

*Dutch aeroplane company VOF
introduction to comp. Version 2*

INTRODUCTION TO COMPOSITES



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1. Information

The Dutch Aeroplane Company (DAC) was founded on June 30th 2000 for the purpose to develop and market a small home-build aircraft.

1.1 The RangeR

At Cranfield Jan Laurier and Evert-Jan Cornet met the French aircraft "Dieselis". Built by Paul Lucas and Serge Pennec. This "Dieselis" used an automotive diesel engine. The diesel engine increases the weight of the aircraft but it has quite some advantages that justify this penalty.

A diesel has no spark ignition (no spark plugs and magneto's). The advantage of an injection pump and no carburetor, there's no risk of carburetor ice. The use of diesel fuel will reduce the chance of flammability. Its elevated torque range at mid-range rpm's permits the installation of a fixed pitch propeller with good cruise performance. A diesel engine has low fuel consumption, so it has an excellent range with a single tank.

After the first meeting with the "Dieselis" Jan Laurier and Evert-Jan Cornet traveled to Brest (France) to meet Paul Lucas. With Paul Lucas we discussed if it would be possible to transform the "Dieselis" into a kit aircraft. The conclusion was that the aircraft needed to be redesigned. The original "Dieselis" was mainly built out of wood.

The Dutch Aeroplane Company (DAC) started looking for an aircraft designer or company that could convert a wooden design ("Dieselis") into composites. After a long search, Aircraft Designs Inc. owned by Martin Hollmann was selected. Martin Hollmann has designed a lot of aircrafts and has many years experience in aviation.

Martin Hollmann and DAC made some changes by redesigning the "Dieselis". First the construction material was changed from wood into composites. This change will save the builder hundreds of hours of building time. The size and shape of the fuselage has been changed to accommodate larger pilots and passengers. A roll bar has been implemented for safety and easier access to the cockpit. The wing got a new laminar profile. The bottom wing skin is already connected to the main spar. Further, it's easy to (dis)connect the wing for storage and transportation of the aircraft.

During the design of the RangeR, Aircraft Designs Inc. used the JAR-VLA regulations for this project. Stress and flutter analyses are used for all structural parts. The adaptation on the engine and design of the redrive are made with the co-operation of Serge Pennec (builder Dieselis) and specialized companies like Technical Training Equipmnet (TTE). The newest Isuzu Y17DT turbo diesel with intercooler (90 hp) is used for the aircraft.

The RangeR is an innovative two seat aircraft that looks great and performs well. Further the low fuel consumption and low noise make it an ideal aircraft to own.



Figure 1: The RangeR

1.2 Getting started

The “assembly manual” contains a checklist with all the parts included in the kit. You have to read the “Introduction composites” before starting to build the airplane. This part will give you an introduction of composites, how to use composites and safety issues about composites.

1.3 Contact

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2. Technical specifications

2.1 Engine

- Engine: Isuzu Y17DT (Turbo and intercooler)
- Reduction drive belt drive: 1:1.66
- Power: 90 hp at 4400 RPM
- Propeller: 2 blade fixed pitch
- Fuel: Fuel diesel, jet fuel
- Fuel tank contents: 26.4 U.S. gal.

2.2 Dimensions

- Length: 6.0 m / 19.68 ft
- Wingspan: 9.75 m / 32 ft
- Wing area: 10.2 m² / 110.22 ft²
- Cabin width: 1.15 m / 45.3 Inches

2.3 Weights

- Gross weight: 750 kg / 1.650 lbs
- Empty weight: 500 kg / 1.102 lbs
- Useful load: 250 kg / 551 lbs

2.4 Performance

- Cruise speed (8000ft): 244 km/h / 131 kts
- Max. Sp. at (12000ft): 278 km/h / 151 kts
- Stall speed (clean): 89 km/h / 53 kts
- Stall speed (flaps 30°): 81 km/h / 44 kts
- Take off distance required: 153 m / 500 ft
- Landing distance required: 134 m / 439 ft
- Range at cruise sp.: 2300 km / 1429 NM
- Fuel consumption: 10 ltr/h / 2.6 USG/hr

3. Introduction to composites

The use of a combination of different materials, which result in superior products, started in antiquity and has been used continuously down to the present day. In early history mud bricks were reinforced with straw to build houses; more recently man-made stone was reinforced with steel bars (reinforced concrete) to build modern buildings, and bridges, etc, and now composites of matrix reinforced with fibers are used to build airframe structures. Modern composites owe much to glass fiber-polyester composites developed since the 1940's, to wood working over the past centuries, and to nature over millions of years. Numerous examples of composites exist in nature, such as bamboo, which is a filamentary composite. Through the years, wood has been a commonly used natural composite whose properties with and against the grain vary significantly. Such directional or isotropic properties have been mastered by design approaches, which make advantage of the superior properties while suppressing the undesirable ones through the use of lamination. Plywood's, for example, are made with a number of lamina. Such a stacking arrangement is necessary in order to prevent warping. In the language of modern composites, this is referred to as the symmetric lay-up or zero extension-flexure coupling (orthotropic).

Within the sport aviation world, the term "composite aircraft" is synonymous with sleekness of design and speed. These airplanes, composed largely of fiberglass, are becoming more and more popular. Certainly when we attend a large fly-in we see rows and rows of composite aircraft. To many of us these airplanes are somewhat mysterious. How are they built? What does the word "composite" actually mean? Are they safe? How difficult are they to build?

Actually, composite aircraft construction is not a new idea. Gliders have been constructed using fiberglass for many years. Throughout aviation history, advances in design have been made. Beginning with wooden structures that were covered with fabric, technology then advanced to welded steel framework and on to aluminum. As each type of construction was introduced, design improvements were made in strength and aircraft performance. Composite construction is yet another advancement for the aircraft industry. Fiberglass construction has been and continues to be used in manufacturing a number of parts found on most airplanes. Of course, we now see many airplanes that are constructed almost exclusively out of composite material. Composite technology has certainly changed the entire aviation industry and in particular sport aviation.

Amateur built composite airplanes were actually introduced during the 1970's when Ken Rands introduced the KR-1 (See figure 2). Burt Rutan also introduced the VariViggen that featured some composite construction, and the VariEze in 1976. This airplane design included a more comprehensive type of composite construction using moldless techniques. The term "moldless" will be defined later. The VariEze was very successful, inspiring Rutan to develop the Long-EZ (See figure 3).



Figure 2: The KR-1



Figure 3: The Long-EZ

During the 1980's, several other designs were introduced to sport aviation enthusiasts as popularity of this type of construction increased. It was during this period of time that aircraft "kits" were first introduced. Supply companies began offering material kits to builders to simplify the building process. Plans for composite airplanes could be purchased and then materials for each phase of construction could be obtained on an as needed basis. The amount of time needed for completion is a factor in building an airplane from a set of plans. With this in mind, several companies began introducing their own airplane designs in kit form. The objective was to allow the builder to spend less time actually constructing the airplane. A large number of parts and pieces were manufactured by the company and sold to individuals. This concept introduced the prefabricated kit airplane that is popular today in all types of construction.

From the late 1980's through today we have seen many composite aircraft kits offered to prospective airplane builders. The 1990's have seen a tremendous growth in the popularity of amateur built composite airplanes. Higher performance airplanes with many varying appearances are being offered by a large number of kit manufacturers and also by designers who offer plans. This is truly an exciting time for our industry.

Before beginning the explanation of composite construction, let's define the word "composite." The dictionary defines a composite as 'a complex material such as wood or fiberglass, in which two or more distinct, structurally complementary substances combine to produce structural or functional properties not present in any individual component.' In simple terms, a composite structure has more strength than the individual components that make up the structure itself. For our purposes, the component parts comprising a composite structure consist of a core material, a reinforcing material, and a resin binder. Each of these substances alone has very little strength but combined properly they become a composite structure that is very strong.

To further explain the structure, the core material (See figure 4) keeps the reinforcement fibers separated so they can be kept in maximum tensile (tension or stretching) strength. The reinforcement fibers carry the load. They must be properly oriented to achieve their maximum potential. The resin keeps the fibers in place so they can maintain straightness and deliver their maximum strength. The resin also binds the fibers to the core. Therefore, a composite structure is really a mixture of critical components. When loads are applied to a wing, as an example, the majority of the stress occurs at the outer surfaces. To take advantage of this principle, a

sandwich panel is designed with two working skins on the outside that are separated by a lightweight core. This type of design concentrates the strength in the area of high stress (outer surfaces) while 'reducing the weight in the area of low stress (inside the wing).



Figure 4: Core material

To further complicate the issue, you will hear the words "moldless" and "molded" used in composite construction. To define these words as they apply to us is relatively simple. Moldless construction, as the name infers, does not use a mould. This technique allows the builder to construct a part by forming a core material to a desired shape and then laminating the reinforcement material to the shaped piece to make up the final part. The core structure, usually a foam-like material, allows the builder to employ virtually any shape desired. Original designs such as the VariEze used the moldless type construction. Many airplane designs continue to use this type of fabrication. *Moldless techniques* allow the builder to produce a safe, superior airplane without the requirement of expensive tooling or extensive experience.

In contrast, molded fabrication uses a mold to build the part. A master mold or "plug" must first be built this can be done in the same manner as you would build a mold less part. DAC used CNC milled plugs for the wings and horizontal tail to get the highest possible accuracy of these flying surfaces (so that flight properties are not compromised) . A working mold was then constructed from the master and then finally the actual parts had been made from the working mold. Within our industry, molded composite construction is very popular. A large majority of kit manufacturers use this type of fabrication. DAC who fabricates the parts from molds supplies you, the builder, with the parts.



Figure 5: A plug of the RangeR

As an example, a wing kit consists of two wingskins, built from a mold, along with the necessary ribs. You would then assemble the wing by bonding the ribs to the wingskins and, of course, bond the skins themselves together. Compare this with moldless in which you actually form the wing, complying with a set of plans, out of a foam material. You then place several layers of fiberglass on the foam using resin to bind the two. The end result would be very similar. One type of construction (moldless) has a core material you have shaped that is solid whereas molded usually has thin cores that are sandwiched between skins and you actually assemble the supplied parts. Building a molded type composite kit is very similar to assembling a plastic model airplane. The building of most amateur built composite airplanes will require use of both types of construction.

To summarize our general discussion, composite structures combine the best qualities of diverse materials and have opened a new world to the airplane builder. Modern composite construction offers several advantages over conventional techniques. While safety tolerances for metal structures are often designed at 1.5 to 1, lightweight reinforced composites allow "over design" by factors of several times, increasing both safety and performance. These designs also achieve better aerodynamics by eliminating joints and rivets in addition to reducing problems of corrosion. Composite design allows an easy way to achieve a low drag airfoil. Composite airplanes are usually faster for a given horsepower than their counterparts because of airfoil shape and smoothness. One common misconception that does exist is that composite airplanes always weigh less than metal airplanes. This is often not the case. Fiberglass (See figure 6) is heavy. If we were to construct an airplane wing out of solid fiberglass we would have a very heavy airplane. Remember though, instead of doing this we insert a piece of core material between layers of fiberglass to reduce the weight. Kit airplanes (the RangeR also) use, ribs and more contemporary types of construction to achieve the high strength with a lower weight.



Figure 6: Fiberglass

Steps in Building a Composite Airplane

Building a composite airplane entails five stages of construction. These five stages are

1. Decision and planning
2. Basic building and assembly
3. Systems installation
4. Filling and finishing
5. Inspection, certification, and final preflight

3.1 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. Absorbing 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 is impossible because there are individual physiological differences. The bottom line is some people are much more sensitive than others.

3.1.1 Avoiding contact

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 (See figure 7) 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 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 exothermic to the point that heat can potentially reach a temperature that will ignite a fire. To avoid this problem mix small quantities, no more than one quart.



Figure 7: Safety objects

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 eyes. 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. DAC doesn't use vinyl esters so you will probably never work with it.

3.1.2 Core materials

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 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 micro balloons (small glass spheres) release the spheres into the air. Do not breathe these glass spheres. Milled glass, Cab-O-Sill, 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.

3.2 Resin matrix

The resin component in a composite serves to maintain fiber orientation, transfer loads and to protect the structure against the environment. While a composite's stiffness, flexibility and tensile strength are more affected by the reinforcement material, its heat resistance, shear and compressive strength are more dependent on the resin system. Three types of resin systems are available: polyesters, vinyl esters and epoxies. DAC don't use vinyl esters. All three require the user to mix a specific amount of hardener with a base chemical. The chemicals involved are shipped separately and combined only when the builder is ready to use the resin.

3.2.1 Polyesters

Polyesters are most widely used for industrial applications and within the boat industry. They are cheap and set up fast. Polyesters are easy to mix with the amount of hardener added only affecting the time needed to develop full strength. Polyesters are **not** suitable for application requiring high strength. They also will shrink over a period of time. You may have noticed an automobile fender repair where the paint cracked over a period of time. Chances are a polyester filler, it cracked under the paint. In short, polyesters are the least capable resin for structural aircraft use.

3.2.2 Epoxies

Epoxies have come to dominate the aerospace industry and are the basic resins used in most amateur build aircraft. Epoxies differ from polyesters and vinyl esters in that they harden through a process termed "cross linking". Epoxies are essentially long chains of molecules that intertwine when hardened to form a strong matrix of cross-linked chains. This provides an inner structural strength to the resin. When combined with the proper reinforcement material, composite structures using epoxies are unmatched in strength and lightness. Epoxies are packaged in two parts: a resin and a hardener. Like polyesters and vinyl esters, the resin to hardener mixture must be strictly followed. Adding more hardener will not accelerate the cure time; in fact, it may seriously impede the drying and strength of the cured resin. Epoxies are offered with different characteristics including strength, curing time, etc. Care must be taken to follow the manufacturer's recommendation regarding the type to use. Most epoxy cures at room temperature. Once this is complete additional strength is obtainable by raising the temperature of the epoxy through a process called "post curing". Usually this involves raising the temperature above 140° F (60,2° C) for a period of time. If this has not been properly accomplished the heat from a ramp on a hot day can

“post cure” the epoxy on an airplane. Working time with epoxies can be much longer than polyester and vinyl ester because you can use specific hardeners that have custom working times, some as short as four minutes, others over 24 hours at 70° F (21,3° C). This makes removing excess resin that may accumulate much less of a problem. Proper skin protection is a must with epoxies due to skin dermatitis, which can be caused by the chemicals.

3.3 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, aramide like Kevlar® and carbon fiber (graphite). Fiberglass is the most commonly used material. It has the best physical characteristics at the lowest price. One of the most widely used is termed E-glass. This type of fiberglass has the best physical characteristics at the lowest price. One other type with limited use in our area is S-glass that is about 30% stronger than E-glass but the cost is often two to three times higher.

3.3.1 Fiber direction

Without going into great detail, there are 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 (See figure 8). 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”. 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.

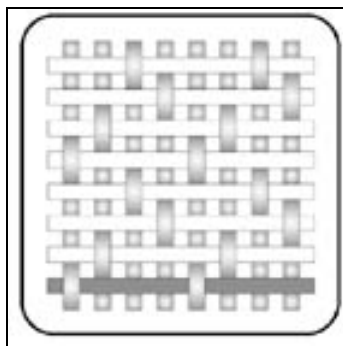


Figure 8: Fiber direction

Carbon fiber or graphite is a very strong reinforcement material. It is used on sail boat masts, golf clubs, etc. Carbon fibers combine low weight, high strength and high stiffness. In the custom aircraft area, carbon is used in critical areas such as

spars, etc. Working with carbon fiber is somewhat difficult and when it fails it will snap like a carrot. Of course, the failure point where this occurs is extremely high.

Kevlar® belongs to de aramides and is a product of the Dupont corporation. It is a very tough material with a high strength and is used in making bulletproof vests. Kevlar® is very effective in applications requiring resistance to abrasion and puncture. However, its use in primary structures is often limited by the relatively low compression strength and difficulty in handling

3.3.2 unidirectional fiberglass

With unidirectional fiberglass, all of the major fibers (See figure 9) 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 an in tapes. DAC only uses unidirectional fiberglass in the bar of the wings.

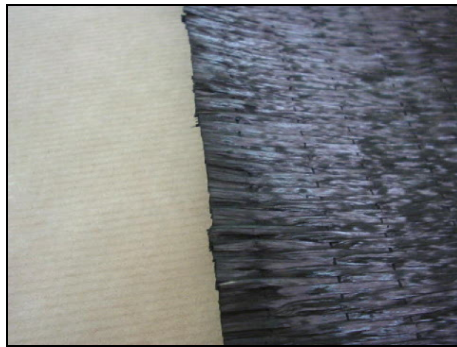


Figure 9: Unidirectional

3.3.3 Bi-directional fiberglass

In this glass, the major fibers run in two directions (See figure 10), 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.



Figure 10: Bi-directional

Bi-directional cloth can be stitched together in more than one layer to form what is known as bias cloth or triax cloth depending upon the number of layers involved. The most important thing for you to understand is that you must use the type and style of cloth called for in your plans. Do not experiment with cloth. The designer of the RangeR has specified the cloth to use based upon structural analysis. Use what they tell you to use. You will use bi-directional fiberglass to build the RangeR.

3.3.4 Handling and 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 shapes 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 (See figure 11 and 12). 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 (12,7 mm) 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.

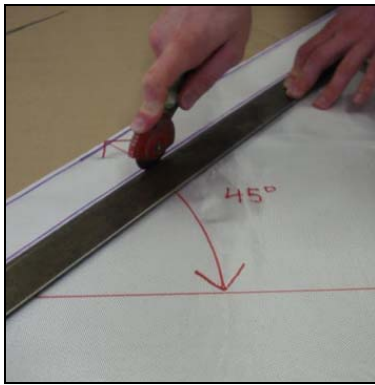


Figure 11: Cutting on a 45° bias



Figure 12: Cutting with a rotary cutter

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 (See figure 13 and 14). This is the best way to transport the fabric to your structure. 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 (the purple lines indicates the fiber direction) 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. Eying it will work fine. It is important to cut the fabric in the orientation called by the plans of DAC.

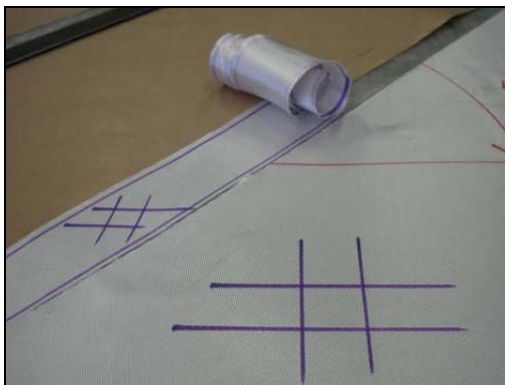


Figure 13: Rolling up the cloth



Figure 14: A large roll

3.4 Prepregs

Possibly you have heard of the term prepreg. This term simply refers to fabrics that have the resin already impregnated into the weave. They are shipped to the end user that way. Prepregs are manufactured primarily for high tech applications. Fiberglass is actually passed through the properly mixed resin and then the resin-

impregnated roll is immediately frozen. The fiberglass is then kept in the frozen state until it is applied to the structure.

You will probably never work with a prepreg. Your kit manufacturer DAC does. There are several advantages to prepregs. First of all, the resin system is properly mixed with accurate proportions of resin and hardener. The glass is wetted with the proper ratio of glass to resin. The threads of the material are more thoroughly impregnated with resin versus the commonly used hand lay-up. This is achieved through the squeezing process when the prepreg is manufactured.

Disadvantages of prepregs consist mainly of the requirement to store them in a freezer and the use of an expensive heat controlled oven. When shipped or stored, the temperature must remain cold to prevent the resin from curing. If they are warmed for any period of time they may begin the curing process. Prepregs are usually sold in larger quantities to production companies. It is not likely you will ever work with a prepreg unless it has been used to construct the part you are assembling. The major parts of the RangeR are constructed of high quality prepregs.

3.5 Preparation of composite parts

The procedure for preparing composite parts prior to bonding 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. It is important that you follow the directions found in the "assembly 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 DAC) 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 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 that the underlying fibers are not damaged or cut. The surface should be thoroughly abraded (roughed) to completely remove any glossy areas.

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 know 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.

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. Followed 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.

3.6 Peel Ply

Peel ply (See figure 15) is nylon or polyester fabric (similar to the fabric used on airplanes) which is used after a lay-up has been completed to remove excess resin and to ensure an adequate bond between layers of glass. DAC uses peel ply with red lines so that it is well visible. This material is placed on the resin before it has cured. It is squeezed 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 materials has the following advantages:

- Peel ply causes the fibers to lay flat
- It reduces the amount of sanding necessary
- Peel ply increases the adhesion in subsequent bonding and the adhesion of primers
- It reduces the amount of resin used on the structure

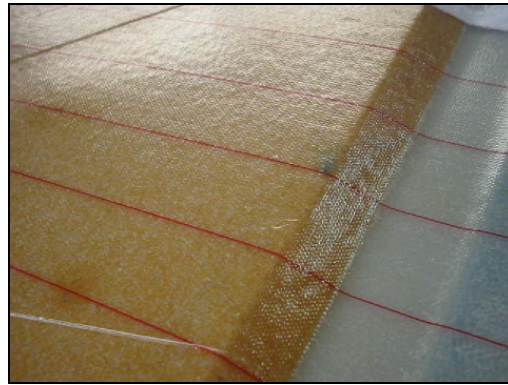


Figure 15: Peel ply

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 lay-up 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 completely impregnate the peel ply and thus fill the weave. After ensuring the peel ply is saturated on the lay-up, 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 DAC 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 entire peel ply you will see that the laminate is very smooth and requires little preparations 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. Without using peel ply, the composite surface will require extensive sanding or filling to prepare it for bonding or painting.

3.7 Bonding

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 are 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 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 component together. If we are bonding together two pieces that are perpendicular to each other as in figure 16, then we must create a fillet.



Figure 16: A "T" bond.

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: 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. Lowering one side of a part and raising a side of the second part usually accomplish this. 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 17). With this type of overlap the builder is required to lay down the structural adhesive and apply some clamping pressure. The fuselage of the RangeR is bonded by a joggle.



Figure 17: A "joggle"

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. Each of these will provide the proper surface preparation without cutting or damaging underlying fibers.

3.7.1 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 - provided you carefully follow instructions. You must first of all remove any peel ply, prepare the surfaces, and then the pieces must be properly jugged 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 (See figure 16).

3.7.2 Preparation

Most of the construction process of the RangeR 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. Prepare the piece according to the instructions of DAC. The first step is to cut and trim the component parts (See figure 18, 19 and 20).



Figure 18



Figure 19



Figure 20

They will usually have you use sandpaper to scratch up the surface. You still want to make sure you have the proper fit between the pieces. A certain amount of sanding may be necessary to ensure this fit (See figure 21, 22 and 23). 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 DAC.



Figure 21

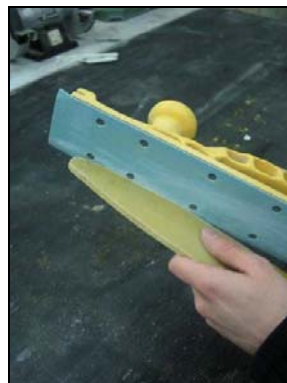


Figure 22



Figure 23

3.7.3 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 (See figure 24, 25 and 26). 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 24 shows the two 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.



Figure 24



Figure 25



Figure 26

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

3.7.4 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 Super-Fill is used to make a non-structural fillet. Substituting micro balloons with cotton flox, if required, makes structural fillets.

Creating a fillet is relatively simple. Mix the Super-Fill or micro (See figure 27 and 28) 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. 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 (4,76 mm) to 5/16-inch (7,94 mm) radius.



Figure 27: Mixing a fillet



Figure 28: The mixture

After placing the Super-Fill 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 or a sanding block will until you have the appearance of a smooth fillet (See figure 30). You are now ready to bond the pieces using reinforcement material.



Figure 29: Rounding an end



Figure 30: Placing the fillet

3.7.5 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 instructions (See). 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 lay-up 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 lay-ups is to pre-impregnate the material with resin while it is between two sheets of plastic. Clean 1- or 2-mil (25,4 μm or 50,8 μm) 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 (76,2-101,6 mm) larger than the fiberglass both in length and in width. Using a Sharpie marker, draw lines 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 lay-up. 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. 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 (See figure 31). This will ensure that the bond is not resin-starved.



Figure 31: Moistening with resin

Remove the plastic from one side of the tape. Place the strip down with the remaining piece of plastic facing up (See figure 32). Use a squeegee or brush over the top of the plastic to remove any air bubbles and to smooth the resin evenly (See figure 33). 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 in (50 mm) wide the next layer would be 3 in (76 mm) wide. The widest piece will be on the top.



Figure 32: Placing the strip



Figure 33: Smoothing the resin

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

As you will see from the completed piece, 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 certain neat and clean.

The final step is to place peel ply over the material. Laminate a strip of peel plies over the surface and allow the resin to cure. This will eliminate the sharp edges that will otherwise result from the fiber- glass material.

Remember to remove the peel ply after the resin has cured.

3.7.6 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° F (16° C). Most of the adhesives have a working time of 1-2 hours at 77 ° F (25° C) 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 stripes 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.

4. Basic lay-ups

Now that we have set the stage and we understand some of the basics to make a "T" bond, let's get to the fun part: doing an actual lay-up. First of all, what is a lay-up? 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 lay-up. If you are building a plans built airplane you will become very proficient in doing lay-ups. In a plan built composite airplane you actually build most of the parts of the airplane and then bond them together. Building parts requires a lot of lay-up work. On the other hand, if you are building a kit aircraft, like this RangeR, you usually will only be required to bond the already completed parts together. However, you will still use the lay-up procedure for many activities on a kit aircraft.

The most important thing we want to recommend prior to our discussion is for you to do practice lay-ups before doing the real thing. Any experience you can acquire doing basic lay-ups will enhance the quality of your work on the actual airplane.

4.1 Preparation

Before you actually begin the lay-up 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 lay-up. 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° F (32° C) 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 DAC. Peel ply on a completed part is often difficult to see. You must remove (See figure 34) this peel ply material prior to proceeding. The parts will not bond together if done over peel ply. The parts that are supplied with the 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 lay-up 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 lay-up process. You should prepare the part according to the instructions provided by DAC. See the "assembly manual". 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.



Figure 34: Removing peel ply

4.2 Filling Cells of Foam

If you are doing a lay-up 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. Follow directions of DAC if you have to do this. A slurry mixture of micro balloons and resin is generally used to apply this first coat of material. Super Fill may be used very successfully to fill the cells on polystyrene foams.

4.3 Cutting the Cloth

This subject is discussed earlier. As a quick review, you should use a Sharpie pen to mark cloth. Cut the cloth according to the directions provided by DAC. Usually this will involve cutting on a 45-° angle (See figure 9 and 10). 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.

4.4 Mixing Resins

When everything is prepared you can mix the resin material. Use only non-waxed cups, usually the 8 or 16 oz (0,22 of 0,45 kg) 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 exothermic. Exothermic temperatures can easily exceed 200° F (93,5° C) 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 2-4 oz (0,050-0,100 kg) of resin at a time. When you are using a resin pump 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 (See figure 35 and 36). 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.



Figure 35: Weigh of the resin



Figure 36: Mixing the resin

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° F (71° C) 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 two minutes. Take a mixing stick and cut the end at a 90° 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 lay-up 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.

4.5 Lay-up Procedure

After the resin is completely mixed pour some of it 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 lay-up. 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 hair dryer in one place for any length of time keep it 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° angle or less will move less resin. Holding it at 90° 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 lay-ups.

4.6 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 delaminating problems. In the "assembly manual" you will read when someone else have to inspect your work.

5. Composite fillers

Many applications of composite construction require a filter material to thicken and/or reduce the density of the resin mixture for various purposes. The resulting mixture of the filter 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 filter material. Several different filter materials are used with resins. The more popular ones will be discussed.

5.1 Micro spheres

Micro balloons, 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 micro balloons not to inhale any of these glass particles. Quartz "Q cells" is another type of micro balloons 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 micro balloons 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 micro balloons to one part of resin. The third type of micro is called "dry micro." This mixture requires about five parts of micro balloons to one part of resin and it is used as a filler material.

Micro must never be used between plies of a lay-up, as the final strength will be severely decreased.

5.2 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 that is much harder and heavier.

5.3 Milled Fiber

As the name implies, milling fiberglass into a very fine consistency makes this filler material. Milled fibers have a higher strength than cotton floss. The mixture of milled fiber and resin is used as structural filler. It is also often used to form a fillet that requires structural integrity. Milled fibers and resin are used to form a "hard point" on a fiberglass structure. The hard point 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.

5.4 Chopped Fiber

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

5.5 Cab-O-Sill

Cab-O-Sill 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-Sill simply keeps a resin from running when you are applying it to a difficult area.

5.6 Super-Fill

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

6. Basic shop 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



Figure 37: Scale and depressors

- Saws (hacksaw, coping saw, and pad saw)
- Carpenter's level
- Carpenter's square
- Clamps
- Sanding blocks



Figure 38: Sanding blocks

- Electric hand drill
- Fabric scissors
- Rotary cutter
- Grooved laminate rollers
- Charcoal filtered respirator
- Brushes and rollers



Figure 39: Brushes and rollers

- Knives (including utility knife and large serrated knife)
- Respirator
- Rubber squeegees
- Straight edge
- Vacuum cleaner
- Hair dryer



Figure 40: A hairdryer and grinder

In addition, you will need mixing cups, tongue depressors for stirring, and a large supply of latex gloves. Other tools that is nice to have consisted of a “Dremel” tool with bits for shaping and cutting, a die grinder, drill press, band saw, rotary or orbital sander etc.

7. Reading blue prints

Although most kits are not put together from blue prints but instruction manuals, it is important to be able to work from drawings. The drawing will depict the completed part and also detailed machined parts to a level of detail so that a machinist can make them. Dimensions, tolerances, finishes are specified. Composite parts drawings shows ply lay-up schedules and materials used. Often the supplier and his phone number are also shown. The practice is to make the drawings as small as possible and big enough to show the necessary detail. Ribs and fuselage sections are drawn full size and require large sheets. These full size patterns are used for making molds and tooling. Some other sections are also drawn full size so those dimensions can be scaled off of the drawing. For builders of a prototype it is important to read these drawings but for a builder of a kit aircraft it is not necessary.

Reading blue prints takes common sense and it is not hard.

8. Workshop space

To begin this discussion it is important to note that you do not need a pristine laboratory to build the RangeR. Like most aircraft building projects, if you have a two-car garage you have what is needed. 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 lay-ups, 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 lay-up.

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° 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° angle to facilitate cutting on a bias. The table should be wide enough to handle the fabric you will be using. 60 in (1500 mm) should be enough. You should be able to unroll about 4-5 ft (1200-1500 mm) 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. This material can be 1/8 in (3 mm) thick high-density polyethylene or something similar.

Another table can be constructed to do your resin mixing and basic lay-ups. This table should be roughly 3 by 8 ft (900 by 2400 mm) 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 that is 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.

DO NOT USE an unventilated combustion type heating sources to warm your shop. Gas or kerosene fired salamander heaters produce copious amounts of CO₂ and H₂O. These are primary ingredients needed for producing an amine blush. So, USE electric heaters or ventilated exhaust type combustion heaters to keep your shop warm.

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 and to move the air outside the workshop. If you really want to do it right, mount an exhaust hood over your lay-up 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° F (18,5° C) resins become thick. The colder the temperature, the thicker the resin. That means you will have difficulty pouring the resins from their containers. 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° F (71° C) or so until the crystals dissolve. So you should avoid mixing resins or doing any lay-ups if the temperature is less than 65° F (18,5° C) or if the humidity rises above 80%. If you do a lay-up at this temperature you should immediately move the part into a warm room for curing.

Purchase a thermometer and a humidity indicator (See figure 41) and place them in your work area. The best solution is to place an air conditioning unit in your workshop. 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.

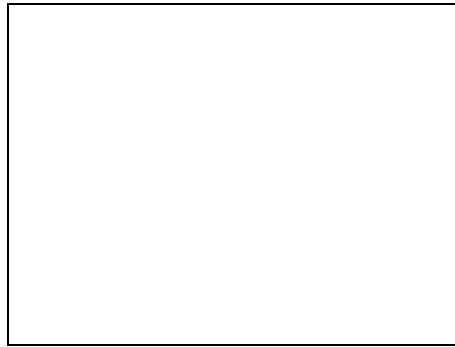


Figure 41: A thermometer and a humidity indicator

8.1 Organizing shop area

The RangeR can be built in a two-car garage. The fuselage sits on its wheels and is pushed outside to mount the wings. It only takes a few minutes to put the wings on. Then the wings are jiggged up to the fuselage while the aircraft is outside with the wings on. In the evenings, the wings are removed and the RangeR is stored inside.

8.2 Storage of pre-molded parts

The manner in which your pre-molded parts are stored is very important. Care and thought should be exercised when laying pre-molded parts away for some future use, which could be months away. Try to store these parts in a position so as to not produce any distorting forces (i.e., store them supported in a position as close to actual use orientation as possible).

Unlike fiberglass composite parts, the carbon fiber parts are much stiffer and less prone to distortion. However it is still highly recommended that great care be exercised when storing these valuable components. Also, all composite parts should be kept away from direct sunlight for any extended periods of time. An afternoon or a day is perhaps ok. However a week, for example, in direct sunlight would not be acceptable.

8.3 Shop and floor area

Since parts will likely be placed on the floor occasionally, oil, grease and dirt must be removed from the floor to prevent contamination of the parts. Many builders use old carpeting on the floor in work areas. The carpeting not only covers the soiled concrete floor, it is also much more comfortable to stand on for extended periods of time.

A word of caution. When you get to the point in building where you are working with the electronics, be aware that static electricity can destroy your electronic equipment if small precautions are not taken. One of the most effective antistatic floor sprays

and certainly one of the cheapest, is to put a couple of teaspoons of regular laundry style fabric softener (any of them will do) in a spray bottle, fill the bottle with water and spray the carpet once or twice a week lightly to control the static.

9. Composite finishing

Finishing a composite airplane requires a considerable amount of time. Many experienced builders state that 1/3 of the total building time on a composite airplane is consumed during the finishing process. Obviously, this stage of construction is very important to the builder because it determines the final look of the aircraft.

Why is finishing necessary? A completed composite part will exhibit a rough look. The weave of the reinforcement material will be very apparent. Filling the weave is required as the first step to a smooth final finish. We have all seen the extremely smooth surfaces found on composite aircraft. That finish is the result of a lot of hard work. There are no shortcuts to this process. New products are being developed that make the work easier but time and effort is still required.

It is also interesting that most composite aircraft are painted white or a light color. This is necessary because of the heat build-up that occurs when the airplane is parked in the sun thus creating a high skin temperature. This is detrimental for two reasons:

- It causes epoxy to shrink more than normal
- It will overheat and damage foam cores

In 90° F (32° C) ambient temperatures white paint has a skin temperature of 140° F (60° C) and black painted skin can reach 210° F (99° C). You have two choices - either fly only at night or paint the airplane white or a light color.

10. Finishing problems

Before beginning our discussion on how to finish a composite surface, let's take a look at problems that currently exist on several completed aircraft that are flying today. Too much filler of any kind can create problems. Fillers are to be used for just that and not for building parts. In areas subject to flexing and on leading edges, excess filling may cause a problem. Indeed, this has caused problems on many aircraft that are in the field today.

Secondly, polyester fillers and surface primers have been used on a number of aircraft throughout the years. Polyester resin is prone to shrink and then crack with time. The shrinkage of the polyester filler or primer will certainly result in the final finish cracking and sometimes even peeling. In other words, when the polyester shrinks it takes the topcoat with it. This occurs even when a high quality polyurethane paint is applied over polyesters. There are a number of airplanes being repainted today because too much polyester filler or primer was used.

Thirdly, thick coats of high build automotive polyurethane's will also crack. Most two-part polyurethane's will flex very well as topcoat paints but thick coats of the product

will crack. You should apply only enough paint to get the color and gloss you desire and then quit. The quest for the perfect finish should be done with sandpaper and a buffer, not the spray gun.

Lastly, epoxies must be protected from UV radiation. Epoxy resins are subject to deterioration when exposed to sunlight. One-resin manufacture cautions that their highest-grade epoxy can totally break down in 15 months if not protected from the sun. This is true of all epoxies. The symptom is chalkiness followed by delaminating. The best way to protect epoxy is to use a primer that will block sunlight. When paint manufacturers state that their products have 100% UV protection, they are talking about the paint or primer that is being protected from UV radiation and not the substrate it is covering. Primers that totally block the sunlight are simple insurance policies.

Aircraft composite filling and finishing has taken most of its technology from the automotive industry. The reason for this is because automotive technology has been available and people are familiar with it. The problem in doing this is that airplanes flex more than cars. Again, this can result in a cracking problem if the wrong type of filler or primer is used.

10.1 Finishing steps

The purpose of this chapter is to show you the finishing steps. There are three steps.

10.1.1 Step 1 - Filling

The classic method filling rough areas or weave patterns is to use a homemade "micro or slurry," a mix of epoxy with micro balloons. The idea behind this is to offset the epoxy resin with a lighter material. You add micro balloons to epoxy until you get a consistency like peanut butter. You then trowel or squeegee the mixture into the area you want to fill (See figure 42).

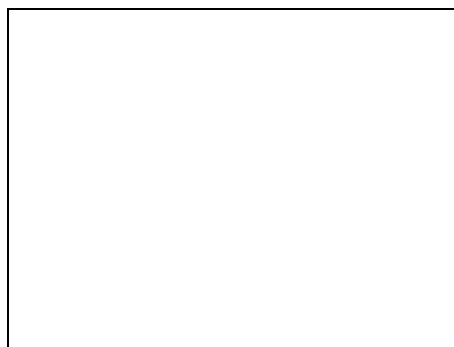


Figure 42: Filling the RangeR

Many people have used a polyester in place of micro. A polyester will shrink with time. It is also heavier than slurry. We do not recommend the use of a polyester on an airplane unless you want to repaint it after a few years.

Another product available is called Super Fill. This commercially formulated product is a pre-mixed epoxy filler. It eliminates the guesswork necessary in mixing your own micro. It is made in a high-shear mixer that allows more filler to be used. When mixing your own micro, if you add too little filler the mixture is difficult to sand and if it has too much filler it will become weaker in shear. Many builders are now using Super Fill instead of mixing their own slurry. Of course, weight is important when we are filling. Hand mixed micro can weigh as little as 6 lb per gal (2,7 kg per $4,55 \times 10^{-3} \text{ m}^3$) compared to polyesters that weighs about 12 lb per gal (5,4 kg per $4,55 \times 10^{-3} \text{ m}^3$). Super Fill weighs in at 3 1/2 lb per gal (1,6 kg per $4,55 \times 10^{-3} \text{ m}^3$) making it the lightest mixture.

The filler is mixed by weight and then spread onto the area to be filled. You must be careful not to put too much Super Fill on the surface. Too much filler of any sort has the potential of cracking over the years. You start with very thin coats of filler forced hard into the surface. Prior to applying Super Fill, you must ensure that the surface is clean. It must be free of any wax from release agents. Sand the surface using 180-220 grit sandpaper as a final step before applying Super Fill.

Super Fill will have a consistency of soft peanut butter when properly mixed. It should be spread over the surface using a squeegee. This should be done at a warm temperature for best results 75° F (24° C) or higher. Your objective should be to fill the low spots in the fabric weave without totally covering the high spots. Super Fill should be translucent over the high areas and fill the low areas. Don't use Super Fill or any filler as a build-up to give shape to leading edges or fillets. Fillers are not structural materials. Any build-up of Super Fill more than 1/4 in (6 mm) is too much.

You should start with a very thin coat of Super Fill forced into the surface. This coat simply ensures bonding of the fill coat that will follow immediately. Put on more Super Fill and start to fill the fabric weave. Don't leave excessive squeegee marks. If you are doing a large, flat surface you can use a broad metal trowel to apply Super Fill. We recommend using peel ply over Super Fill. This will enhance the smoothness of the surface when the filler has dried and the peel ply is removed.

Be sure you remove all peel ply.

If you feel as though you have not filled an area enough add another coat. Let Super Fill dry overnight prior to sanding.

Now we are ready to sand - the composite builder's favorite activity. A few rules:

1. Use only high quality sandpaper. Cheap sandpaper can leave scratches.
2. Hand sanding is usually more accurate than using a machine sander. It is very easy to damage a surface by sanding through the underlying fabric.
3. Spend very little time with rough grit sandpaper ... 40-80 grit should be used sparingly.

4. Gradually change the sandpaper grit. Go about 100 grit at a time. This will assist in achieving smoothness.
5. Use straight edges to find high areas and depressions on the surface. On curved areas you can use a template.
6. Stop sanding with about 240 grit sandpaper. You don't want it to be too smooth or it will not hold the primer coat.

10.1.2 Step 2 - Priming

Actually, priming a composite airplane includes a small amount of filling. The filling step completes 90% of the needed surface preparation. The remainder is usually accomplished using a filler/primer. Several primer/fillers are available on the market. The objective of a filler/primer is to fill small imperfections left from the major filler and to fill all pinholes. Fillers/primers are often sprayed on the surface. After about the second coat those dreaded pinholes (every composite builders' curse) appear. Several coats of filler/primer will be needed to fill these pinholes and not bridge them. A new product that has appeared on the market will actually fill pinholes. The name of that product is UV Smooth Prime. Many filler/primers only bridge pinholes. That means they reappear after each sanding.

Let's discuss the new method of priming a composite surface prior to painting. Poly-Fiber, Inc. has developed this new product and it has been on the market for about 2 years. The entire system is called Flight Gloss. It uses Super Fill as the primary filler. The primer used is a product called UV Smooth Prime. UV Smooth Prime is a non-hazardous waterborne urethane that is applied using a paint roller. It incorporates an ultraviolet blocker that protects the resin from the harmful rays of the sun. It also fills pinholes rather than bridging them. It can be sprayed on the surface if desired. There are no hazards involved in spraying - simply use a simple respirator to protect your lungs from particles. Smooth Prime is also white in color making it easy to apply the topcoat paint.

After you have filled the surface using Super Fill, you are now ready for the UV Smooth Prime. Poly-Fiber recommends applying this primer with a foam roller. The type of roller is important. It should be a fine closed-cell foam roller found at most paint or hardware stores. It is used for painting. The rollers come in 4-6 in (100-150 mm) widths and have one end rounded and they are usually white in color.

When your final sanding is complete following the filling stage, you then begin the priming phase. Many completed kit parts do not require any filling at all. You can bypass that stage and go directly to the priming step. Again, it is imperative that you thoroughly clean the surface to ensure no release agents or other contaminants exist.

DO NOT use any solvents immediately prior to using a waterborne product

Solvents will leave a residue that will actually curdle a waterborne primer. Wash with soap and water prior to this step.

What about temperature when you apply the product? UV Smooth Prime will dry as water will dry. That means in high temperatures it will dry rapidly and in low temperatures it will require a longer time. The worst combination is low temperature and high humidity. You can add heat to the area without a problem due to the fact that the product is non-flammable.

UV Smooth Prime must be cross-linked to achieve maximum strength and chemical resistance. You simply use a syringe and add a small amount of the required cross-linker chemical to the UV Smooth Prime. The proper amount is specified in the directions. The cross-linker must be added at the time of application rather than at the factory. The chemical process that ensues actually causes a hardening of the material. After cross-linking the product must be used within eight hours. The cross-linker is a strong skin sensitizer. You should keep it out of your eyes and off of your bare skin.

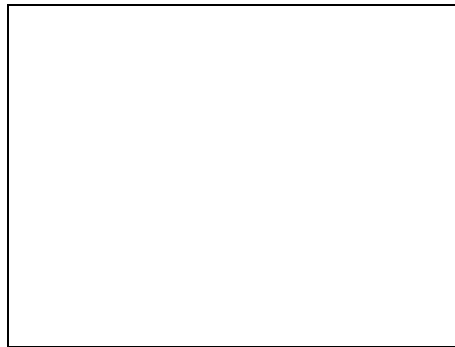


Figure 41: Priming the RangeR

Six rolled on coats of UV Smooth Prime are recommended as a primer for most composite surfaces (See figure 44). As an option, you can roll on the first three coats and spray on two more. Rolling is much more efficient in filling pinholes than spraying. This is why the system requires rolling on at least the first three coats. Spraying on the final coats will save time. After the required numbers of coats are in place, allow the surface to dry and sand once with 280-grit sandpaper. The surface is then ready for the topcoat paint. No sanding is recommended between coats. A minimum of is also required between coats. Let's summarize the steps of priming:

1. Properly prepare the surface by thoroughly cleaning with soap and water and sanding, if necessary.
2. Mix the proper amount of cross-linker with the UV Smooth Prime. Only mix the total amount you will be using within eight hours.
3. Apply the first three coats using the proper type of foam roller. This will fill pinholes. Allow two hours of drying time between coats.
4. You may then apply three more coats using the foam roller or two coats sprayed on.
5. Allow the coats to completely dry.

6. Dry sand the surface using 280 grit sandpaper. DO NOT wet sand.
7. Inspect the surface for imperfections. Additional coats may be rolled on or sprayed as necessary.

10.1.3 Step 3 - Final Topcoat

The topcoat you apply is one of your choices as long as it is light in color - usually white. There are a number of excellent topcoats on the market. Most of them are polyurethane paints and you need to be aware of the health hazards involved if you are spraying them. A forced air breathing system must be used. Use the product as directed by the manufacturer. Polyurethane paints may be applied directly over UV Smooth Prime. If you are using another type of primer you should complete the priming process by using the product recommended by the paint manufacturer as a final coat.

To continue with the non-hazardous Flight Gloss System developed by PolyFiber, a waterborne polyurethane topcoat is available. This paint is called Top Gloss and it is cross-linked prior to application just as UV Smooth Prime. It is sprayed on after the Smooth Prime has thoroughly dried. You will apply the first coat as a tack coat that fully covers the surface. Often, a waterborne paint will have a slight orange peel effect until it dries. It will usually dry smooth. Before you actually paint your aircraft surface that you practice on another piece of material. Waterborne paints spray differently than any paint that you may have used before. You must apply light coats. Top Gloss is thin and needs to be sprayed carefully.

After you have applied the first coat, let it dry at least 6 hours. This will give the paint time to level out into a smooth surface. Put another coat on without flooding it. If the surface is not level, let it sit for a few days and sand it level using 600 grit sandpaper. If it looks good allow it to dry for at least six hours and then paint the final coat. If you wait more than 24 hours between coats you must scuff sand the surface using 600 grit sandpaper before applying another coat. This will ensure proper adhesion.

After allowing the final coat to dry for at least 7 days, you can now use a buffer and with little effort have a near perfect finish. Buff out the paint using a high-quality automotive buffer - one that you can adjust the speed. Buffing is required of virtually any topcoat to achieve an award winning finish (See figure 45).

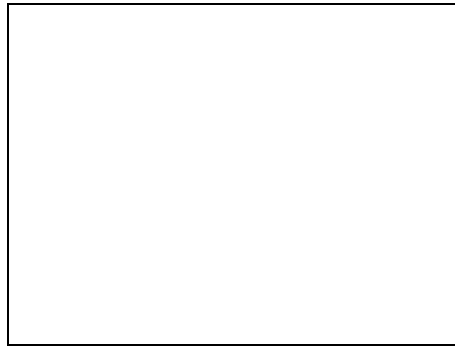


Figure 42: The RangeR

10.2 Additional considerations

Should you prime a composite airplane and then fly it before painting? Varying opinions exist concerning this step. Primers of all types are porous and not designed to be unduly weathered. We all know that before painting the surface must be clean and free of grease, oil, etc. Flying off your time with the primer showing does not help this problem. You can easily taint the surface to the point that the topcoat paint could actually fail within a few years. You would probably blame the paint when in fact, the reason would be the imperfect primer-to-paint bond caused by all of the contaminants absorbed into the primer. Ideally, you should fill and prime parts as they are completed. This also avoids another common problem that is often referred to as "settling." Settling is a common problem found in composite finishing. An airplane is painted and buffed and it looks beautiful. Three months later the weave pattern of the fiberglass begins to appear. What is happening? This is simply a result of the settling and shrinking of the primers and topcoat paint into the weave or pinholes of the composite surface. There are a number of reasons for this irritating phenomenon.

- All coatings whether solvent or water based will shrink and settle somewhat after application.
- When an aircraft is in service, the heat from the sun will bake and cure the primer and coatings, shrinking them further. Additionally, some epoxy resins will actually post cure with skin temperature heating thus slightly altering their surface texture. Another reason to post cure.

How do you avoid this problem? Again, fill and prime parts as they are completed. Let the settling occur in your shop while you are finishing other parts. Another way to overcome this problem is to paint the airplane and not color sand or buff for three months. This allows the paint to settle before you sand and buff. If you have a painted aircraft that is experiencing this problem, you can sand and buff the surface. The age of the finish does not matter.

11. Abbreviations and glossary

11.1 Abbreviations

- Hp	Horsepower
- RPM	Revolutions per minute
- Gal	Gallon
- in	Inch
- ft	foot
- m	meter
- kg	kilogram
- lbs	pound
- km/h	kilometer/ hour
- kts	knots
- NM	nautical mile
- Ltr/h	liter/ hour
- USG/h	US Gallon / hour

11.2 Glossary

- Anisotropy	Evenly strong in any direction like aluminum.
- Isotropic	Strong in any direction.
- Orthotropic	Strong in an specific direction like laminates.
- Fraying	Abrasion
- Tape glassing	A band of fiberglass cut at an 45 degree angle to bond pieces together.