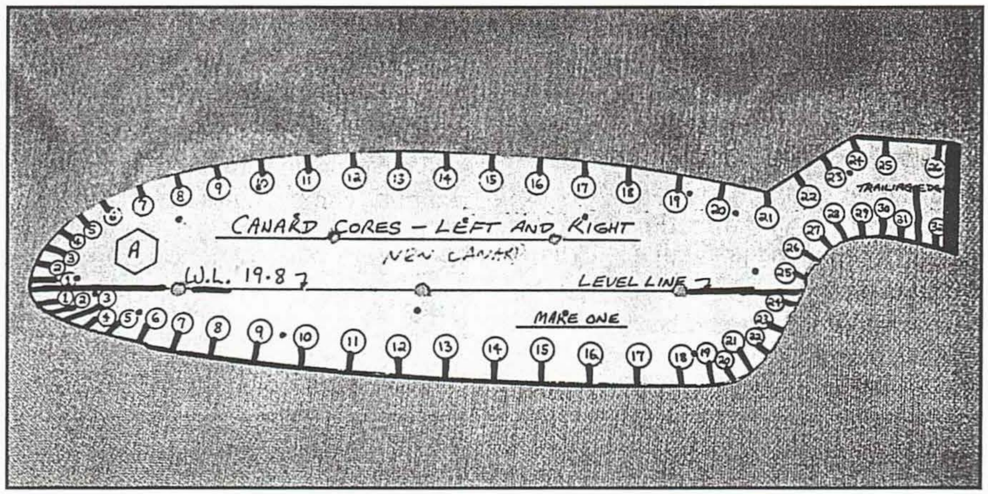
COMPOSITE CONSTRUCTION

Part II

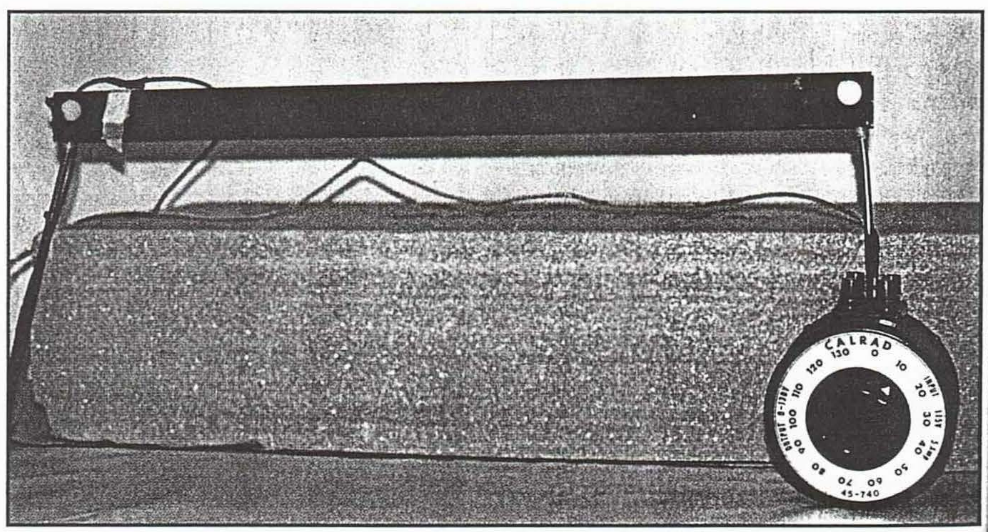
BY RON ALEXANDER

Last month I began a series of articles introducing composite construction. As a review, I discussed the history of composite aircraft within the sport aviation field, defined the term "composite," and listed the stages of building a composite airplane. The stages of construction are (1) decision and planning, (2) basic building and assembly, (3) systems installation, (4) filling and finishing, and (5) inspection, certification, and final pre-flight. Our discussion this month will begin with the basic building and assembly phase.

Basic building starts with safety. Safety considerations are of the utmost importance as you begin the actual construction of your composite airplane. Working with composites can be hazardous if proper precautions are not taken.



Template for hot wiring.



Hot wire device and polystyrene foam.

SAFETY ISSUES

All resins, hardeners, catalysts, solvents . . . in short, all chemicals used in composite construction should be considered hazardous. Some of these are more hazardous than others but all pose a potential health problem. Absorption of these chemicals through the skin is a major hazard. Epoxies can be absorbed through skin contact and the effects are cumulative with extended use. You may use a certain epoxy for years with no adverse skin reaction and then you suddenly become sensitized and develop a painful rash or other problem. A wide variance of opinion exists among professionals concerning the best way to protect your skin (hands in particular). It is impossible to make an emphatic statement concerning how to protect your hands. It's impossible because there are individual physiological differences. The bottom line is some people are much more sensitive than others. If you are just beginning to work with resins and your chance of contacting the chemicals is minimal, you can use Invisible Gloves, a skin barrier cream. The key to using Invisible Gloves is to recoat at least every hour. Barrier creams provide adequate protection when you have limited exposure. Latex gloves also offer protection and are widely used. Some people will use both Invisible Gloves followed by latex gloves. Sweating of the hands often contributes to an allergic reaction. To preclude this many people will use cotton glove liners followed by vinyl or butyl gloves. Overall, butyl gloves offer the best possible protection but they are expensive. You will need to decide which method works best for you. **Avoid skin contact with epoxies.** There are no safe epoxies.

Wear long sleeve shirts to protect your arms. Never wash your hands with

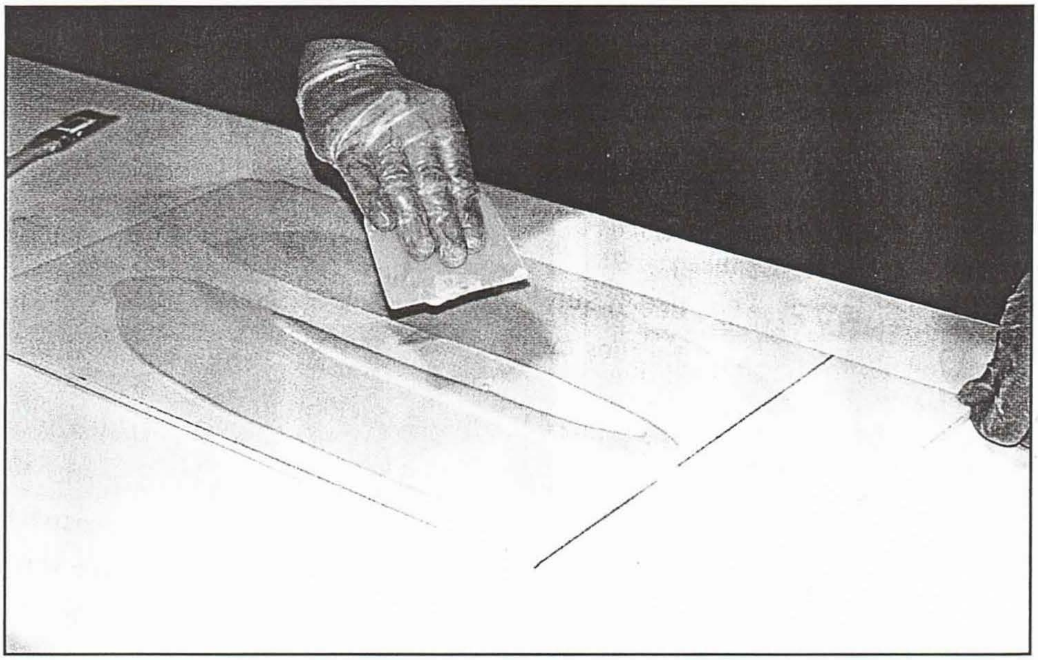
AIRCRAFT BUILDING

BASICS OF COMPOSITE CONSTRUCTION

PART TWO

BY RON ALEXANDER

In the May issue of ***Sport Aviation***, I presented the first part of a series of articles on the basics of composite construction. Workshop space, tools required, and the methods of working with core materials, cloth, etc. were discussed. In this part I will continue with fillers, safety issues and basic layups.



Spreading slurry to fill foam cells.

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 one part of resin. The third type of micro is called "dry micro." This mixture requires about five parts of microballoons to one 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 two parts of filler to one 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.

Super-Fil

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 vinylester 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. Always use soap and water.

Have adequate ventilation so you

solvents after you have been working with resins. Use only soap and water. A good cleaner for composite tools is ordinary apple cider vinegar. Denatured alcohol also works well. There is really no reason to use solvents with composite construction. Do not breathe the vapors emitted when using resins. Ensure that you are in a very well ventilated area and use a charcoal filtered respirator as an added precaution.

An additional hazard involved with using resins is the exothermic reaction that results from the curing process. A rapid increase in temperature results when the curing process of the resin system begins. Mixing large quantities of resins should be avoided. Often a large quantity of resins will exotherm to the point that the heat can potentially reach a temperature that will ignite a fire. To avoid this problem mix small quantities, no more than one quart.

Vinyl ester resins pose another type of problem. Skin sensitivity is often not as pronounced as with epoxies. However, vinyl esters must be catalyzed using MEKP (methyl ethyl ketone peroxide). This chemical is very hazardous if it contacts your eye. Be sure to wear eye protection if you are using a vinyl ester. Additional problems can be encountered if you are promoting vinyl esters. Usually a vinyl ester has been promoted when you receive it.

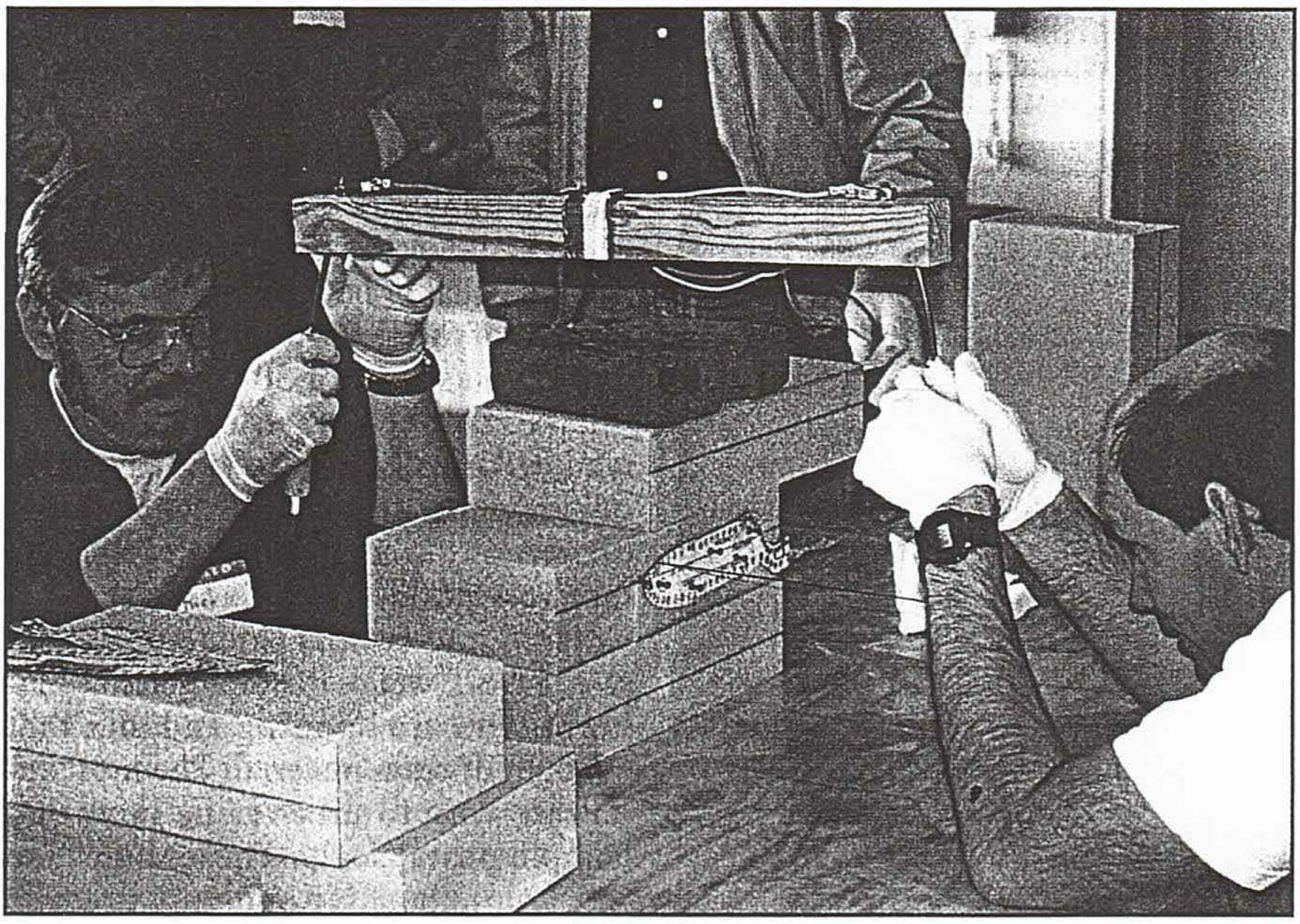
As I discussed last month, cutting the core materials can pose a safety problem. The only core material that we cut using a hot-wire device is polystyrene. All other foams emit a poisonous gas when burning. They must be cut using a saw or knife. Remember, do not burn the excess scraps of urethane foam. The gas emitted is cyanide. When cutting using a saw be sure to wear a dust mask to prevent breathing of the particles.

Sanding of reinforcement materials will release small airborne fibers into the air. To protect your lungs from these particles you should wear a dust mask or a respirator. Also, protect your skin from these small particles of glass. Mixing microballoons (small glass spheres) emits the spheres into the air. Do not breathe these glass spheres. Milled glass, Cab-O-Sil, and cotton flox also present the same problem. Do not breathe these particles or allow them onto your skin. Eye protection should also be used to prevent the particles from reaching your eyes.

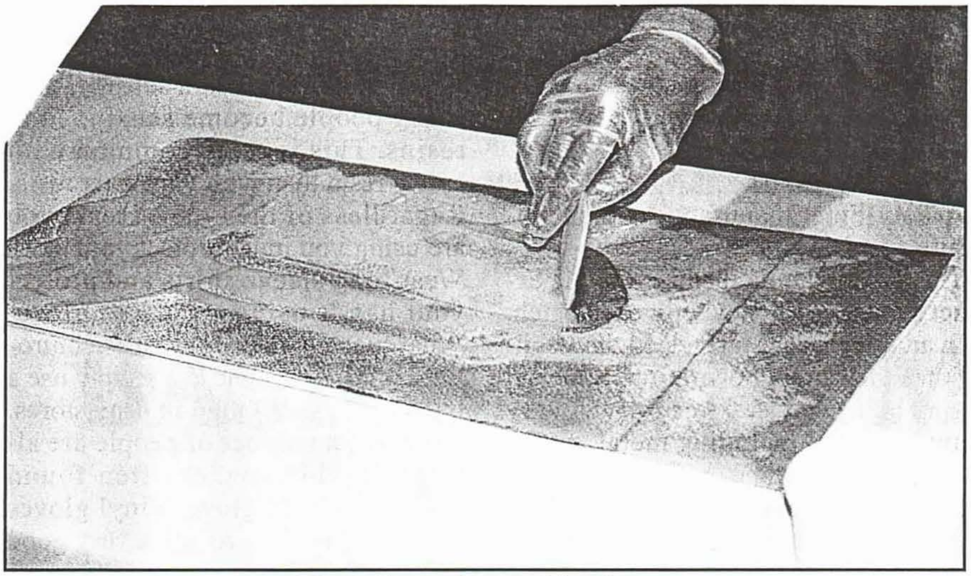
Composite construction does have certain hazards. However, with every type of construction we are confronted with different types of safety problems. Proper knowledge and adequate preparation will protect you from the risks involved in building a composite aircraft.

BASIC BUILDING TECHNIQUES

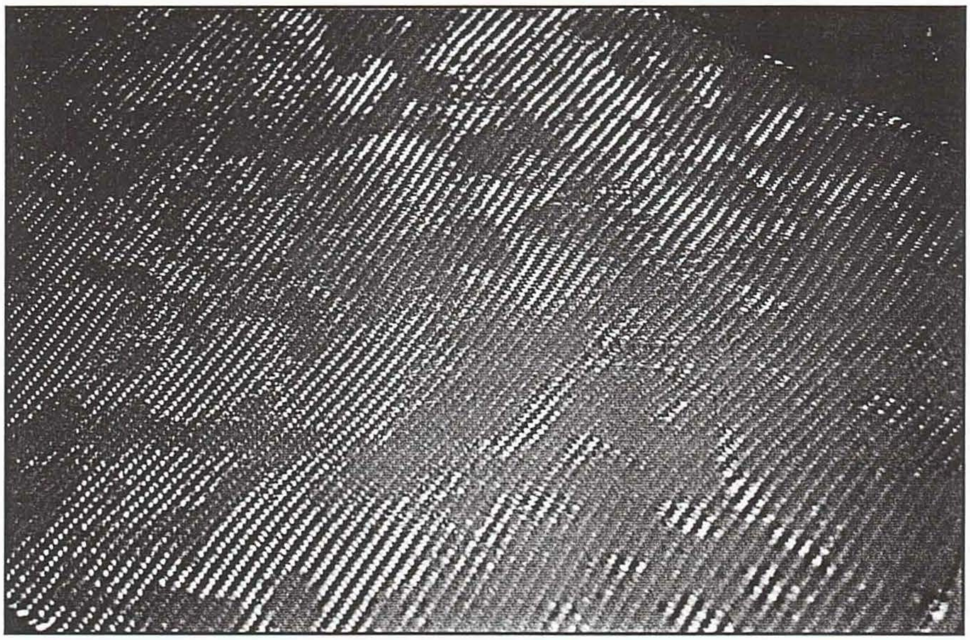
A brief outline of each step involved in composite construction follows. This discussion is introductory in nature providing an overview. The actual



Hot wiring foam.



Spreading resin onto fiberglass.



Light areas are resin starved.

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.

Vinylester 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 vinylester, MEKP, is destructive to the eye. A face shield is preferable to use when mixing MEKP with the vinylester resin. Again, skin sensitization is not as common when working with vinylester 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 steps involved require a more detailed analysis than space permits.

Cutting Foam Cores

If you are building an airplane from a set of plans you will be cutting the foam cores into the shape of an airfoil. Many kit airplanes come with premade parts precluding the necessity of learning how to shape a section of the airplane. Assuming you will need to cut the foam core, I will briefly outline the procedure.

You will need a large work table on which to lay your foam pieces for shaping. If we are using polystyrene foam we will make a template the shape of our airfoil from our plans using masonite or aluminum as a backing. Duplex nails are used to secure the template to the foam. Notice that the template has numbers on one side. These numbers are used to ensure uniform cutting by the two people necessary to hot wire the foam. One person calls the number where the actual wire is located and the other ensures that the hot wire on their side is on the corresponding number. Our hot wire device is nothing more than an inconel wire mounted between two posts with a source of electricity providing current through the wire. The wire becomes hot and actually melts its way through the foam forming a very smooth, even surface. Hot wire devices can be up to about 60" wide. Anything longer than that is difficult to handle.

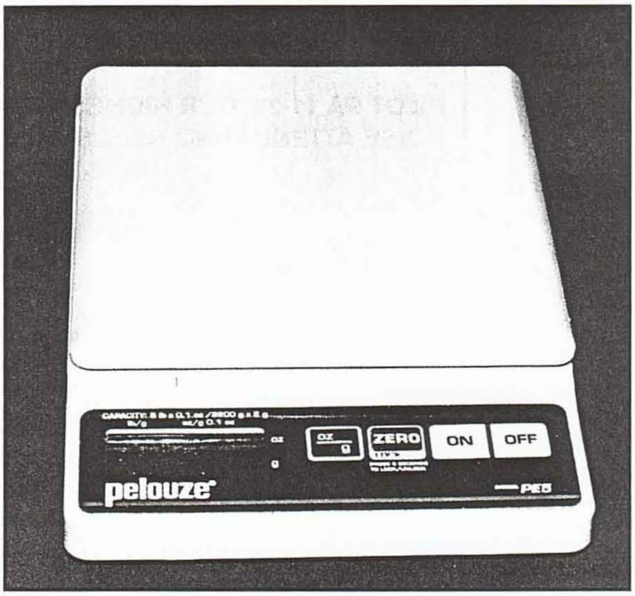
As you may ascertain, several pieces of foam will need to be cut and shaped then glued together to form a complete airfoil such as a wing. Final shaping of the piece is usually done by sanding. Once each piece has been properly shaped, all pieces are then glued together using a resin mixture. This completes the airfoil section. Usually additional shaping is necessary after the parts are glued. The entire foam structure is then prepared to accept the reinforcement material. Polystyrene foam has large cells that must be filled. If these cells are not filled the resin matrix will be absorbed into the foam through these cells. This will result in excess resin being used which adds to the overall weight. In addition, a poor bond with the reinforcement material may result due to voids that may be present. These cells are filled using a filler material. This can be a mixture of resin and microballoons mixed to the consistency of a thick gravy. Another filler often used for this process is SuperFil that is a lightweight, premixed material manufactured by Poly-fiber. A thin layer of the filler is then placed on the core material using a rubber squeegee. Urethane and PVC foams usually require a different viscosity of microslurry because their cells are very small.

Application of Reinforcement Material

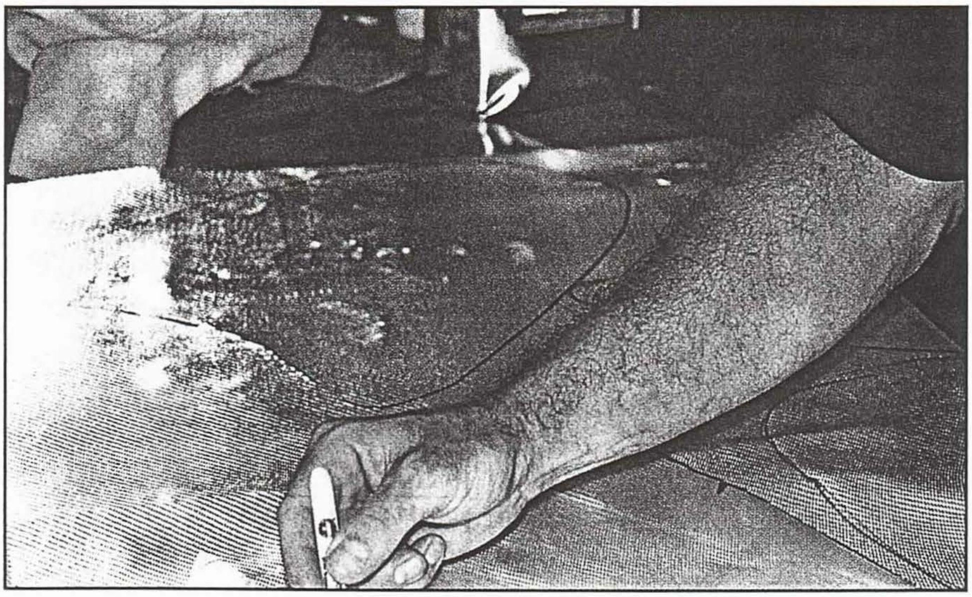
Recalling our composite structure, we have basically three materials. One is the core (usually foam), the second is the reinforcement material (usually fiberglass), and the third is the resin matrix (usually epoxy) which binds the materials. The three together form a very strong part.

After the foam has been properly sealed, we now are ready to "lay-up" the layers of reinforcement material. The type of material and the number of layers are determined by the aircraft designer. Be sure to follow the manufacturer or designer's plans. The fiberglass is usually placed on the foam in layers with the strength required determining the number of layers.

The work area should be clean with the ideal temperature being 70° to 80°F. Cut your pieces of fiberglass using shears designed for cutting this type of material. Keep the pieces clean. As a goal to minimize the overall weight of the airplane, the weight of the resin should equal or be slightly less than the weight of the fiberglass you are laying up. If you strive for 50-50 weight distributed between the resin and the glass you will usually achieve your objective. It is essential that you wet out the fabric thoroughly while being careful not to use too much resin. Excess resin is wasted and simply adds additional weight. So, weigh the fiberglass or material you are bonding and mix that amount of resin material. The most accurate way to mix resins is with a simple postal scale. These scales are fairly inexpensive and they provide both ounces and grams as units of mea-



Postal scale to weigh resins for mixing.


Marking fiberglass for cutting.

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

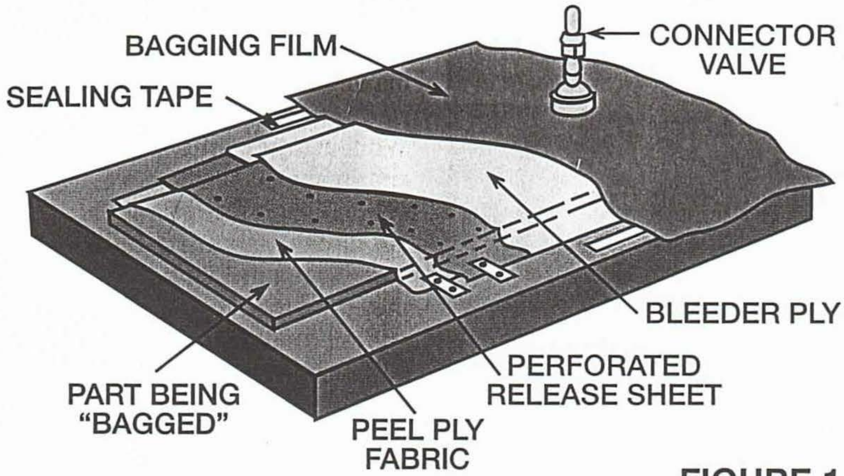


FIGURE 1

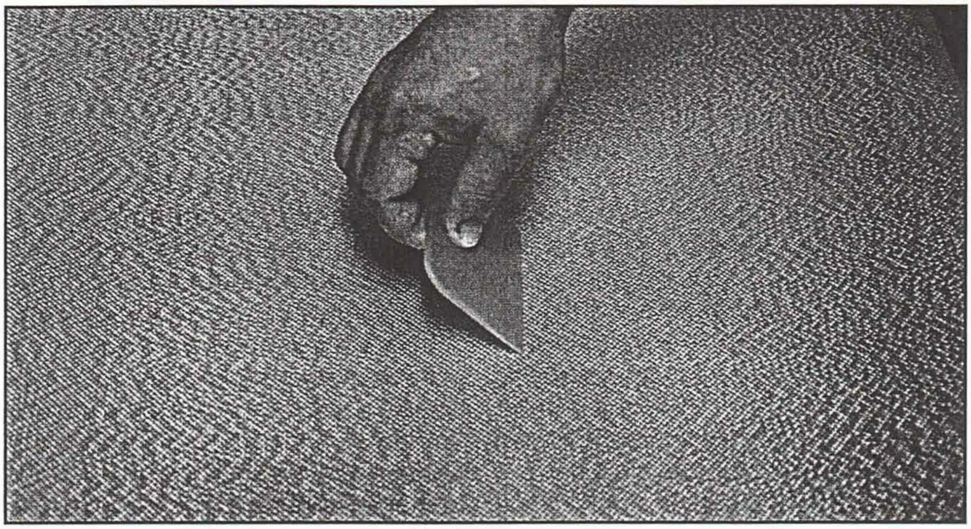
surement. Prepare yourself for mixing resins by protecting your skin. Using a measuring cup weigh the proper amounts of resin and hardener as noted on the container. Mix the two together by stirring with a mixing stick for a period of at least two minutes to ensure adequate blending. At a temperature of 70° you will usually have a working time of about 45 minutes, depending on the resin system used. Place the fiberglass on the foam surface orienting the fibers according to the design and then pour a small amount of resin on the fiberglass. Use the rubber squeegee to spread the resin onto the glass. Brushes and grooved laminate rollers are often used in the laminate process Be sure to cover the glass uniformly with the resin mixture. Clean up your tools using apple cider vinegar. Points to remember — proper mixing of the resin is essential to ensure adequate bonding strength, mix small amounts to avoid the exotherm problem, thoroughly wet the fabric without using excess resin, and don't forget to protect your skin.

Use of Peel Ply

Peel ply is a nylon or polyester fabric (similar to the fabric used on airplanes) which is used after a layup has been completed to remove excess resin and to ensure an adequate bond between layers of glass. This material is placed on the resin before it has cured. It is squeegeed into place actually wicking up resin from underneath the peel ply itself. The resin is then allowed to cure and then the peel ply is removed from the laminate. The result is a very smooth surface, derived without sanding, which will result in greater adhesion of subsequent layers of material. The use of peel ply on laminates (layers) of material has the following advantages: (1) peel ply causes the fibers to lay flat, (2) it reduces the amount of sanding necessary, (3) peel ply increases the adhesion in subsequent bonding and the adhesion of primers, and (4) it reduces the amount of resin used on the structure.

Vacuum Bagging

The term is familiar to many builders but often not understood. Vacuum bagging, very simply, is a more sophisticated method used to remove excess resin and to improve laminate quality. Vacuum bagging is a process using a vacuum pump to "draw" a vacuum on several parts of a laminate. This draws the parts very tightly together forcing out all voids and excess resin. The process also serves to hold reinforcements, resins, and core materials in close conformity to complex shapes. Without a doubt, vacuum bagging increases the time and materials cost of a laminate. However, it offers significant advantages when optimum strength to weight is essential. While specific materials may vary depending on the particular application, the basic components of a vacuum bag assembly include laminate (layer of glass), peel ply, bleeder



Basic lay-up.

Clean up items.

ply, bagging film, sealant, connector and vacuum pump (see Figure 1).

As noted, peel ply is also used with this application. The vacuum pump is attached through the connector valve into the bagging film. The bagging film contains the vacuum and applies pressure to the laminate. It must be able to stretch and conform without rupturing. Bleeder ply absorbs the excess resin and communicates the vacuum evenly over the entire surface. A perforated release sheet allows excess resin to transfer from the part being bagged to the bleeder ply. Peel ply separates the cured laminate from the bag assembly allowing removal after curing. The removal of the peel ply is usually not done until the surface is ready for painting or secondary bonding. Keeping it in place will protect the laminate surface from dirt and oil. A tremendous amount of pressure can be applied using this process. As an example, a vacuum of 15 inches of mercury will produce a force exceeding 1000 pounds per square inch. As you can see, this is a very efficient means of removing excess resin and eliminating voids.

Post Curing

Post curing is a process used to obtain maximum strength from a resin. To understand post curing it is necessary to define the term Glass Transition Temperature or Tg. The transition temperature of a resin from a hard glassy state 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. Post curing is performed by raising the temperature of the laminate above standard room cure temperature. 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°F below the Tg specified for the resin. The post cure temperature should never surpass any maximum temperature of another material in the laminate such as the foam. Without post curing the Tg will only be approximately 40°F above the temperature at which the resin was cured. On a hot day the temperature of a structure can exceed the Tg which could cause the entire matrix to soften. This softening can result in the matrix of the heated portion being softened and pulling away. The once smooth surface now exposes the weave of the fabric. Structural integrity can also be affected by high temperatures in structures that have not been post cured.

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 your part or the entire airplane. Introduce the heat gradually to the temperature specified by the resin manufacturer. Usually this will be between 140° to 180° F. Again, care must be taken to not exceed the breakdown temperature of other components such as the foam.

The above discussion will provide you with a basic understanding of composite construction. Most composite kit aircraft do not require shaping the airfoil section from foam. Instead, you are provided sections of the airplane that have to be bonded together. Next month I will conclude the discussion of composite construction by presenting information concerning bonding techniques and finishing composite surfaces. Hopefully, at the conclusion of these articles you will have a basic understanding of composite airplanes and how they are assembled. At that point you will be prepared to decide which airplane you want to build.

The author may be reached at ralexander@sportair.com. Diagram furnished by Richard Kunc.

The schedule for EAA/SportAir workshops is as follows:

November 1-2 Chino, CA
November 22-23 Atlanta, GA
December 6-7 Griffin, GA

For information on available workshops, prices, curriculum, etc., call 1-800/967-5746 or visit web site www.sportair.com ◆