic from one side of the tape. Place the strip down with the remaining piece of plastic facing up. Use a squeegee over the top of the plastic to remove any air bubbles and to smooth the resin evenly. After the tape is in place you can then remove the top piece of plastic. The process is then repeated for additional layers of cloth. (Be sure to remove the plastic). Plans usually call for the pieces of reinforcement material to be stepped out with succeeding layers. In other words, if the first layer is 2 inches wide the next layer would be 3 inches wide. The widest piece will be on the top.

Thoroughly inspect the piece for air bubbles and resin starved areas.

As you will see from the completed piece (Figure 7), the tape is providing the strength of the bond. This is a very efficient and effective method of bonding two composite parts together. Again, it is a commonly used technique for installing ribs in wings or bulkheads in a fuselage. Use of the plastic is not necessary, but it does allow you to remain neat and clean.

The final step is to place peel ply over the material. Laminate a strip of peel ply over the surface and allow the resin to cure. This will eliminate the sharp edges that will otherwise result from the fiberglass material. Remember to remove the peel ply after the resin has cured.

Joggles

Joggles are simply joints that have been pre-molded to fit precisely together. They overlap each other and are usually bonded together using a structural adhesive. This type of construction is very common in the mating together of fuselage parts. After bonding the parts together at the joggle, reinforcement material is usually applied for added strength.

Often, you will be required to trim excess material off a joggle prior to bonding. Usually you will place the two pieces together and then drill holes to allow for the installation of clecos. (The same clecos used for sheet metal construction.) Some instructions call for the use of clamps or even strips of wood glued on the surface to hold it in place and to maintain proper alignment. This will often be done in a jig to ensure alignment of the parts.

After the pieces are mated together, and the proper fit attained, you will then mix the structural adhesive. Structural adhesives are usually in a thick paste form. They consist of a Part A and a Part B mixed according to instructions. You want to be sure the ambient temperature is at least 60 degrees +. Most of the adhesives have a working time of 1-2 hours at 77 degrees F. Be sure you are ready to glue prior to mixing the adhesives.

Remove the clecos or other fasteners as you apply the adhesive to both parts. Instructions will often tell you to replace the clecos with rivets after applying the adhesive. The rivets are later drilled out after the adhesive cures. The resulting holes are then filled. Fiberglass strips are usually applied as a final step.

This provides you with a very basic idea of how to accomplish composite bonding. The key to doing this correctly is to practice. Cut a few pieces to form a "T" and bond them together until you perfect the process. This will save you a lot of problems when you begin working on the real thing.

PREPARATION OF COMPOSITE PARTS

Above, I outlined a brief procedure for preparing composite parts prior to bonding. This step is most important and needs to be amplified. The quality of a bond is directly affected by the preparation of the two parts being joined together. If contamination exists on either part the bond may be weakened even to the point of subsequent failure. Let me emphasize that you should follow the directions found in the kit manufacturer's manual regarding proper cleaning techniques. However, the preparation procedure is important enough to warrant more detailed discussion.

First of all, when bonding to an outside mold surface (such as many of the parts you receive from the kit manufacturer) cleaning and sanding of the parts is always required. When aircraft parts are molded a release agent is applied to the inside of the mold itself allowing the part to be removed when cured. This mold release agent must be removed prior to any bonding activity. The agent is barely visible. Water will usually remove this agent. After removal of the agent and any contaminants sanding is then accomplished.

Any surface that is smooth because of being next to a mold must be sanded prior to bonding. Any primer that may be present must also be removed. Sanding is generally the accepted way to prepare the surface. Opinions vary on the proper grit of sandpaper to be used. Usually 80 grit to 180 grit is recommended. Our workshop experience has shown that 180 grit sandpaper is usually satisfactory to prepare the surface. Use of 180 grit will ensure the underlying fibers are not damaged or cut. The surface should be thoroughly abraded (roughed) to completely remove any glossy areas.

Abaris Training, located in Reno, Nevada, instructs the military, airlines, and aerospace industry on composite construction and repair. I consult with Mike Hoke, the President of Abaris, regularly concerning composite construction. His company is considered to be one of the leading composite training companies in the United States. The following quote was taken directly from their training manual regarding surface preparation. "High surface energy is the goal, not mechanical roughness. One must shear up the top layer of molecules on the surface, creating many broken bonds, without damaging or breaking underlying fibers. A water break test can be used to determine surface energy. If surface energy is high, clean distilled water will spread out in a thin uniform film on the surface, and will not break into beads. If a water break free surface can be maintained for 30 seconds, one has achieved a clean, high energy surface suitable for bonding. If the surface is contaminated or at low energy, the water will break into rivulets and bead up.

Note that tap water will not work. It is dirty enough to contaminate the surface itself, and one will never pass a water break test using it.

It is important to note that the "high energy" condition, once achieved, is short-lived. Within about 2-4 hours the effect is lost. In composites, one should therefore wait as late as possible in the process before surface abrasion is performed, so that all else is ready and the adhesive can be quickly applied."

Dry the water off of the laminate with a hair dryer prior to applying the adhesive. If it is wiped with a cloth it will likely contaminate the area again. Do not use a heat gun for this process. The heat is too intense and may damage the cured resin.

This process also applies to peel ply surfaces. Even though a peel ply surface fractures the top layer of resin, it leaves a glossy, low energy surface in the weave pattern of woven cloth. This must be abraded for proper bonding.

So, how should you clean parts prior to bonding? The best procedure is to simply sand the surface, as discussed, and follow by a thorough cleaning with soap and water. If you are using solvents, use them initially to remove contaminants and then abrade the surface. Follow by soap and water and then immediately dry using a hair dryer. Remember to begin the bonding process within a few hours after preparing the surface.

AMINE BLUSH

Sometimes when working with epoxy resins, you may encounter what is referred to as an amine blush. The development of an amine blush is most visible under high humidity conditions. An amine blush is a surface effect resulting from the curing agent reacting with Carbon Dioxide (CO2) in the atmosphere rather than the epoxy resin. The by-product of this reaction is a compound that forms on the surface of the curing resin and readily absorbs moisture from the air. Under high humidity conditions, it will cause white streaks to appear on the surface of the resin and the uncured laminate. During cure, the white streaks usually disappear, but left behind will be a greasy or oily residue. Sometimes, this residue appears in the form of sweat like droplets. This residue is water-soluble and will wash off with warm water. Depending on the severity of the blushing event there may even be areas of surface tackiness. This tackiness is only on the surface, and will not effect the overall properties of the cured laminate.

Amine blush must be removed before any additional laminates are initiated. Sanding will remove blush but it will also quickly gum up your sandpaper. Wiping the surface with a warm wet rag prior to sanding will reduce the gumming tendency.

The best approach is to avoid amine blush altogether. Some resin systems are inherently resistant to developing amine blush. And for others, it may seem impossible to avoid it. But there are some things you can do to minimize it greatly. Number one and foremost is - DO NOT use unventilated combustion type heating sources to warm your shop. Gas or kerosene fired salamander heaters produce copious amounts of CO_2 and H_2O. These are the primary ingredients needed for producing an amine blush. So, use electric heaters or ventilated exhaust type combustion heaters to keep your shop warm.

You should avoid mixing resins or doing any layups if the temperature is less than 65 degrees F. If you do a layup at this temperature you should immediately move the part into a warm room for curing. Purchase a thermometer and a humidity indicator and place them in your work area. Avoid mixing resins and working with resins if the temperature is below 65 degrees F or if the humidity rises above 80%. The best solution is to place an air conditioning unit in your workshop area.

You can reduce the susceptibility to blush in the following ways:

- Work in the prescribed environmental conditions.
- Use "dry" and ventilated heating sources
- Use peel ply. Amine blush usually forms on the outer-most portion of a layup. By using peel ply the amine blush is removed when the peel ply is removed.
- Cap all resins as soon as possible. This reduces their exposure to the elements.
- Use a resin with demonstrated blush resistance. Some resins are more susceptible to blushing than others blush.

Use of peel ply, purchasing a blush resistant resin, and working in the right temperature and humidity will all work together to minimize amine blush.

HARDPOINTS

Often you will be required to mechanically attach another piece to a composite structure. One method of doing this is to fabricate a "hardpoint". If you mechanically attach a piece to a fiberglass part, the fiberglass must be reinforced in the area where it will be fitted to accept the loads imposed by the attachment. An example of a hardpoint is found on the GlaStar airplane. A welded fuselage frame is placed inside a pre-molded fuselage shell. The two are attached using machine screws that are placed through hardpoints fabricated in the fiberglass shell.

The most common method of fabricating a hardpoint is to route out a small amount of foam core material between the inner and outer laminates of the shell. See Figure 1. You must be sure not to remove any of the reinforcement material on the outer and inner shells. A piece of piano wire bent 90 degrees and placed in a drill works well for this step. The core material may then be removed using a shop vacuum. After the core material has been removed, a mixture of resin and milled fiber is injected to fill the void. After the material is injected through the drilled hole, a small piece of tape may be applied to keep the resin mixture from escaping. After curing, this material provides the strength needed to serve as an attach point. You must ensure that the entire area is filled with material and no air bubbles are present. After the material completely cures, a hole is drilled through the reinforced area to receive the screw or bolt.

This is one example of a hardpoint. Various kit manufacturers use different methods. Complete instructions on fabricating a hardpoint will be included in your assembly manual.

POST CURING

Post curing is a process used to obtain increased strength from a resin. If an epoxy resin is allowed to cure only at room temperature, its ultimate strength is rarely achieved. Post curing will increase two critical performance properties of an epoxy, chemical resistance and heat resistance. Fuel tanks constructed using an epoxy will benefit considerably from post curing. Post curing the entire airplane will increase overall resistance to the heat build-up inside the airplane resulting from the high temperatures found on any ramp in the summer. This build-up of heat can reach the glass transition temperature causing a weakened state of the resin itself.

To understand post curing, it is necessary to define the term glass transition temperature or Tg. The glass transition temperature is the point where the physical properties of a resin material start to decrease as temperatures are elevated. The temperature at which the resin "transitions" (T) from a hard, glassy state (g) to a soft rubbery state is called its Tg. At the Tg the tensile strength, chemical resistance, and hardness are significantly reduced while the flexibility is increased. As you might imagine, we do not want our completed airplane to reach the Tg temperature. To prevent this from occurring, one method is to post cure the resin. Another way is to paint our airplane a light color (usually white) to preclude the temperature on the inside of the airplane from being excessive. On a 90 degree F day, it is not unusual for the temperature inside your airplane structure to reach 180 degrees F plus. This is why you see most composite airplanes painted white. The white color helps reflect the heat keeping the temperature inside the airplane component parts as low as possible.

Another term often used is referred to as the Heat Deflection Temperature (HDT). The value of this number provides us with an idea of the upper service temperature limit for a plastic.

This is the temperature at which a resin will begin to soften if placed under a load. The HDT is usually about 20-30 degrees C lower than the Tg of a resin. The reason this is true is because the test to determine this value is accomplished under a load. For this reason, HDT is often a better indicator of the true upper service temperature limit for a given resin.

Regardless, it may be difficult for you to find the value of the Tg and/or the HDT of a resin. Resin manufacturers sometimes display one or both of these values within their instructions but many do not. You will have to seek out this information and determine the temperature and time required at that temperature for a post curing operation.

Should you post cure? Post curing is not absolutely necessary but it certainly is advantageous for all epoxy resins. Some resin manufactures require a post cure as standard practice. Basically, post curing your component parts and your composite airplane will ease your mind concerning the quality of your layups and bonds. If you are somewhat unsure about whether or not the resin properly cured on a particular layup or bond, post curing will likely solve that problem. If you are using epoxy to construct a fuel tank, you should definitely post cure that area. Post curing will ensure adequate fuel resistance not only for today's fuel compositions, but tomorrow's as well. Without post curing, you may encounter a gummy substance in your fuel tank that can plug gascolator screens and filters.

The bottom line in discussing this issue with Gary Hunter-an acknowledged expert on resins who works for Shell Chemical Company (a major manufacturer of epoxy resins) and EAA Technical Counselor-Gary recommends post curing a composite airplane. In his opinion, it takes all of the worries out of the construction process as it pertains to resins. It is a little more insurance that you are getting the maximum performance available from your resin system.

What about vinyl ester resins-do they require post curing? It is not necessary to post cure vinyl esters but it is helpful. Room temperature cured vinyl ester resins develop a larger portion of their ultimate properties, than most room temperature cured epoxies, and as such, they tend to be more resistant to chemicals overall. Therefore, the benefits of a post cure are not as significant. However, post curing simply improves these attributes even more.

How do we post cure? Raising the temperature of a typical laminate above standard room cure temperature performs post curing. Again, most resin systems will not reach their full strength unless they are cured at a temperature considerably above room temperature. Usually this temperature is about 40 degrees F below the Tg specified for the resin. The post cure temperature should never surpass the maximum temperature of another material in the laminate such as the foam. (As an example, polystyrene foam swells at a temperature around 165 degrees F). Without post curing the Tg of a resin used on your airplane will only be approximately 40 degrees F above the temperature at which the resin was cured. On a hot day the temperature of a structure can exceed the Tg. That could result in the entire composite matrix softening. This softening can result in the matrix of the heated portion being weakened and pulled away. The once smooth surface now exposes the weave of the fabric. High temperatures inside structures that have not been post cured can also affect structural integrity.

With this in mind, it is important that you follow a post curing procedure. You can do this yourself by introducing the proper amount of heat into a fireproof tent- like structure containing a specific part or the entire airplane. Introduce the heat gradually to raise the temperature to that specified by the resin manufacturer. Usually this will be between 140 degrees to 180 degrees F. Let it warm up slowly and evenly. The resin manufacturer will specify the amount of time required at this temperature. An excellent method of post-curing is to rent a paint booth from a local car painter. These booths are usually heated and you can place your parts or the entire airplane in the booth. Put a couple of fans within the booth to circulate the air for even heating rates. Another built-in area to post cure is your attic. The temperature of most attics will reach 140 degrees F. Granted, you have little control over the heating but small parts can be post cured in an attic area. A regular oven can be very effectively used to post cure parts. You can purchase foil back insulation material and construct a small post cure booth. The insulation can be taped together using duct tape. See Figure 2. You can then place a thermostat controlled electric heater in the booth with a couple of thermometer probes placed through the insulation to indicate the temperature.

It is important that you properly support parts to prevent any distortion. This does not mean that you have to place a wing back in a jig. This is assuming the resin has cured for at least a week. (If you are immediately post curing then you should leave the wings in the jig). Regardless, you must provide adequate support. This means positioning a wing on a flat surface with the leading edge down, as an example. Cowlings should be in place on the airplane or set on the floor with the forward edges down.

After the part has been heated for the required amount of time, slowly cool the temperature. Do not simply pull the part out of the heated area. Again, care must be taken to not exceed the break down temperature of other components such as the foam.

Many kit planes are manufactured from heat cured prepregs and as such, they are essentially post cured as delivered. However, the adhesive bond lines and tape layups the builder makes to assemble the prefab pieces will only have a room temperature cure. It only makes sense to post cure these bond lines and layups so the properties will better match the prefab parts from the manufacturer. This can be accomplished by introducing heat into a closed-up fuselage or wing area for a certain amount of time. After all, being made from foam or honeycomb cored composites, they are naturally insulating structures.

One way to do this is to use the exhaust from a vacuum cleaner as a mild source of heat. Many builders have used this procedure to introduce heat into a fuselage area for a period of time. All of the bulkheads that have been bonded and other resin applications will be post cured.

When to post cure is another question. It really does not matter when you post cure. It is usually best to wait at least 2 weeks after you have completed your layup or bonding to allow the resin to cure as much as possible at room temperature. Even if you have completed the work 6 months ago or longer you will still derive benefits from post curing.

Similarly, the fillers and faring compounds used to smooth and contour your airplanes painted surfaces will benefit from a post cure. Fillers inherently shrink as they cure, and after a few months in the hot sun a show quality finish can literally shrink away exposing the weave of the reinforcing fabric and other unsightly discontinuities. This is commonly referred to as "Print Through". Post curing your airplane after the filling work but prior to priming and painting will essentially pre-shrink these fillers and allow you to see and re-fill any resultant print through prior to final painting.

As you can see, there are many ways to post cure. There is nothing absolutely critical about the method. The slow introduction of heat up to the desired level followed by the proper time at that temperature is important. Again, slowly lower the temperature when you are through. As Gary Hunter states, "post curing is not absolutely necessary, but the results are always comforting on that first encounter with clear air turbulence."

<Note: Ron is working on the final section of this article. Once completed, the article will be appended and updated>

Information on the **EAA/SportAir workshops** can be obtained by calling 800-967-5746 or by contacting the website at www.sportair.com. The author may be emailed at ralexander@sportair.com

SportAir also has available a **video** on **Basic Composites**. This video may be obtained through the EAA Video Sales.

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