Version 2

Workmanship for Fly Baby Builders
By Ron Wanttaja
And the Fly Baby Community

In this article, we'll address some of the basic workmanship issues that have to be followed when building a wooden airplane like a Fly Baby.

You will also want to review the Hardware section on the PB100 Web page, which gives information about standard aviation hardware such as nuts, bolts, and cable fittings.

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1 WORKING WITH WOOD

Wood is a perfect material for aircraft. It's strong, it's light, it forms complex shapes with ease, it doesn't get weaker from fatigue like metal, and the power tools to work with it are fairly inexpensive.

Wood is probably the safest and most satisfying medium to build an airplane from. Sawdust smells good and won't kill you. Varnish might make you high, but won't give you hives. Buy your tools at the hardware store. Dip a wood strip in hot water and it loosens up enough to tie a pretzel. It reacts predictably when carved or sanded, and mistakes are easily corrected.

Worried about strength? Pound for pound, wood has double the tensile strength of a aluminum. Tools? You don't have to order exotic framistats from homebuilder's supply outfits--good woodworking tools are sold at most good hardware stores. At decent prices, to boot.

Wood is nice.

There are a few disadvantages for the Fly Baby builder, but working with wood is fun and easy.

1.1 All About Wood

1.1.1 Spruce

The premier wood used in homebuilt construction is Sitka spruce. The trees come from Alaska and British Columbia, and the timber is carefully sawed, dried, and milled to produce aircraft-quality material.

Make no mistake about it, aircraft spruce doesn't come from orange-crates. Just like aluminum and steel, there are extensive specifications that certified lumber must meet. Type A wood must have a minimum density of 24 pounds per cubic foot, moisture content between 10 and 17 percent, and the grain slope must be less than 1 inch in 15 (Figure 1).

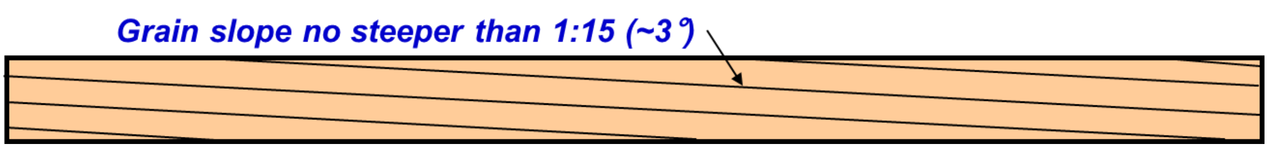

Figure 1: Maximum Grain Slope in Aircraft Wood

When you're using aircraft-quality wood and botch a part, you can't just run off to the hardware store for another piece of wood. Face it, aircraft quality lumber does not end up at "Wood Is Us" at 49 cents a board.

This isn't to say that spruce is the only wood that can be used. Western hemlock, for example, is 14 percent stronger. AC 41.13 allows direct substitution for spruce. But its quality varies more (good hemlock is more difficult to find), and it is about seven percent heavier. Certified lumber in other than spruce is hard to find.

FAA Advisory Circular AC43.13-1B, Chapter 1, provides all the information about selecting wood for your airplane. It also includes how to examine wood to judge whether it's aircraft-quality or not. This is handy if you try to acquire wood locally, but, personally, I'd suggest sticking with the known vendors like Wicks and Aircraft Spruce. If you do with to source wood from elsewhere, contact the Fly Baby community for help and advice.

Drew Fidoe has also published a guide for testing non-certified wood to determine if it's adequate for a Fly Baby.

You can use the hardware-store stuff for non-structural items, like turtledeck stringers, and there's a surprising number of small repairs I've made to my airplane using oak. But don't replace anything resembling a structural component with non-approved wood.

One neat use of that hardware-store wood: You can use it for practice! If you're unsure of a cutting or shaping procedure, grab a bit of hemlock or poplar from the big-box stores and try it out on there, first.

1.1.2 Plywood

The other wood you'll be working with consists of multiple thin plies of bass, mahogany, birch, fir, or poplar bonded glued together under heat and pressure: plywood, in other words. It comes in various combinations of thickness, plies, and grain orientation. Between three to seven plies are used. The grain refers to the relative orientation of the grain for each ply, usually either 90-degree or 45-degree.

Plywood is used several ways. The basic Fly Baby fuselage is a truss made from 3/4" spruce pieces, but the entire truss is covered with a sheet of 1/8" plywood. Gluing the plywood to the truss makes the truss far stronger.

The plywood is available from the usual aircraft suppliers, although builders have been finding other, cheaper sources. You need wood rated for exterior uses; marine-grade is a good alternative, though it may be pricier. Bowers recommended mahogany plywood or exterior door skins, though both seem to be a lot rarer these days.

The Fly Baby community seems to feel that Okume plywood is a good alternative. Luan seems available, but the consensus seems to be for Okume.

If you get plywood with an uncertain heritage, you can try a test to see if it's waterproof: Cut off a small sample and boil it on the stove for an hour. Let it drain and cool, then cook it at 150 degrees until it's dry, and stick it in the freezer. Repeat this cycle a couple of times. If the sample doesn't delaminate, it's probably exterior or marine grade.

On the other hand…it's rare, indeed, that homebuilts are ever boiled.

Almost all the plywood on a Fly Baby is 1/8" thick. Its main use is to cover the fuselage sides (Figure 2). The other major use is the center portion of the wing ribs.

There's a small amount of 1/4, 3/8", and 3/4" needed. Pete calls for "Fir" for these larger sizes. Looking at what they're used for, I'd be sorely tempted to just get some good-quality hardware-store plywood. None of it is really used for strength purposes.

When you're shopping for your 1/8" ply, you'll find that most sources now sell by the metric system. Get the 3 mm thickness. It's very slightly less than 1/8", but Pete says 1/8" is overkill, anyway

Figure 2: Fly Baby Fuselage Under Construction

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1.1.3 Wood Storage

Proper storage is vital. You have to remember that wood is an *organic* material, not something that is manufactured. If it's not stored or protected appropriately, it will deteriorate.

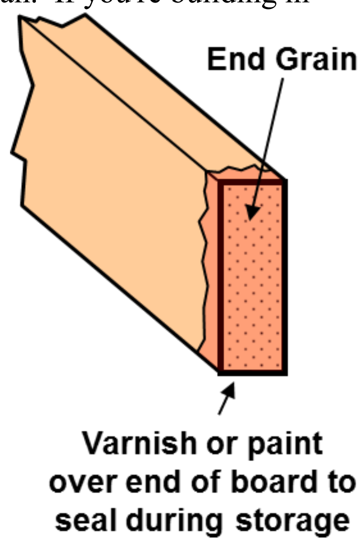
Ideally, wood has a moisture content about 12%. If the moisture gets too low, the wood will dry out and potentially start splitting

On the other hand, if the moisture level gets above 20%, there's the potential for dry rot. "Dry Rot" is actually a misnomer; it occurs when the wood is TOO wet. This isn't a chemical reaction…it's a fungus that feeds on the wood.

So you'd like to keep the wood at an internal moisture level of 12 to 15 percent. The real aficionados buy moisture meters (Figure 3) to monitor how their wood is doing. When new wood is delivered to you, its moisture content is likely to be less than 10%. Store the new stuff with the old stuff for a couple of weeks until its moisture comes up.

Figure 3: Measuring Wood Moisture

Ideally, you'll store the wood in an area with a relative humidity of around 12 to 15 percent, but most of us don't have choices. Obviously, do the best you can. If you're building in a heated shop during the winter, the heated air has low moisture content and your wood will dry out. Get a humidifier and a hydrometer.



One way you can protect the wood is to slap a quick coat of varnish or paint over the ends of stored wood. The end grain (where it's cut across the grain allows a lot of respiration of the wood; sealing up just the end is a good way to slow that down.

WARNING: Do NOT apply this sealant to any area that will eventually be glued. If you try to glue to it, the glue attaches to the PAINT, not the wood. It's a much less strong joint.

Wood must be stored flat, not leaned against the wall. Any small but steady pressure will warp the pieces over time. Make sure it's well supported; don't just lay an eight-foot piece of plywood across two 2 4s. It's an exasperating exercise-- you want the wood supported over its entire length, but you must still allow air circulation or the unequal drying will cause it to warp.

Plywood can be stored flat against the wall, but clamp it to prevent drooping and warping. A ceiling rack gets it out of the way but complicates access.

1.2 Cutting Wood

When cutting wood for a Fly Baby, you're always going to want a relatively clean, smooth cut. For your tables saw, you want a blade with 60 teeth or more that is defined as for fine finishing. Narrow kerf is good, too (the kerf is the thickness of the blade). One Fly Baby builder recommends " hollow ground planer blades," but notes that the fence must be very parallel to the blade. Pete does specify planer blades for all rip cuts (across the grain) for Fly Baby lumber.

When cutting wood, the grain orientation is a key factor. The grain is a remnant of the annular rings, caused by the variation in growth rates through the years. The long wood cells, and the natural cellulose cement that binds them, makes the wood strongest in the direction of the grain.

The plans specify the grain direction for most pieces…if nothing else, the grain will go in the "long" axis of the part. The difficulty of the cut is dependent upon its direction relative to the grain. The cement is actually harder than the wood fibers themselves. Cross-grain cuts are therefore hard work for the saw--it must cut through multiple cement lines. While the cut takes longer and all the cement tends to dull the blade, the saw is easy to guide.

Cutting with the grain is another story. The cement lines act like grooves on a roadway, they complicate lane changes. On the highway, the path of least resistance is along the same direction of the grooves. When met at a shallow angle, they try to force a car straight.

Thus it is with the grain. When a blade hits one of the cement lines, it tries to deflect the saw into a path of lower resistance, along the grain.

If the grain ran dead-straight in the direction you want to cut, this wouldn't be much of a problem. But even the most stringent certification standards allow a 1 inch in 15 inches slope, approximately 3 degrees. If you're cutting a slot 1 inch deep, just following the grain will result in a 1/16-inch gap, which is the maximum allowed when using high-tech epoxies. This gap would be intolerable with conventional aircraft glues.

Another byproduct of this process is the tendency of the wood fibers to break away from the cement, forming splinters. Splinters can make a shambles of a cut line. Some woods are worse than others, pine, for example, splinters easily. Spruce's popularity is due in no small part to its splinter resistance: resistance, mind you, not immunity. It will still splinter.

One way to reduce problems is to carefully select the cutting direction. if the grain is going to divert the cutting tool, cut so the deflection will be away from the piece, not into it.

The vast majority of cutting on a Fly Baby consists of cutting lumber to length or shapes out of plywood. This process is little different from scale models. Thin plywood can even be cut with a modeler's knife. Run the blade along the same line a few times, and break the wood at the line.

For heavier pieces, a number of tools can be used: saber saws, band saws, table saws. Long, straight cuts are best handled by a table saw. Its unencumbered surface makes it one of the few tools that can handle large sheets of plywood. The blade housing on bandsaws often gets in the way.

Alternatives include the circular saw and the saber saw. Table saws have a rip fence to guide straight cuts, and it's a good idea to add one when using these hand tools. Commercial models are available, but a long piece of angle aluminum (or wood, if you can find a straight piece) and a pair of clamps work just as well. Measure the distance from the outer side of the saw's shoe to the opposite edge of the blade, and set the fence this distance away from the cut line. Clamp it in place. When cutting, maintain slight pressure against the fence.

Curving cuts are generally left to the band and saber saws. Circular saws can't make tight turns. Really sharp turns might call for manual tools like coping or keyhole saws.

Don't cut exactly next to the line. Leave a little extra wood to splinter instead of the piece itself. Any splintering usually doesn't propagate far in spruce. There are also special plywood-cutting blades which have small teeth to reduce the problem.

Speaking of plywood, the glues used between the plies are tough on blades. Be prepared to replace them more often.

1.3 Final Shaping

At some point, you'll have to add the final shape to the wood pieces. This might amount to the last adjustment to joint surfaces, trimming away a blob of glue, or a variety of other actions. This requires hand tools of various varieties.

Smoothing the edge of a large piece of wood calls for the wood plane. Also, the tool can be used to make cut edges square with the top and bottom. The longer the plane, the smoother the edge. The amount of wood removed with each stroke of the plane is adjusted by setting the height of the cutting blade.

The draw knife is another type of plane…it's basically the same sort of blade, with a pair of handles. You draw it towards yourself as you trim, hence the name.

Bowers recommends draw knives when shaping the laminated wingtip and tail-feathers tips.

The grain orientation has a great impact on the planing direction. Don't plane into the slope of the grain. For example, if the board's grain slopes downward to the right, plane from left to right. Otherwise, the blade will catch the cement lines and dig in.

A plane is nothing but a chisel on a carrier. Hence, use the chisel in situations where lines of wood must be removed.

But chisels won't leave the smooth surface that a plane will. And some cases just require moderate shaping and smoothing. The power sanders (benchtop, belt, or pad-type) are the obvious choice. But they can't reach everywhere. In these cases, sandpaper and files are the obvious choices.

Files or rasps work best where inside corners must be sharp, or where hard glue deposits must be eliminated. Their design lets them reach into tight crannies for those last minute adjustments.

Sandpaper's various grit sizes allow better control of the amount of material removed. Unless sanding a curved surface, use a sanding block. Wrap a sheet of sandpaper around a piece of 2 x 4 or 1 x 2. This evens out the hand pressure; otherwise the paper directly under each finger will dig in more.

A power option to consider is the small hand-held Dremel Moto-Tool. The company has a tiny sanding drum accessory which is dandy for tight, precision shaping.

Power sanders share the main problem of all power tools: if not watched carefully, they can strip too much material too fast. In addition, watch the edge effects of using power sanders. If you don't work on spreading out the action, the tool can leave indentations at the edge of the working area.

One type of final shaping is the rounding of all edges that won't be joined to other pieces. Nice sharp edges might look good, but they are a weak point for several reasons. They aren't supported very well, and a bit of impact will break off pieces. This isn't dangerous from the point of view of structural strength, but it is unsightly. The part might stay just as strong, but broken-off edges make your workmanship look embarrassingly crude.

Also, the splinters that get started can propagate and disrupt gluing surfaces. And if the corner breaks away after varnishing, the exposed wood surfaces can be a starting point for deterioration. A bit of work with a plane will eliminate these splinters.

The tools used for rounding vary with the size of the piece involved. Small pieces need only a bit of sanding. Too much tool, and you stand the chance of breaking the piece.

1.4 Laminating

One of the nice features of the Fly Baby are the smooth curves of the wingtips and the horizontal and vertical stabilizers. These are attained by using laminations of wood.

Basically, you take a lot of very thin pieces of wood, bend them to the final shape, and glue them together. For a Fly Baby, you actually form the laminated piece right in the place it's supposed to go.

Figure 4: Laminations

When removed from the form, the laminated assembly will spring back slightly. Thus the plans show the wingtips, for instance, with a little extra bend to them. That's so the springback will put the piece in exactly the right position.

For the Fly Baby wingtips, for instance, you'll laminate together eight to twelve pieces of 1/8" x 2-1/2" x 10' spruce or cedar strip. You'll lay the first piece in place to define the curve, then glue additional pieces over the first strip. You'll need a lot of clamps the hold the surfaces together while the glue cures. The clamps must be applied to the centerline of the laminate. If too near one edge, the laminations spread at the opposite end, an effect known as "fanning". The more clamps, the better the result.

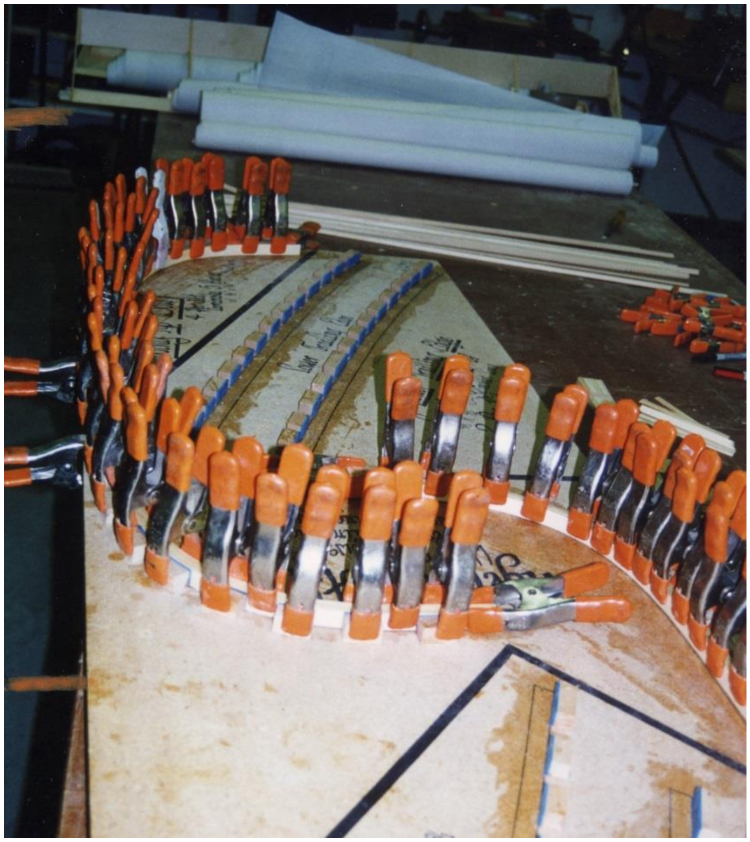


Figure 5: Clamped Laminations

1.5 Scarf Joints

Sometimes, two pieces of wood must be jointed end-to-end. Most of the scarfing in the Fly Baby involves plywood.

1.5.1 Plywood Scarfing

The basic fuselage truss structure of the Fly Baby is covered with plywood, as shown in Figure 6. It's a truss of 3/4" spruce longerons, verticals, and diagonals, with 1/8" plywood glued to it for strength.

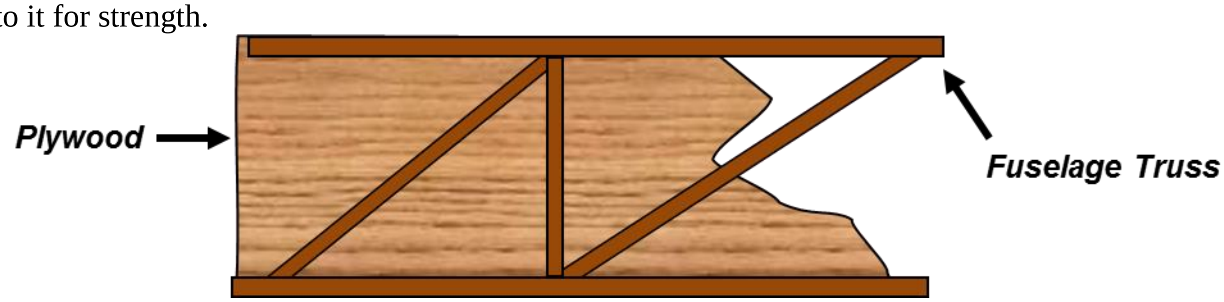


Figure 6: Fly Baby Spruce Truss Covered By Plywood

The Fly Baby fuselage, less the rudder and the area forward of the firewall, is about 14 feet long. Since aircraft plywood doesn't come in sheets longer than eight feet, two sheets are going to be necessary to cover the side.

How to handle the interface of those two sheets of plywood? If you just push the flat ends into each other, there's not a lot of strength there. The sheets are only 1/8" thick, so that's not enough gluing area. Plus, if the pieces don't joint exactly, you're losing even more gluing surface. If the small glued area fails, then you've got a real ugly bump.

Instead, compare this "Butt Joint" to the Scarf Joint shown in Figure 7. Both sheets of plywood are shaved into a 1:10 slope, and the two slopes are glued together. Notice the utterly MASSIVE surface that is glued. That scarf joint isn't coming apart.

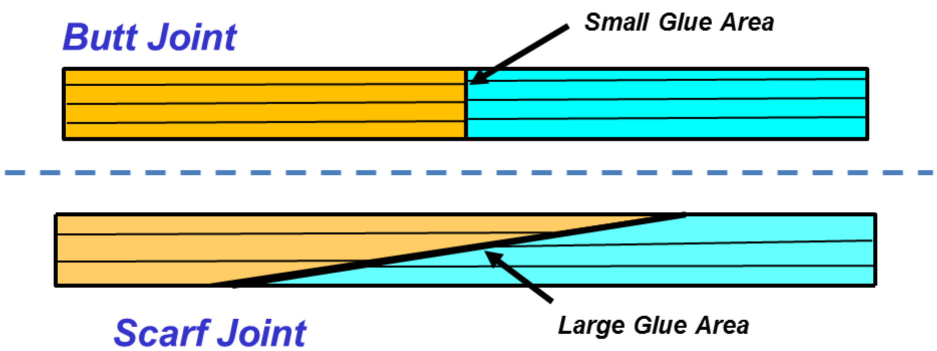


Figure 7: Butt Joint vs. Scarf Joint

So…how does one do a scarf joint? Generally, it a matter of setting a cutting tool at an angle, and moving a plywood sheet through it to cut it on a ~1:10 grade…about 5.5°. This tool might be a router, a sanding block, or even a tool that accepts a handheld circular saw. Making scarf joints in plywood is necessary for many wooden boats, so there's a lot of advice available online. Do an Internet search for "Plywood scarfing tool" and you'll come up with a number of options. Several vendors, including Wal-Mart, sell the tool shown in Figure 8 for about $100.

Figure 8: Commercial Scarfing Attachment for a Circular Saw.

The Epoxyworks web page has a great summary of scarfing methods. Figure 8 illustrates one of their scarfing jigs, using a circular saw.

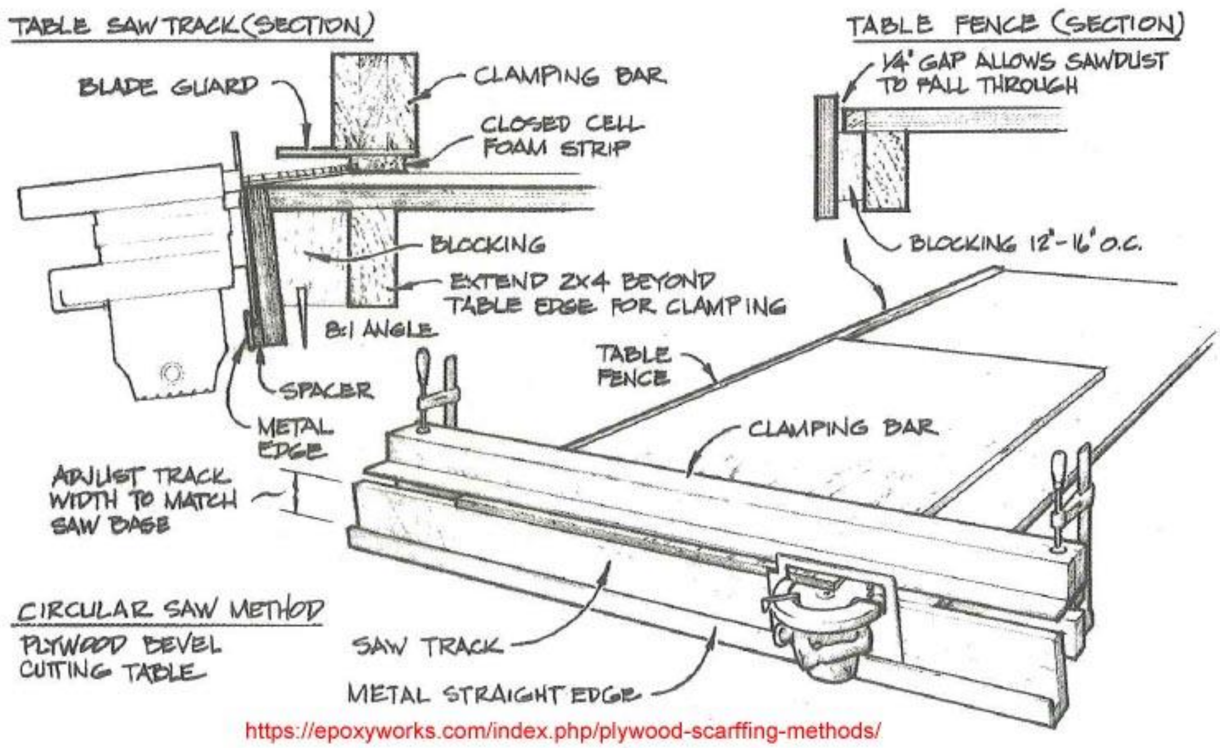


Figure 9: Scarfing Jig

A lot of effort? Well, there are some folks out there who do this BY HAND. Clamp the edge of the wood down, draw a line eight inches from the edge, and use a plane, or handheld sander to apply. To quote Drew Fidoe:

“While a bit crude for some folks, I used a 2" sanding drum on a drill. The 2" diameter drum is 1.5" long, which is about right for the slope length for the scarf on 1/8" plywood. I sanded the scarf freehand using the sanding drum in the drill, watching the veneer lines give an easy reference for evenness of the scarf. It made final adjustments with a sanding block if necessary and the cleaned the surface by scraping with a freshly ground chisel. I used epoxy with a 2 hour-plus cure time to allow for glue soak in the wood. I made 20 scarfs in my repaired fuselage this way and they've all held up great in the past 10+ years of service.”

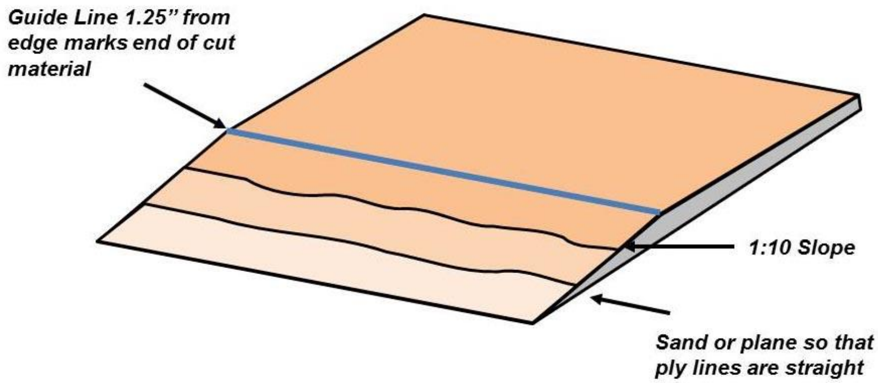


Figure 10: Scarfing by eye

Needless to say, you'd like the practice this a bit on the cheaper wood you can get at the hardware store…..

1.5.2 Longeron Scarfing

The fuselage longerons for the Fly Baby need to be about 15 feet long. It's almost impossible to find square spruce stock that long. If you can find it—and someone will ship it to you—great. Otherwise, you're probably going to have to put at least one scarf joint on each of the four longerons.

The biggest difference between plywood and longeron scarfs is that the grain pattern of the two pieces of wood must be aligned. The scarf should approximately parallel the grain; when completed, only one or two grain lines should show on the cut area. The second piece should be cut in the same fashion. When joined, the two grains should appear continuous, except for a slight joggle at the scarf line

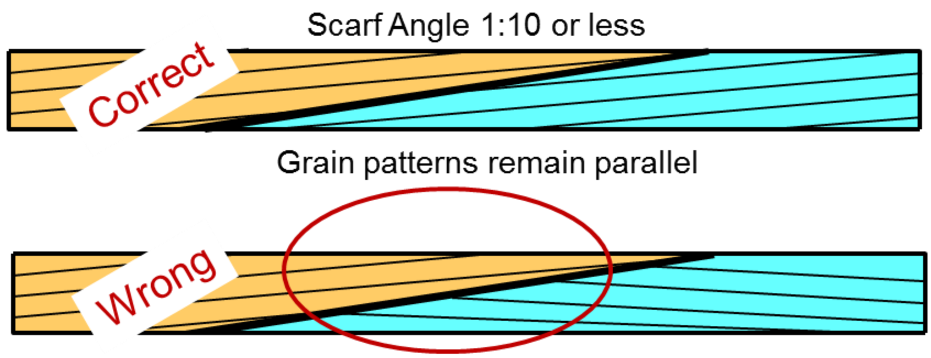


Figure 11: Grain orientation when scarfing longerons

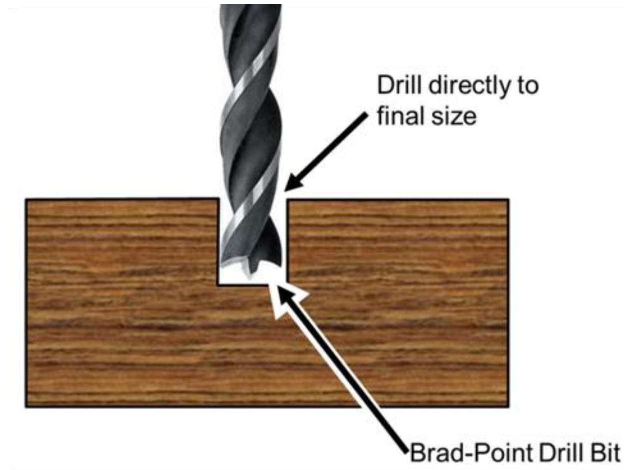
You will need to set up a jig with a table saw or circular saw to cut these scarfs. On the positive side, the pieces are only 3/4" square.

1.6 Drilling Wood

Generally, when you drill in most substances, you drill a hole to almost the right size, then use a ream to enlarge it to the exact size.

For wood, forget all that. Drill the hole directly to the final size. Use brad-point drill bits, as they leave a very smooth hole. Quality of the bits is important; don't get the real cheap bits.

Hole cutters for wood are widely available for those times when no drill bit is big enough. A drill press is almost a necessity, but use of the tool is straightforward. The main thing to watch out for is overheating, caused by trying to cut too much too fast. It dulls the tools and chars the wood. If you smell something burning, back off on the press and let the pieces cool.



Large-diameter holes, especially in plywood, are the saber saw's forte. Start with a drill bit slightly larger than the width of the saber saw's blade. Cut a hole near the cut line on the portion of the wood to be removed. Then insert the saber saw and cut towards the cut line at a shallow angle.

Assuming you're going to insert a bolt in the hole, you'll either want to varnish the hole or install a bushing. See Section 1.8.

1.7 Gluing Wood

1.7.1 Types of Glues

The first decision you'll need to make is what kind of glue to use to join your Fly Baby parts.

Pete specified Weldwood brand plastic resin glue for the Fly Baby. It's a fine product…strong and waterproof.

Then again, this was Pete's recommendation in 1963. Chemical science has improved since then. Not only that, but the FAA now considers this kind of glue obsolete for aircraft use, warning of "…possible rapid deterioration (more rapidly than wood) of plastic resin glue in hot, moist environments and under cyclic swell-shrink stress."

In addition, the glues available for Pete in 1963 had another drawback: All gluing had to be performed with temperatures 70°F or higher. Weldwood and the similar older types of glues require pretty tight tolerances in how the parts fit together, which makes your building task for more difficult.

In the sixty years since Pete started building the first Fly Baby, adhesive technology has seen advances similar to those of other technologies. Epoxy glues are pretty much the standard, nowaways. Epoxies like T-88 have become the de-facto standard in homebuilding.

Figure 12: T-88 Epoxy

Epoxies have several advantages over traditional aviation glues. One is their gap-filling abilities. Epoxies stick to themselves with the same enthusiasm they still to wood, so they can tolerate a little less precision. A second is clamping pressure. Traditional glues require the glue cures with the parts clamped tightly together. You'll want to clamp the parts together with epoxy just to hold the parts in position while the epoxy cures, but it's not as critical.

However, many Fly Baby builders swear by Titebond III, which is available at most hardware stores. Kurt Gubert, the builder of a very nice Fly Baby biplane, expressed his opinion this way:

> *I use Titebond III for almost all my aircraft woodwork as do several friends of mine. It's cheap, available at your local hardware store, completely waterproof and cleans up nicely with water before it sets. Epoxy is a great glue ,but it is toxic and a pain to mix and use and clean up. It's only real advantage over Titebond is its ability to glue end grain. Unfortunately in aircraft wood construction there are usually no joints that depend on gluing end grain.*
>
> *Remember, we're gluing soft wood and thin plywood with poplar inner plies. Almost any modern glue is going to be stronger than the wood. A friend built the wing on his Pietenpol using Titebond 2 before Titebond 3 was introduced. After an engine failure at treetop level he hit on one wing tip. The wing was totally smashed from tip to tip but not one glue joint failed, only splintered wood. Oh, and some will develop an alergic reaction to epoxy.(Ask me how I know,)*

Make your own decisions… discuss it on the Fly Baby mailing or Facebook groups. In addition, Simplex Aero has a great web page that describes the available glues, and the advantages and disadvantages of each.

CAUTION: Whatever type of glue you select, buy it from an aviation vendor, such as Wicks or Aircraft Spruce, or directly from the manufacturer. Counterfeit products are a major concern; most people won't notice if the fake T-88 they buy from the corner store only has half the strength as the real stuff, but that might be critical for an aircraft builder.

1.7.2 Preparation

The amount of allowable joint gap depends upon the type of glue being used. Casein and resorcinol glues require tight joints, while epoxies like T-88 can fill a gap up to 1/16 inch. When cut, the wood surfaces tend to dry out. If possible, glue the parts within a few hours of cutting.

If something gets between the two surfaces being glued, the glue will bond to the contaminant instead. Hence, the surfaces of the joints must be clean. Sawdust is a major culprit. Sanding makes fine tight-fitting joints, but the dust tends to fill the wood's pores and interfere with bonding. Epoxies like rougher surfaces, so straight from the saw is fine.

AC43.13-1B says, "When surfaces cannot be freshly machined before bonding, such as plywood or inaccessible members, very slight sanding of the surface with a fine grit such as 220, greatly improves penetration by the adhesive of aged or polished surfaces. Sanding should never be continued to the extent that it alters the flatness of the surface. Very light sanding may also improve the wetting of the adhesive to very hard or resinous materials."

Get rid of oil and grease with acetone or lacquer thinner. Let the surfaces dry before gluing.

1.7.3 Glue Application

One of the big thing about gluing wood is you need to fill the entire area between the parts with glue. The only way to do that is to put a lot of glue there…enough to make it squeeze out when the parts are clamped together (Figure 13).

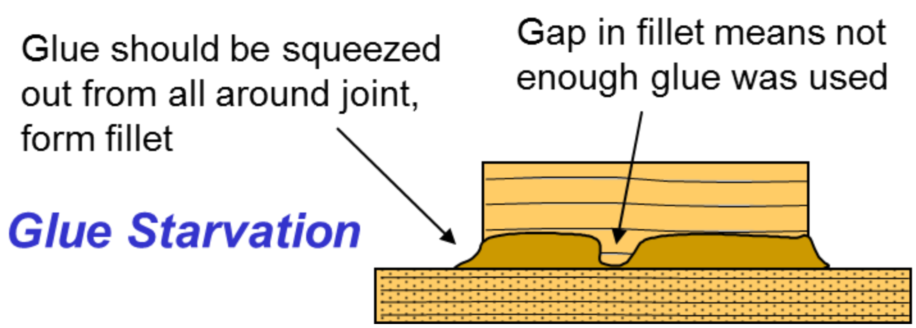


Figure 13: Glue Should Squeeze Out Evenly Between Parts

To avoid glue starvation, spread the glue thickly on both surfaces using a brush. If a piece of lumber has been cut directly across the end, the exposed "end grain" is extremely porous and thirsty for glue. Dab some glue onto the end, wait 20 minutes, then add more glue and clamp the pieces together.

In some cases the pieces aren't joined immediately. Sometimes the plans or the glue manufacturer requires that the glue air-dry for awhile before clamping. For instance, one popular brand of epoxy requires the user wait until the epoxy mixture suddenly gets warm. It then hardens--at which point a second coat of epoxy is applied and the pieces are joined and clamped.

There really is no one set of instructions for wood glues. With Urea Formaldehyde glues the user spreads glue on one side of the joint an hardener on the other. Many glues can be applied while the pieces are damp from the soak and bend cycle. Some can't.

Read the instructions.

1.7.4 Clamping

The parts must be clamped during the curing process. It's not quite as critical for epoxy glues, but casein and resorcinol glues require at least 125 pounds per square inch of pressure.

Clamping should make glue ooze from the joint. If it doesn't, separate the pieces and add more glue. Wipe up the excess with acetone or thinner. Smooth the joint with a (rubber-glove-clad) fingertip or popsicle stick, leaving a small fillet.

Clamping methods vary. Ordinary C-clamps and spring clamps are the most common. C-clamps apply very localized pressure and can damage the wood, so add scrap pieces of wood under the shoes to spread the force over a larger area. Spring clamps can't apply enough pressure for traditional glues, but are just dandy for epoxy-glued structures. There are other types of clamps as well; the only requirement is the ability to supply the required pressure without damaging the wood. Even clothespins can have their uses, if you can still find them.

Any hardware store should carry a stock of various types of woodworking clamps. If the budget allows, pick up a sample or two in advance. Otherwise, keep their stock in mind as you face various jobs. It's always better to use the right tool than to struggle along with the wrong one. Clamps are good things to buy at discount houses like Harbor Freight. Buy enough of them so you have spares in case any break. If you’re using epoxy glues (where clamping pressure isn’t as important), ordinary binder clips could be used, in some cases (Figure 14).

Figure 14: Binder clips as clamps

Large plywood pieces require pressure over a large area, which is tough to supply with conventional clamps. Enter the aircraft nail. The nail is used as a clamp, in either a temporary or permanent installation. They can be used instead of clamps in other applications, as well. The nails should be four times as long as the sheet of plywood being glued.

Nails are kind of passé right now, staples are much more common. The problem is, most staple guns are TOO strong. Pat Hoyt of [EAA Chapter 25 published a guide] to modifying a standard staple gun to reduce the driving force.

The nails or staples do not contribute to the strength of the completed part, once the glue cures. Often, builders remove them. If you install them through a thin strip of wood, the removal task is easier.

This works especially well with staples, as the sacramental wood will absorb much of the force of the staple gun…you probably won't have to tone it down.

One suggestion from the Fly Baby community is to strips of clear plastic cut from soft-drink bottles to staple through. Not only does the clear plastic let you see what you're doing, the plastic generally releases easily if it gets a touch of epoxy on it.

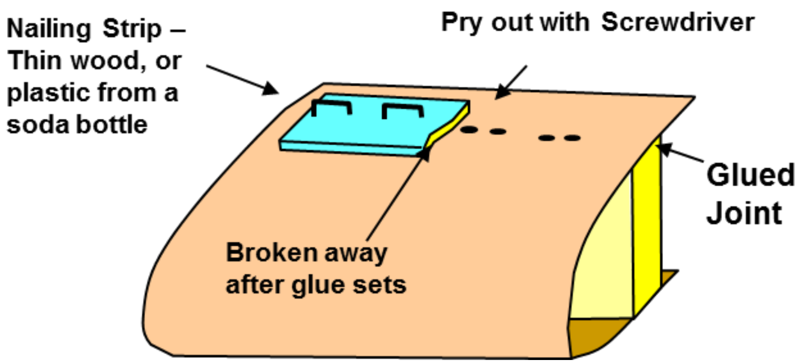


Figure 15: Using nailing strips

In some cases, you'll need something to hold the parts together while installing the nails or staples. Figure 16 shows how Jim Katz did it.

Figure 16: Holding gusset in place for nail installation

1.8 Protecting Wood Structures

As mentioned earlier, wood's moisture content must remain at about 12 percent for maximum life. Too much wetter, and rot can begin. Too dry, and it becomes brittle and weak.

That's the reason you must varnish wood components. It's nothing but a water barrier to maintain the optimal moisture content. It sheds dampness; it seals existing water into the wood.

If the varnish protects the wood, why do older wooden aircraft have rotting problems?

The main problem is old-fashioned varnishes. Wood flexes under load; that's one reason it's strong. The older varnishes are not flexible, they crack when the wood bends. Eventually, the cracks go though to the wood and problems begin.

Modern urethane and epoxy varnishes are flexible, which results in less cracking. Most are two-part systems that must be mixed before use.

They're usually applied with a brush. The skeletal structure of most wooden airplanes makes spraying it on a waste of material. The goal is complete coverage because any gaps are a starting point for rot.

The best opportunity to apply varnish is before gluing. It's hard to get to some of the nooks and crannies before the structure goes together. However, **keep varnish off any surfaces that will be glued (**Figure 17**)**. If the area is varnished, the glue will try to bond with the VARNISH, not the wood below. The bond will not be very good.

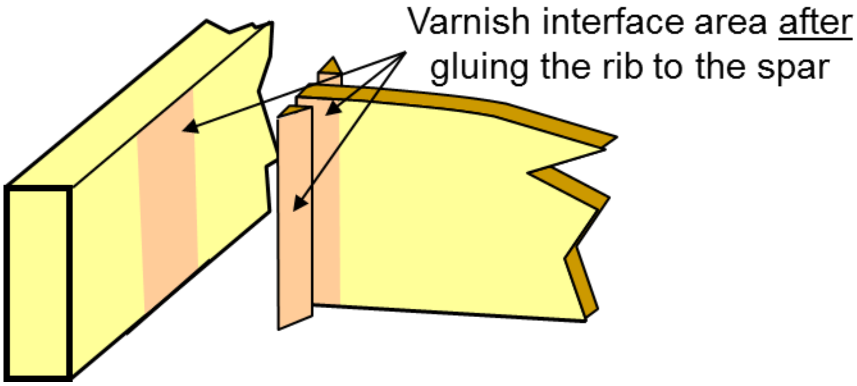


Figure 17: Do not varnish in areas to be glued later

The result is often a compromise. If access will be good after assembly or if the area is one where appearance matters, glue first. Otherwise, varnish the components, leaving a good margin around all areas to be glued. Test-fit the components and mark the limits with pencil. You can keep a careful eye on the marked areas while brushing on the varnish, or the glue areas can be protected with masking tape. Be sure to clean off any residue of the tape's adhesive.

In any case, don't shave the margins too closely. The varnish tends to ooze a little bit. Let the coating dry, then glue. When cured, add a coat of varnish around all the joints.

One of the major factors with varnish, even the modern epoxy types, is the number of coats. The level of protection rises tremendously with the second coat. The Forest Products Laboratory did a test on wood protection. They applied varying coats of a number of protectants, then exposed the wood to 90% humidity at 80 degrees for two weeks. The samples were then rated as to how efficiently they excluded moisture. The higher the number, the better they did:

Finish Type	**One Coat**	**Two Coats**	**Three Coats**
Spar Varnish	0%	15%	30%
Polyurethane Vanish	2%	23%	44%
Polyurethane Paint	41%	61%	70%
Epoxy Paint	40%	78%	83%
Enamel paint	50%	70%	80%
Aluminum Pigmented Varnish	41%	77%	84%

Obviously, the more coats the better. Obviously, two coats should be the minimum. One old A&P I talked to recommended initially applying a thinned coat; it would flow into the nicks and crannies better. Then back it up with two full-strength coats.

One major thing to remember is that the wood has ~12% water…and you're going to be sticking a lot of steel bolts into it. What happens when you immerse steel in water? Rust!

Figure 18 is a great example. This aircraft bolt had been inserted through the top longeron of my Fly Baby to hold the forward metalwork in place. I removed it about 30 years after installation. Not the heavy surface corrosion.

Figure 18: Steel bolt after 30 years in wood longeron

Obviously, this corrosion didn't prevent the bolt (or its ~dozen siblings) from being removed. Did make it a bit harder. There are other bolts in my airplane, much larger, through much thicker wood, that I don't think I'll be able to remove.

What to do? There are two basic approaches.

As a minimum, varnish the wood at any point where metal will be in contact. Obviously, this includes bolt holes (Figure 19).

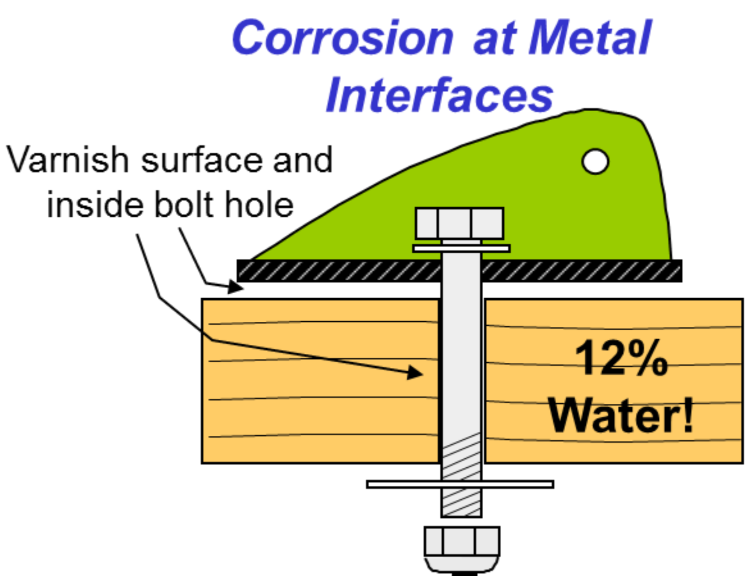


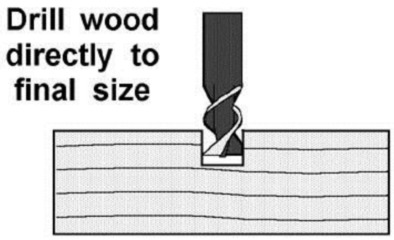
Figure 19: Varnish all bolt holes in wood

The other option is to install a bushing into the wood. Buy steel tubing with the inside diameter the bolt size. It doesn't have to have thick walls…the minimum size will do. Tubing with an outside diameter of 1/4" and a wall thickness of 0.028" would work for AN3 bolts. Drill the larger hole size in the wood, and glue the bushing in place. The nice thing is, the glue will protect the bushing from the moisture in the wood.

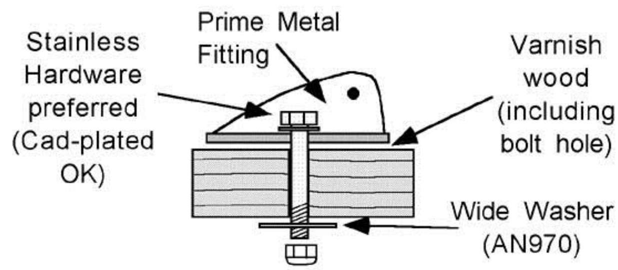
ShopSheet

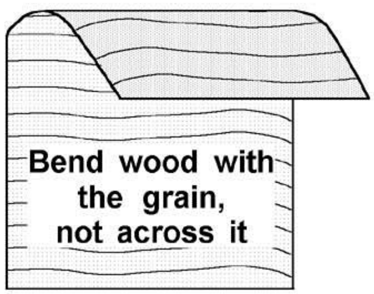
By Ron Wanttaja

Wood Hints

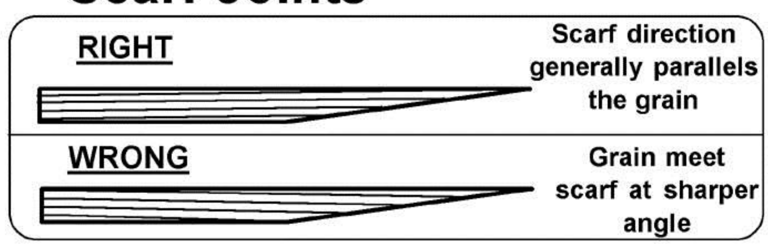


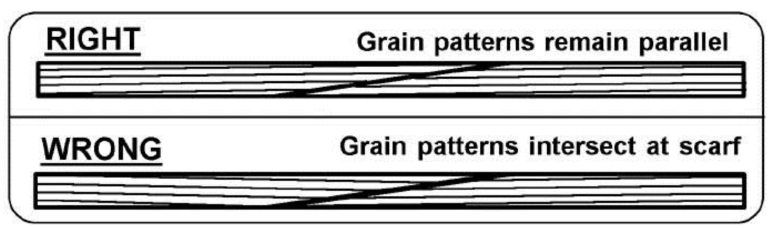
Wood/Metal Interfaces



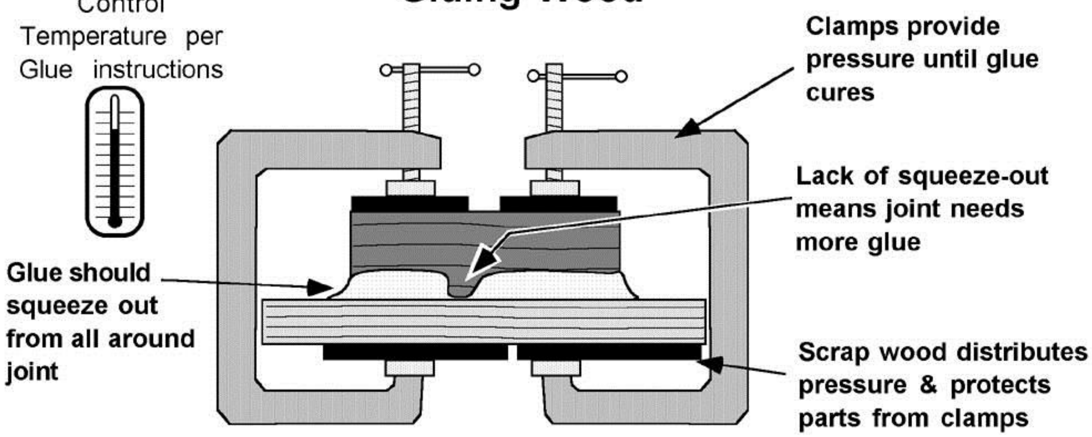


Scarf Joints





Gluing Wood



2 STEEL PARTS

Steel alloys are identified by a four-digit code that specifies the alloying components. One steel alloy is used on the Fly Baby: 4130, which incorporates chromium and molybdenum, called chro-moly steel, for short. You'll hear it pronounced, "Crow-molly".

Alloy 4130 is usually sold normalized, that is, it has been heated to its critical temperature and allowed to cool at room temperature. It's required after any sort of heat treating (including welding) to equalize stresses and maximize the hardness.

Occasionally, you might find 4130 in the annealed condition. Don't use it on your Fly Baby without additional treatment. It's soft and easily formed, but has no real strength. You can use it to build complex parts, but the parts must be heat treated afterwards. Look in the Yellow Pages under "Heat Treatment - Metal."

The steel alloy and condition is printed directly onto the metal. The condition is often abbreviated: 4130 N for normalized; 4130 A for annealed.

A Fly Baby takes several thicknesses of steel, but mostly 0.063” and 0.093”. The latter seems to be no longer available, so use 0.100” instead. A Fly Baby also uses limited quantitites of other sizes, from 0.032” steel for the tail post anchor on the tail, to 1/4" steel plate to help anchor the flying wires to the landing gear.

The steel is available from the ordinary aviation suppliers, such as Aircraft Spruce or Wicks. Sometimes, you can find it locally…check the Yellow Pages under "Steel Distributors." There's nothing specifically aircrafty about 4130 steel. As long as they can supply normalized 4130, you’re good to go.

One glitch: these companies often have a minimum order stipulation. Locally, several local outlets won't sell less than $100 worth of metal at a time. In other words, if you need just a two-foot piece, you're out of luck. Also, their prices operate on a sliding scale--the more you buy, the less per-pound you pay. On the other hand, there’s a chain store called “Metal Supermarket” that specializes in small orders. Some cities also have scrap dealers where you can just buy by the pound.

One point to remember: never buy ungraded and unmarked metal for your airplane. If you buy from a scrap dealer, make sure the piece is marked with the original manufacturer's printing. Sure, you can tell whether it's aluminum or steel. But no one can determine the alloy or temper just by looking at it. Sheet metal has the alloy and temper/condition printed in repeating blocks, so only the smallest pieces will end up unlabeled. The printing often indicates the thickness, too.

The printing also indicates the grain of the metal. The grain is the long axis of the metal before it's cut and rolled. This becomes important when bending the material.

One last warning: Don’t use the word “Airplane” around anyone but an aviation supplier. They’re leery about selling for aircraft. If you have to state a use, say, “Off-Road Vehicle.” You’re not lying, right?

2.1 Cutting

Most hand tools just aren't suited for anything larger than the thinnest steel. Hand tools cut steel eventually, but your hands won't be worth for a while much afterwards. A bandsaw is a necessity for steel. Use a very slow blade speed; about 120 fpm.

Bowers designed many of the steel parts of the Fly Baby to be made from standard-sized metal strips. You can easily find these strips at the usual vendors.

There are many companies who can take a computer file and cut the parts with a water jet, plasma cutter, or a CNC mill. "Racing speed shops" apparently have this type of capability…check your local listings. You can find templates (Figure 20) for the steel parts of a Fly Baby on the PB100 web page.

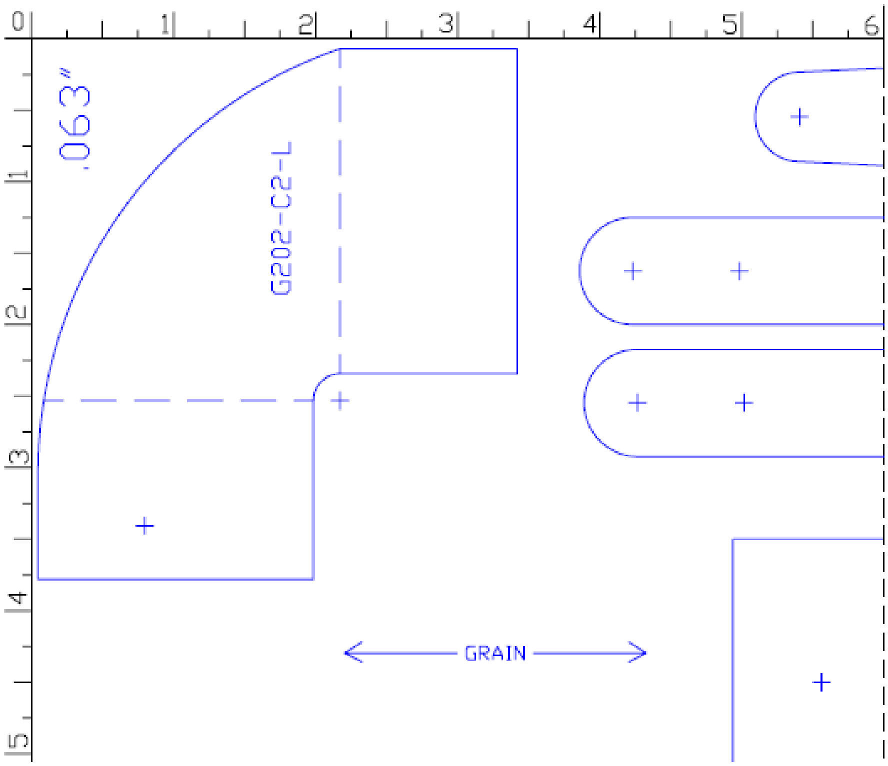


Figure 20: Sample Steel Template

In any case, these are fairly simple diagrams that a commercial shop may be able to implement fairly quickly.

When you have them cut out by machine, DON'T have them cut the bolt holes, to the exact dimension. Just have them do a pilot hole, and you can drill to the final dimension once you have the part.

2.2 Smoothing

Once you have the piece cut out, you'll need to smooth the edges. A benchtop belt sander will do, or, for the thicker steels, a grinder.

You'll want to smooth all angles into curves. Discontinuities produce "stress risers," locations where the stress in the metal can concentrate and cause cracking. You can see examples on the left of Figure 21. The inside sharp corners are especially bad. Use a file, sander, or grinder to smooth all inside corners.

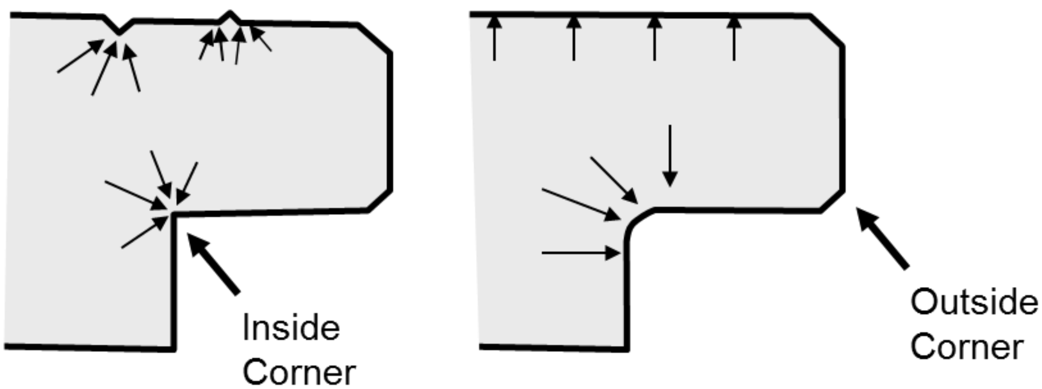


Figure 21: Stress Risers

The outside corners shown in Figure 21 don't have to be smoothed…but I recommend it. Sharp corners here might catch and cut you while you're working on the airplane, and rounded corners will hold the paint better.

2.3 Bending

Some of the steel parts on a Fly Baby have to be bent to their final shape. 4130 steel is designed to be bent, and to be bent without cracking at room temperature, either using pressure, or just whacking it with a hammer.

However, there are a few fundamental rules. First and foremost is the minimum bend radius. You cannot form the steel into a sharp edge; it has to bent around a shape with curve on it. The radius of the curve depends on the thickness of the steel. For the 4130 N steel used on a Fly Baby, that bend radius has to be three times the thickness of the metal (Figure 22).

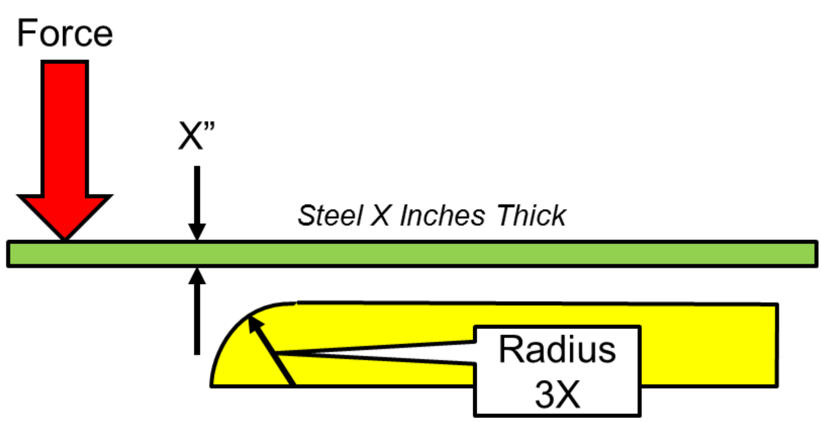


Figure 22: Bending 4130 Steel

Here's a table of the required minimum bend radius for the typical steel thicknesses used on a Fly Baby:

Table 1: Minimum Bend Radius for 4130 Steel

Steel Thickness	Bend Radius
0.032	0.1 inch (around 1/8”)
0.063	0.189 (about 3/16”)
0.100	0.300 (a bit over 1/4")

The bend radius isn’t much, but it has to be there.

Pete designed these parts so that they could be formed using an ordinary bench vice bolted SOLIDLY to the work surface. You’re going to be applying lots of pressure. You are also going to have to tighten the vice HARD around the piece of steel you’re working with.

Now, this can have some problems. The jaws of the vice are hardened steel, probably with a cross-hatch pattern on them to give a more solid grip. If you tighten those jaws directly on the piece of steel you’re working with, you may well imprint that cross-hatch pattern on your part.

You don’t want that. So always pinch the part between two pieces of wood for protection. One of those pieces of wood needs to have the bend radius built into it. Get some small pieces of oak from the big-box hardware store; you’re going to need a hard wood. Add the appropriate radii to several pieces of oak, and write the radius on the wood with a Sharpie.

Important to the bending process is the orientation of the grain of the steel. The grain in metal refers to the direction it was drawn through the rollers while being formed. The grain is the long axis of the metal before it was cut and rolled. Any printing is applied along this axis.

Clamp the piece of steel in the vice between the two pieces of wood (one including the bend radius) with the grain vertical.

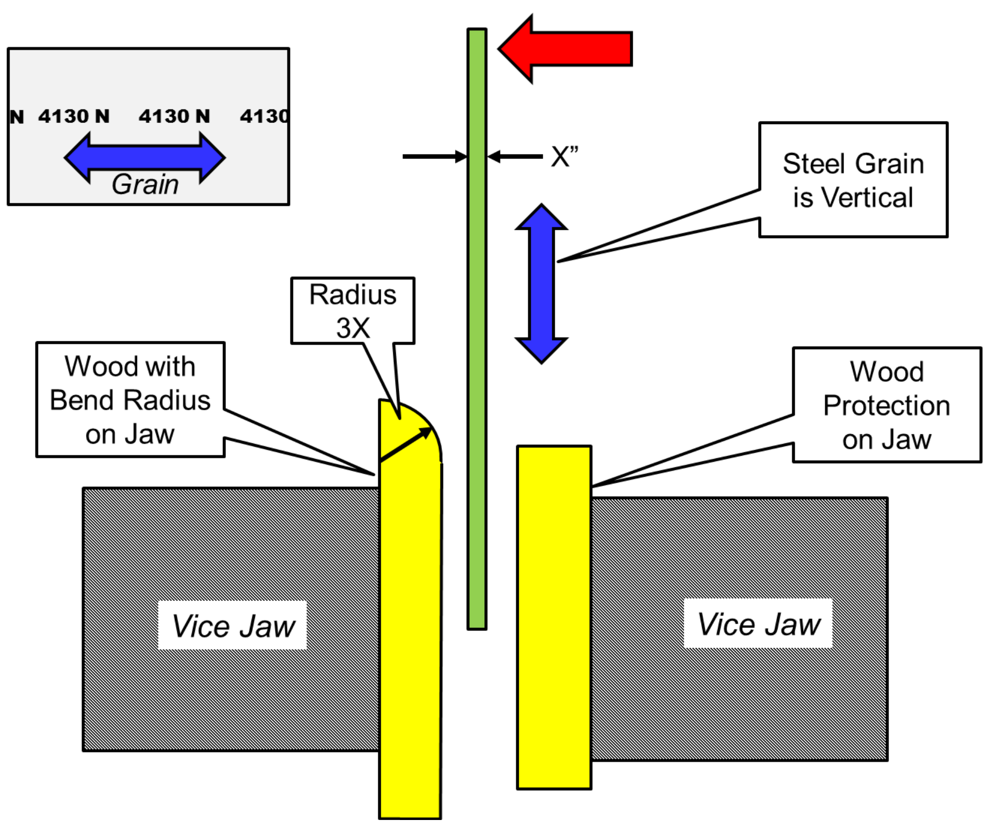


Figure 23: Setup for Bending Steel in Bench Vice

Once everything is solid, bend the piece of steel to the appropriate angle. Push the steel blank with your hands, or slam it with a hammer with a rubber or plastic head (to avoid marring the metal). Most of the bends are to 90 degrees, but keep in mind that you may have to bend it a little bit further due to springback.

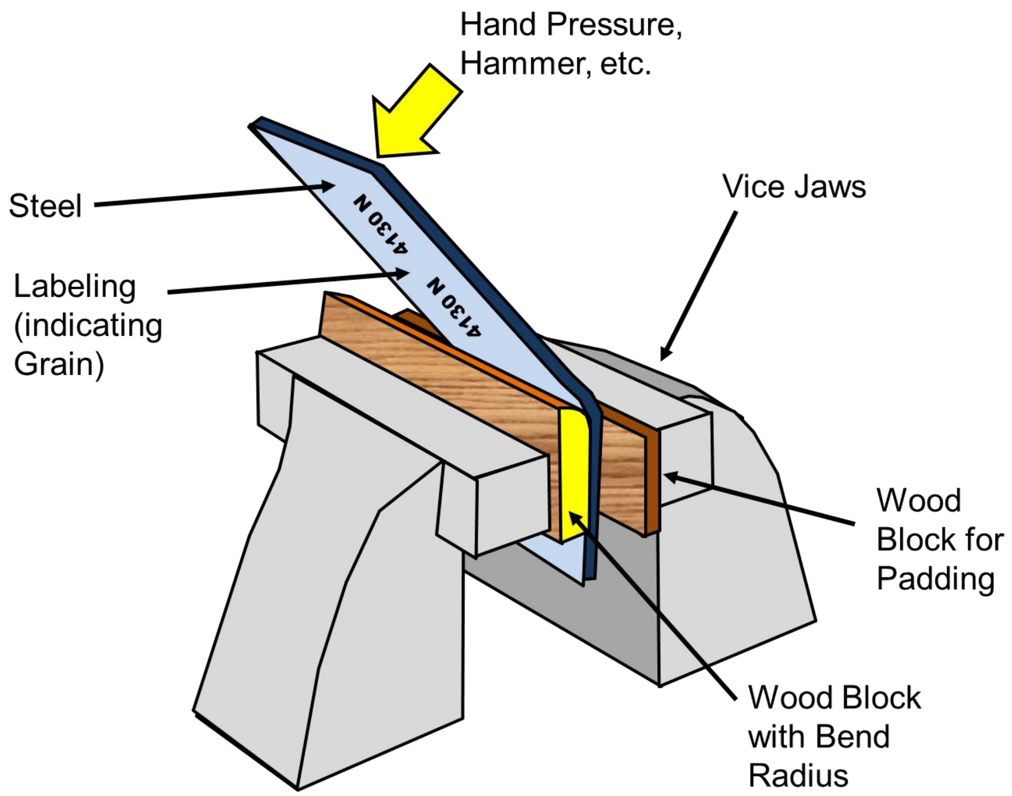


Figure 24: Steel Bending Process

The preceding assumes you don't have a bending brake. The brake automates the previous process; about all you have to do is clamp the metal in place and lower a lever. Brake prices vary from about $30 for light-duty ones to over $500.

However, don’t forget about the bend radius. These brakes usually include sharp-edged blocks to bend the metal over, which of course do not support the bend radius requirement.

Also, small bending brakes have a limitation as to the maximum thickness of the material to be bent. The inexpensive ones are limited to 16 gauge; about 0.063”. You might try one on the 0.100” pieces. It could work, since you’re not bending a very wide piece. However, don’t forget the minimum bend radius.

2.4 Drilling

If a hole is drilled too close to the edge of the steel piece, the little bit of metal between the hole and the edge might tear away under stress. You must maintain an minimum edge margin, or distance, from the center of a hole to the nearest edge, to maintain full strength.

The standard edge margin is twice the diameter of the hole. For example, the centerpoint of a 3/16-inch (AN3) hole shouldn't be closer than 3/8 inch (2 x 3/16] inch) to any edge. This can be easily measured where only a single edge is concerned, but is complicated when you must drill a hole near several edges. By happy coincidence, the wide-diameter series of aircraft washers (AN970) has an outside diameter just slightly larger than the correct edge margin for the appropriate center hole. Align the washer so its edges just come to the part's edges, and mark the center of the hole for drilling.

In a similar vein, the minimum separation between hole centers is three times the diameter. Remember, the edge margin ensures full strength, and applies to all holes: bolt holes, rivet holes, lightening holes. However, if the application isn't under high stress, you can shave the edge margin. A good example is lightening holes in plywood or metal ribs. They violate the edge margin constraints, but there's very little force trying to crush them flat. Instrument holes also need not follow the edge margin rules unless the panel is a structural member.

Pete's drawings included all the edge margin rules, so don't reduce the size of parts without consideration of the effect of the edge margin.

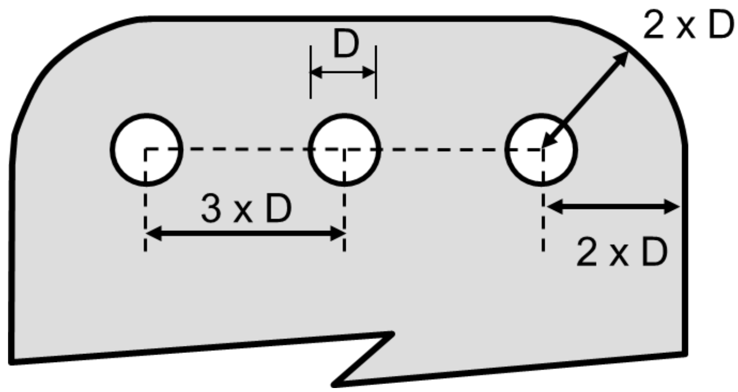


Figure 25: Required Edge Margin

When you drill, you want the hole exactly where you place the bit. To keep the bit from skittering, use a punch to dimple the metal at the drill point. An automatic centerpunch is best--it can be worked with one hand, as shown in Figure 26.

Figure 26: Automatic Center Punch

Drill holes to one size less than the final size (for instance, drill 11/64 inch for a 3/16-inch hole). Then drill to the final sizes.

Drilling directly to the final size is sloppy--the cut bits of metal rattle around and enlarge the hole. By first drilling slightly undersized, only a slight amount of metal is actually cut during the final drilling. This ensures the hole is exactly the desired size.

The drilling process has likely left a ridge-shaped burr around each hole. You must eliminate these burrs for the same reason as you smoothed down the edges of the part, to eliminate stress concentrations. The best way is to take a deburring bit or countersink and twirl it by hand on each side of the hole. This cuts the ridge off and bevels the edge.

A major cause of burrs is dull drill bits. To sharpen a bit, hold it in your right hand with just the tip showing. With an underhand motion, loft it towards the nearest trash can. Then go buy another. Bits are cheap enough that you should maintain a stock of the smaller ones.

Some folks deburr a hole using a large-diameter drill bit. But the bit tends to chatter and leave small nicks, even when turned by hand. While better than not deburring at all, this method isn't recommended.

Once the holes are deburred, the part is finished, though you might want to go over the edges with emery cloth to clean up last-minute dings. A small piece of metal has been magically transformed into an aircraft-quality part.

2.5 Protection

Steel rusts, of course, so it needs to be protected. Since most of the steel parts will be bolted to wood (with its 12% moisture content), this is even more important (though the wood should already be protected by the time the steel part is attached).

There are many good systems for protecting steel parts. Epoxy primer and paint systems are popular and readily available; in some cases, the paint can act as its own primer.

Enamel paint is a traditional solution, but the consumer-grade enamels available at the typical hardware stores is sometimes of questionable quality. Marine-grade enamel might be a better choice.

Finally, powder-coating produces a hard, near-impervious coating. However, it does cost a bit, and there are some concerns that it won't reveal any cracks under the paint surface.

Whichever type of paint used, preparation is important. Make sure all rust is sanded off. Try to round the edges a bit; a very sharp edge might be a starting point for a chip. Don't worry about sanding the steel to a glass-smooth surface. The paint will handle minor irregularities, and will stick better to a rough surface

Finally, before applying the paint, put on a pair of disposable latex gloves and wipe-down the part with mineral spirits. From that point on, handle the part only with gloves, since oils from your skin will interfere with paint bonding.

3 ALUMINUM

The Fly Baby's use of aluminum is limited. There are a couple of aluminum spacers, but the primary use is for exterior covers. These would include the engine cowling and the turtledeck areas, both forward and aft of the cockpit (Figure 27), as well as the wing leading edges.

Figure 27: Forward Turtledeck with aluminum cover removed

Pete specifies aluminum of at least 0.020" thickness in these areas. This is pretty thin and is very easy to work. Builders often go to a little thicker aluminum for these areas. My airplane has ~0.040" aluminum, which is almost TOO thick. It's very solid (which is nice), but of course the panels weigh twice as much as the material Pete calls for. Since you're going to be cutting it mostly by hand, that thicker material is harder to work, as well. N500F had 0.025" aluminum, and it stood up pretty well over time.

Aluminum is alloyed with other metals for maximum strength. The type of alloy is given by a four-digit number, like 2024 or 6061. The first digit identifies the major alloying elements. Alloy 2024 has copper has the main alloying ingredient, while 6061 has magnesium and silicon. The next digit indicates major modifications in the basic process, such as changes in percentages. The last two are essentially serial numbers for an exact alloy.

The alloy number is always followed by a dash, and a temper designation, like 6061-T3. Temper designations range from zero (i.e., "2024-0") to -T9 ("2024-T9", with the first digit after the T indicating the actual temper. Other numbers after this first digit are modifiers that don't really concern us. The temper indicates the degree of workability of the metal. T3 might crack if excessively worked, but you can fold a zero-temper sheet in half and it probably won't break. However, it's only half as strong as -T3 in the same alloy.

Alloy 2024 pretty much the standard for Fly Baby panels. It's strong, has moderate corrosion resistance, and not as brittle as some of the alloys. However, while pure aluminum won't corrode, 2024 comes with a thin layer of pure aluminum, referred to as "Alclad."

Most if not all applications using 2024 will specify Alclad. The Alclad status, as well as the alloy and temper, will be printed on the sheet. The term BARE is a positive indication that the sheet is not clad.

Typically, the "T3" temper level of 2024 will be used. So when you shop, look for "2024-T3". Alloy 6061-T6 is often used in homebuilt airplanes, too. It's not as strong as 2024, but it's a bit less prone to cracking.

The wing leading edges must be covered with a harder material to hold the wing shape. Pete specifies "0.016" Aluminum Flashing" here. This is basically soft aluminum, sold at hardware stores, intended as roofing material. You can use better stuff if you want, or cover the leading edge with different material (see the Companion Guide for Article 2).

Note: Pete occasionally refers to "Dural" or "Duraluminum" in the articles. This is an old trade name; just assume he said "aluminum."

3.1 Cutting

Mark your cut line on the aluminum with a felt tip pen ("Sharpie" is a trademark name for a common brand).

Cutting aluminum in the 0.025" range is pretty simple. An set of aviation "tin snips" is all you really need. These come in "Straight", "Left," and "Right" units…the directions indicate how the snips are set up to support curves. When you use them, perform a cut to about ~1/4" from your line to start with, then do a careful cut to the line afterwards.

The Zenair folks cut a lot of thin aluminum using a OLFA P-800 hooked cutter or similar (Figure 28).

Figure 28: Hooked Cutter

Lay a straightedge along the cut line, and score the aluminum along the lines with the cutter. Flex it a few times, and the metal should break off with a clean line (Figure 29).

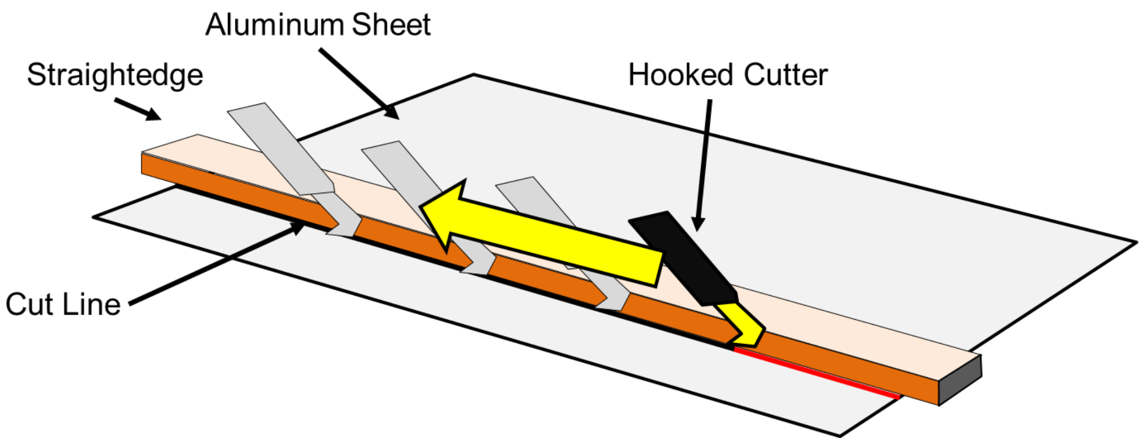


Figure 29: Long cuts on thin sheet aluminum using hooked cutter

Other builders have used routers, circular saws, saber saws, table saws, bandsaws, etc. to make these kinds of cuts. Tin Man Technologies has a good web page on methods that can be used.

3.2 Smoothing

Aluminum is nice to work with. I use emery cloth, around 220 grit or higher, to smooth out the cut edges. For long edges, consider wrapping a sheet of emery cloth around a ~8" long piece of wood, and staple it to the backside. This helps keep everything straight.

There's also a tool called an "Edge Breaker" (**Error! Reference source not found.**) which is esigned to dress the edges of long, thin pieces of wood. They sell for just $10 or so. Never had one, myself, but others like them. For thicker piece of aluminum, clamp them between two pieces of wood in the table vice and use a file (Figure 31).

Figure 30: Edge Breaker in action

Figure 31: Filing heavier aluminum

3.3 Bending

There's actually very little bending required for the large panels the Fly Baby uses. If necessary, clamp the area to be bent between two pieces of wood, and bend it by hand. That's how I added the bends in the aluminum belly panel in Figure 32.

Figure 32: Aluminum Belly Panel

Otherwise, the techniques described for steel in Section 2.3 will work. However, aluminum can't bend as tightly as 4130 steel, and a whole new bend radius table is necessary:

Table 2: Bend Radius for 2024-T3 Aluminum

2024-T3 Thickness	Bend Radius
0.020	0.06 inch (around 1/16")
0.025	0.094 (about 3/32")
0.032	0.128 (about 1/8")
0.040	0.168 (about 3/16")
0.630	0.315 (about 5/16")
0.090	0.483 (about 1/2")
0.125	0.750 (3/4")

The above table shows the routine, normal bend radii. The actual minimum is about half the value shown, but there's rarely any reason to take things down that tightly.

The little benchtop bending brakes available at places like Harbor Freight do pretty good with aluminum. Again, though, they need special care to get the bend radius right.

3.4 Drilling

Basically the same rules as for steel. See Section 2.4.

3.5 Protection

My Fly Baby, about forty years old, has the usual aluminum cowling and turtledeck covers. The insides of both are bare aluminum, with no protection. Neither shows any sign of corrosion. The coating of pure aluminum on the outside (the "ALCLAD") seems to be working.

On the other hand, the exterior side of these panels is painted to match the airplane. Unless aluminum is properly prepared, paint doesn't stick. The original builder of my airplane was a professional painter, and all the paint on the OUTSIDE of the aluminum panels has weathered the years very nicely.

I didn't do anything special when I made the aluminum belly panel in Figure 32. I buffed up and primed the surface, but didn't do anything else. Consequently, the paint on the outside is gradually flaking away.

So if you want your paint to stick, prepare the aluminum. Every item should be cleaned, etched, alodined, and primed before assembly.

Most of the aluminum is bolting to other aluminum surfaces, but not all. As has been mentioned several times, wood has a 12% moisture content, and keeping the aluminum directly against it may lead to corrosion. Varnish the wood, and at least prime the metal.

3.5.1 Cleaning the Surface

Cleaning means the removal of surface grime and corrosion. When finished, wipe it down with MEK or acetone to get rid of fingerprints. Don't handle the metal with bare hands--the whole purpose is to clean off fingerprints and similar impurities.

3.5.2 Etching

Paint doesn't like to stick to smooth, shiny surfaces. So we etch the surface using a weak acid solution. The etchant is generally a phosphoric acid solution; be sure to dilute it according to the instructions. Brush it onto the aluminum surface, working the acid into the metal with a Scotchbrite pad. It stinks a bit. After five minutes, rinse the part under running water.

There are several quite satisfactory self-etching primers on the market that require only minor cleaning prior to application. Check with your fellow homebuilders and the kit manufacturer for recommendations. If you decide to go this route, you’re done until after the component is installed.

3.5.3 Alodining

If you go with the traditional route, the next step it to alodine the aluminum. Alodine is a chemical conversion coat; it chemically changes the outer layer of aluminum to make it more corrosion resistant. You can actually see the result of this process, as the end result is an attractive gold tint to the aluminum. Alodine is basically applied like the etchant--apply it, let it sit for a bit, then clean it off.

Don't confuse alodining and anodizing. Anodizing requires immersing the parts in an electrolytic bath. It makes the aluminum practically impervious to corrosion and makes a wonderful base for painting, but isn't something you do in the average garage. Some of your parts might come anodized, though--the surface is a smooth, uniform black.

3.5.4 Priming

Once the metal is alodined, the primer can be applied. The primer is then sprayed on. Zinc chromate is the traditional primer, but several alternatives are available, such as zinc oxide and epoxy-based primers.