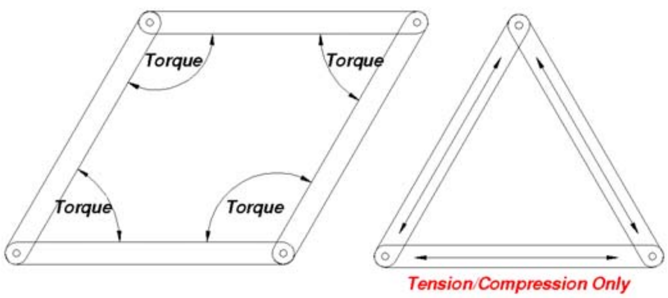
Constructing Fuselages for Strength
by Larry Cunningham

With the renewed interest in construction techniques, it is particularly gratifying to find information shared on the pages of ***Stunt News*****,** Internet forums, and in videos from **Windy Urtnowski, Bob Hunt**, and others. This wealth of ideas and information is a boon to us all.

In this spirit, this article describes fuselage construction details for my latest ship, ***Special Effects*** (***FX*** for short), which applies ideas from several sources. The result was a very strong, straight, and lightweight fuselage; I deliberately avoided expensive or exotic materials and concentrated my efforts on common structural design techniques.

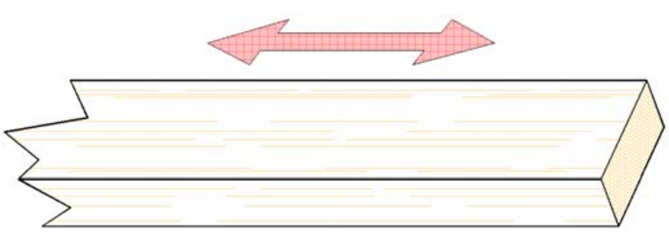
With this introductory discussion in mind, let's look for these ideas and features in the ***Special Effects*** fuselage design.fuselage design exploits the following structural features:

- triangular shapes
- fibrous tensile strength
- lamination
- stressed skin



Unlike other polygons, triangles impart NO TORQUE to their corner joints..

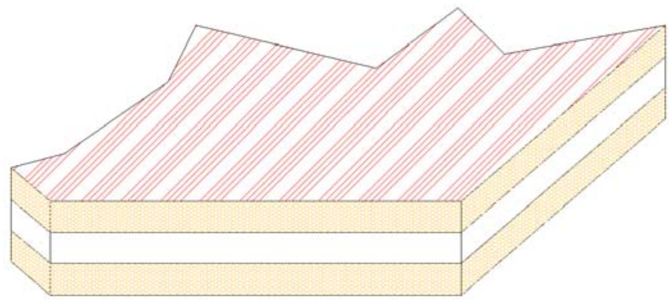
Triangular shapes have the property of distributing applied forces to structural members as [pure] compression or tension. Unlike other polygons, a triangle imparts no torque to its corner joints - in fact, the corners of a triangle could use "pin" joints (completely free to rotate).



Fibrous materials exhibit maximum strength in tension

Consequently, structures incorporating triangles are inherently rigid. They are implemented with diagonal members, which effectively "complete the triangle"; such structures are often loosely referred to as "geodetic" or "geodesic".

Worth noting here is the extreme strength of any wood in **tension or compression**, forces applied parallel to the length of the grain. This is primarily due to the internal structure of the wood itself. And almost all fibrous materials exhibit maximum strength in tension.



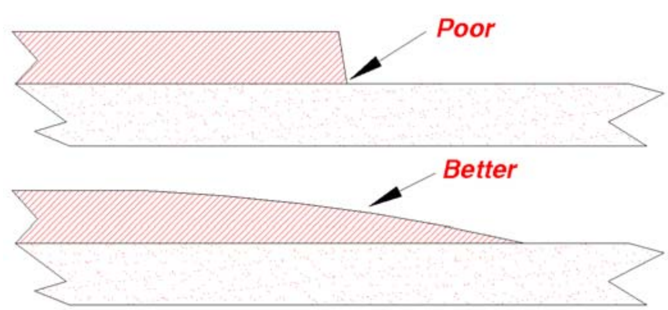
Plywood is a common example of lamination

Lamination refers to the layering of structural elements, usually to exploit directional strengths of the material. Plywood, which alternates grain between sheets, is a common example of lamination. Dissimilar materials are often used in the layers.

Lamination to accommodate curvature

Another use for lamination is to make a structural member conform to a curvature, for example a wing tip perimeter.

Each [thin] layer conforms more easily to a shape; when the layers are adhered together in a laminate, they tend to hold their shape because they are extremely rigid: to deform the laminate, forces must overcome the great tensile and compressive strengths of the wood.



Discontinuities are natural stress points

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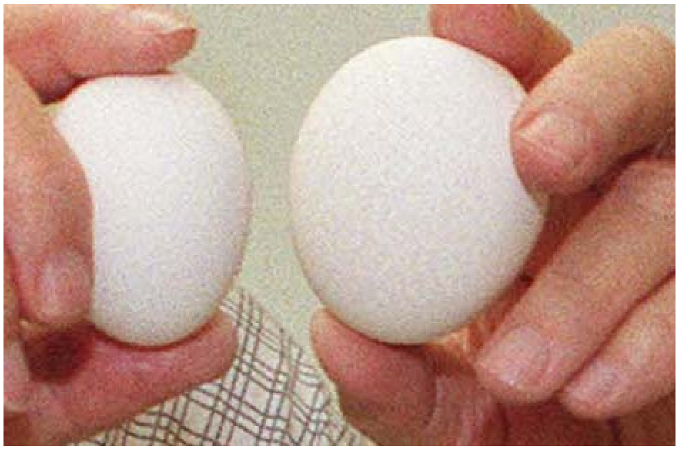
Distribution of force in a structure is extremely important to its overall service strength. Large forces smoothly distributed over a large area are easily withstood while even a small force applied to a point will be prone to failure. Discontinuities of structure are natural points for concentration of forces, sometimes referred to as "stress risers".

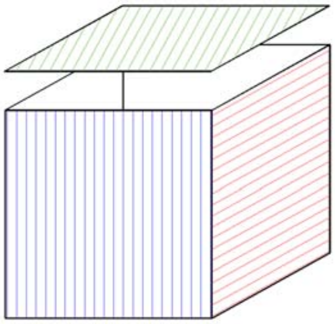
The more dissimilar the materials (e.g. in elasticity), the worse this problem becomes. Therefore joints and other transition points need to be smooth, tapered, graduated, and otherwise shaped to avoid such weak spots.

A **stressed skin** or **monocoque** structure exploits the notion of smooth distribution of forces. For distribution of forces, a smooth curved surface is clearly superior to a flat one with sharp corners. Perhaps less obvious is how curved surfaces minimize surface area (material and weight) to "enclose" a three-dimensional volume.



Stressed skin structures are very strong

A common example of a stressed skin structure is an egg. In spite of the brittle nature of its thin shell, an egg is incredibly strong in compression when the force is smoothly applied to its ends.

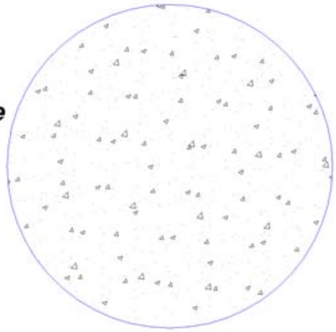


Closing the box

It is has been observed that great strength is added to any open structure by "closing the box". A major benefit here is what I will dub "self-constraint".

Specifically, each part of the structure provides strength to handle forces in a particular direction. But in addition, each part is constrained in its less strong orientation. Consider a simple cube shape. Each of the six square side surfaces not only can bear load well in a particular direction, but also constrains the edges of four other side surfaces.

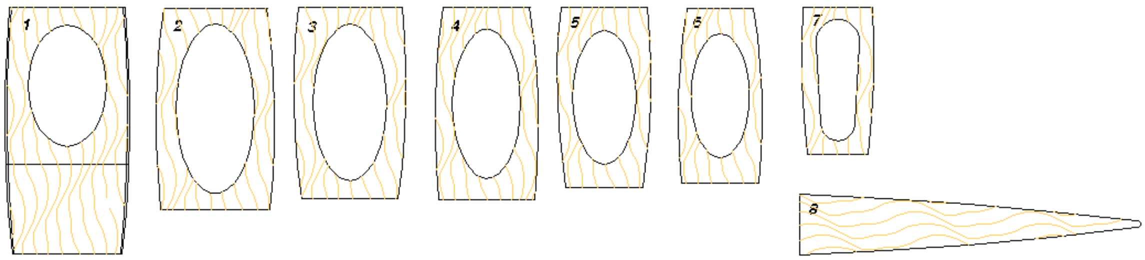
A sphere has minimal surface area

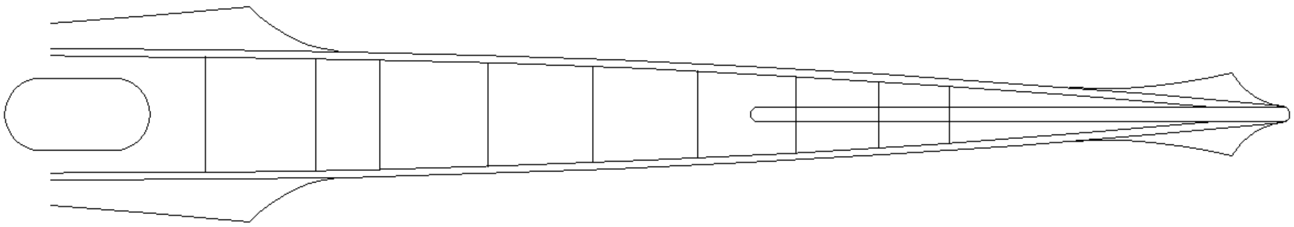


A sphere is clearly superior to a cube, because it offers less surface area (minimal material and weight) and a very uniform and smooth structure, which is everywhere constraining itself to the spherical shape.

With this introductory discussion in mind, let's look for these ideas and features in the With this introductory discussion in mind, let's look for these ideas and features in the *Special Effects'* fuselage design.fuselage design.

Formers are 1/16" Horizontal + 1/32" Vertical Balsa Plywood





FX fuselage sides have 1/8" convex curvature

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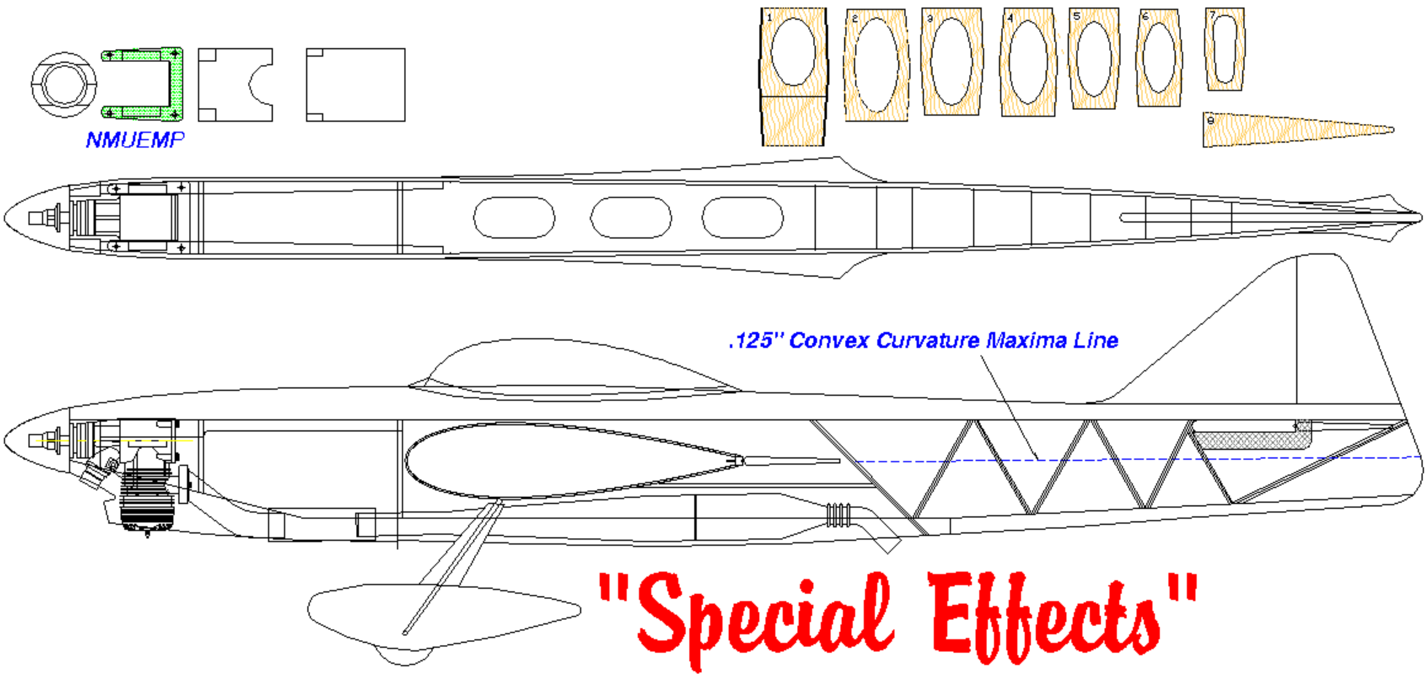
Begin with **curvature**. The ***FX*** fuse sides are curved in both horizontal and vertical directions. The horizontal curvature is visible in the top view.

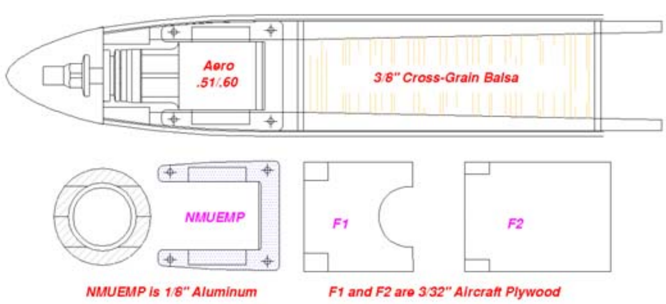
At the nose, I used the molded technique demonstrated in **Bob Hunt's *Stunt Flyer Video Magazine*** (Volume 2, Number 3). Instead of straight engine mounts and a nose block sanded to curvature shape to mate with the spinner, the fore ***FX*** fuselage sides are "molded" using a foam fixture to provide the desired curvature.

Of course there is a labor-intensive process associated with cutting and shaping the [hard maple] engine mounts to fit the fuselage curvature, but this is not particularly difficult. The aft engine mounts are tapered to reduce mass and smoothly distribute force.



The cross-grain balsa filler block between the aft engine mounts is pretty standard practice nowadays; here the compressive strength of end-grain balsa is exploited in the engine "crutch" design.

Note how the plywood nose ring is kept intact - its strength is again exploited. Yes, we do have to remove the prop and spinner to install/remove the engine! But we assume that the cowl adds virtually nothing to the strength of the nose. Therefore the nose ring is an important structural element.



New Mexico Universal Engine Mounting Plate

In the interest of easy engine changes, the ***FX*** nose was designed to use the **New Mexico Universal Engine Mounting Plate**. Simply, this is a U-shaped 1/8" aluminum bracket with a common corner bolt pattern, custom fitted to each engine. As a result, using a custom ***NMUEMP*** and cowl, ***FX*** can accommodate any of [at least] the following engines:

- **Aero .40/.51/60 piped**
- **OPS .40 piped**
- **ST .46,.51,.60**
- **Moki .51**

What does the NMUEMP contribute to fuselage strength? By being U-shaped, it becomes another stressed member (as the engine case would). It also provides a common interface for various engines, some of whose case bolt holes are not optimally placed for the [curve shaped, 3/8" x 1/2" maple stock] engine mount. The mounting plate and engine install as a "module".

On **Jim Young's** recommendation, the ***FX*** fuel tank area was made large enough to accommodate a Sullivan 8 oz. plastic tank. This results in a wider fuselage (2.5") than I initially wanted, but I have subsequently come to like its dimensions.

The tank is held in position with balsa shims and a bolted plywood plate, which serves as another stressed member inside the nose, yet still provides easy access.

FX fuselage sides are 3/32" balsa sheet, with 1/32" plywood doublers laminated on the inside surfaces using slow epoxy. With a thick wing section and pipe area below, extending the 1/32" ply doubler aft of the flap hinge line helps protect the fuse sides until the wing is installed. The ply doubler aft edge mates with the first aft former, in the interest of maximizing strength.

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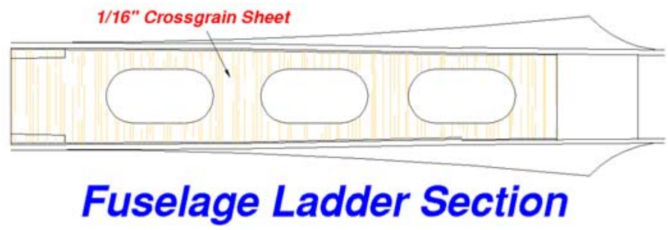


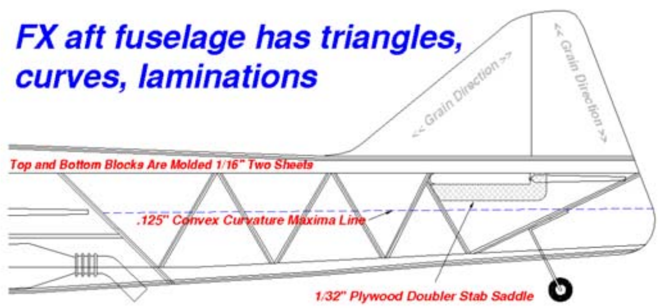
A "ladder" section of balsa sheet is added to the top center area of the fuselage, which enforces its shape and curvature until the wing can be installed. It also serves as a floor for the cockpit area.

End-grain balsa (in compression) is used here as well, with rounded cutouts to reduce weight. This technique was copied from **Steve Buso's *Cascade*** plans.

The horizontal curvature in the aft portion of the ***FX*** fuselage is fairly pronounced. One consideration was increased width at the front of the stab area. This makes for additional torsional resistance for the stab, as well as more room for the elevator control horn connection. But the curvature also contributes to fuselage rigidity.

As mentioned earlier, the ***FX*** aft fuselage sides are also curved vertically - that is, a convex curvature of 1/8" is provided on each side. The trick here was to accommodate the aft side curvature in two axes, while using diagonally placed "geodesic" formers inside. This was accomplished using **AutoCAD** projections for each critical point: the top and bottom corners and the intersection of a "high point" line of curvature along the fuselage sides. Given these three points for each fuse former side, a perfect arc (segment of a circle) was drawn through them. The result is very accurate former templates.

One other thing to notice about the formers is the use of a smooth elliptical cutout holes. Smooth, rounded contours are always superior to sharp, square corners for distribution of forces.

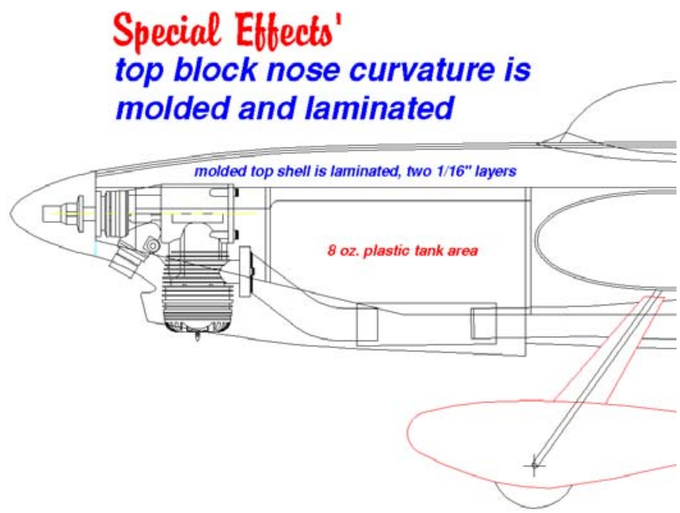


Although the aft formers are inclined diagonally, their major strength contribution is compression, so that grain needs to run horizontally. At the same time, I prefer to cut out a large center hole in each former prior to installation. Horizontal grained balsa has a tendency to split and break easily once the center hole is cut, even in 1/8" sheet. I constructed a laminate of 1/16" horizontal and 1/32" vertical grained balsa for these formers. The result is an adequately strong but very light former which does not split or break easily.

Diagonal positions for each former were drawn as lines on the inner aft fuselage sides, and each former was very accurately glued in. Extreme accuracy of the former shapes paid a huge dividend here: no fuselage jig was required to produce a perfectly straight structure. The former shapes enforce both vertical and horizontal curvature and twists are virtually impossible to develop if the formers are accurately glued in. It simply has no choice to fit otherwise. It is not necessary to wet the fuselage side sheets to accommodate the slight convex curvature.

All but the first and last ***FX*** fuse formers are placed on "ideal" 60-degree inclinations. The last former's triangular shape turned out ideal for mounting the tail wheel wire. I would argue that the inclination of the tail wheel mount adds considerably to its strength as well. Triangles again!

Diagonal former structure contributes greatly to "closing the box", with both vertical and horizontal components. Ultimately, less material is needed to achieve the desired strength. Without a top or bottom block, the ***FX*** fuse aft structure was already extremely rigid. The slightly "cupped" convex surface shape of the aft fuse sides contribute significantly to twist resistance.



Windy Urtnowski's videos (***Spitfire Construction Series***) taught me an easy method for molding top and bottom blocks. I found that I could produce a top block mold with less effort than completely carving a single top block. The mold mandrel was made from my useless "RC" (ball bat grade) balsa, and NOT hollowed. The mandrel is mounted on 3/4" pine, with 1/16" music wire CAed to the seam between. This wire (Windy's invention) produces an accurate "dent" line on the inside bottom edge of the molded top block, which makes it very easy to trim the molded part to its proper height.

Experimentally I determined the following recommendations. Buy 1/16" x 4" sheet wood, in lengths of 42" or more. The very softest and lightest wood is not required or even desirable: extremely soft balsa does NOT offer the greatest strength/weight. However, a clear A-grain sheet should be used. Mold the shell as two laminated 1/16" pieces. Soak the sheets thoroughly with warm water with plenty of ammonia - it stinks but does the job! Allow several minutes for the sheets to soften. You will find that the wet 1/16" sheets conform to the mold quite easily.

Wrap the sheets on the mold with wide Ace bandages, beginning near the center and moving toward the most "stretched" area (e.g. the nose section of the top block shell) last. Wrap fairly tightly, and allow the end of the sheets to overlap an inch or so past the end of the mold: wrap just past the end of the sheet. It is usually necessary to trim the overhanging edge of the sheet to allow a tight wrap, particularly at the aft portion.

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Left overnight to dry, the shells are unwrapped and carefully peeled (as a pair) off the mold. It takes only a few minutes to roughly trim the bottom of the sheets at the dented mark left inside. Use a fine saw to trim off the overlap on the front and aft ends. Properly wrapped, the shell outer surface usually shows marks from the bandage surface, but these are easily sanded off : do the sanding with the shells on the mold.

The 1/16" shells tend to stick together and act like a single 1/8" shell. Carefully peel them apart apply the thinnest possible layer of slow epoxy glue to their inner surface. Reassemble on the mold and re-wrap to hold the laminated layers while the glue cures. When the finished laminated part is removed and its edges sanded to final shape, it is extremely light and rigid enough to hold its shape off the mold.

The entire ***FX*** fuselage top block is a single molded unit. Both the nose curvature into the spinner backplate and the aft curvature to a sharp point were accommodated - all it takes is a little patience. And 1/16" laminated sheets!

Moreover, you can mold up another part the following day! Didn't work perfectly? You are out a couple of sheets, try again and do better next time. Save the imperfect shells - curved sheets have uses!

I recommend that sheets be laminated with epoxy or some other material (perhaps slow, thick CA) which does not require air to cure. The idea of adding a sheet of fiberglass, CF veil, or even silkspan inside the laminate "sandwich" occurred to me and I experimented with the same. What I found was that it was easier and just as effective to add such material on the inside surface, using nitrate dope, which is quite light and sticky and dries in air.

Once you graduate to molded top and bottom shells, you'll never carve and hollow an expensive soft balsa block again. Balsa molding (thank you, **Al Rabe**!) has to be one of the most significant construction techniques of all time.

Special Effects' **under side, belly shell and cowl in place**

The entire ***FX*** fuselage was covered with .5 oz fiberglass cloth, adhered with nitrate dope. After a very light sanding, a layer of medium grade silkspan was applied over the fiberglass, again adhered with nitrate dope. (Butyrate dope works nearly as well as nitrate, if you prefer.) Here's another example of composite construction: low tech lamination.

Although the original ***FX*** engine cowl was carved balsa, I am making up a hard rubber mold for epoxy/fiberglass layup. The fiberglass cowl will save weight and be superior in strength and durability. Further, the same cowl "blank" can be cut out to accommodate various engines.

The "belly" shell of the original ***FX*** is removable and slides into position on supporting "pins" (1/8" brass tubing). This feature complicated the work and added weight. On subsequent ships the belly shell will be fixed, glued permanently into position.

Molded belly shell and cowl removed

The original molded belly shell did not quite fit the pipe - it was slightly too small for the aft portion. I simply made up a second mold block with a bit more room, which was glued on the opposite side of the 3/4" pine block. Now I have belly molds for both piped and non-piped versions of ***FX***!

I always try to "pre-finish" a fuselage before the stab and wing are installed. For the ***FX***, a 1/8" rudder was used, using two pieces with the grain as shown. The same fiberglass and silkspan treatment was used on the rudder before it was installed, with Epoxolite fillets on the fuselage/rudder joint. My prefinishing used ordinary talc and clear nitrate dope, sprayed on and "wet-sanded" using #600 sandpaper and **Prep-Sol I**. Almost all the filler coat gets sanded away; two or three applications provides a smooth, nearly perfect surface which is ready for the color coat.

At this point, my prefinished ***FX*** fuselage, ready for installation of stab, wing, and the canopy detail weighed in at only 7.65 ounces! That included rudder, cowl and removable belly shell. Yet it was easily the strongest fuselage I had ever built.

I added one little styling feature which doesn't contribute much to strength, but did not weigh much. The ***FX*** flap fairings have small sections of curved 1/16" molded scrap added above and below, for a "3D" shape effect. This particular gimmick met with mixed reviews at the ***Mesilla Valley Model Airplane Club*** "show and tell".

So there it is. Application of simple structural techniques and common materials can produce a very rigid, lightweight fuselage. I hope your interest has been stimulated and you found something you can apply to your next fuselage structure.

-Larry Cunningham