Making Lighter Rubber Scale Planes
By Dan Garsonnin
An article published in the November Issue of MaxFaxd of the DC Maxecuters, Stew Meyers, Editor

I would like to address the subject of rubber scale designing and building, the essence of which is maximum strength with minimum weight and good looks. That's a pretty broad subject, and I'm better at rambling than I am at organizing, so this won't be the easiest read - I'm sorry for that.

I invite anyone to make comments of any kind, about any aspect of this article, technicalities, or indeed, even its presentation. At a later date, I hope to be able to supply photos to help substantiate and illustrate what I've written here. Perhaps a sketch or two wouldn't hurt, once I learn to use my new machines.

I hope to speak to those builders who are thinking of going beyond simple kit building, or building to a plan. A modicum of experience will be needed.

A very beginning step might be to replace kit material with your own lighter, stronger, or more suitable material. Further steps may include modifying portions of the model by discreet removal of bits of material, such as with hollowing, thinning, punching holes in ribs, scalloping between supports, etc., or even adding material for strength such as a gusset to prevent a tissue wrinkle, or other known structural, scale, or aesthetic weaknesses in the design.

A trap to avoid is over-lightening; i.e., a piece whose lightness/strength is out of step with the rest of the model, and may fail before the rest of the model. Admittedly, there will always be weak points, which we strive to correct, but beware of creating new ones by flagrant material removal. 1/16" balsa can often be reduced to 1/20" or even 1/32", but the remainder of the model must be also suitably light. I can't remember when I last used wing ribs thicker than 1/32" on a Peanut, but then the rest of the structure is also very light. Lighter planes do land easier, bounce better, and are much kinder on strut supported top wings.

By this time, the builder is probably chafing at the inadequacies of the kits or magazine plans, and scratch building and designing enters the picture. Now, you can choose any design, to any scale, incorporate standard structures and features, plus your own innovations. And if you thought that model building was fun and satisfying, designing and scratch building your own is the ultimate.

When a concept of a scale model first occurs to me, it is often with an overall appearance, or style, in mind. On occasion, the style comes first and I seek a model to suit it. Sometimes the style is determined, almost dictated, by the requirements of a contest event. The style might be rigidly scale with as much realism as possible or it may lean a little more on the whimsical or sporty side with lots of clear-coated, brightly coloured, open tissue, paying homage to traditional charm. The intensely scale job will need focus on weight reduction but some fudging in technique can exist if it is to be covered by an opaque finish. The more traditional style will be easier to keep light, but the building quality and technique might be even more visible and critical to the satisfaction that the model offers.

My approach has been that somehow, the thought of a cutesy, brightly coloured, transparent, open-tissue thing, posing as a WW II warplane doesn't appeal. Anything since 1940 will likely feature lots of opaque finish and perhaps sheeting to resemble the hard skin of metal aircraft, and any open tissue will likely be hidden or disguised as much as possible.

Lightening construction members: As soon as weight becomes a factor, the material in construction members is moved closer to the outside surfaces or extremities of that member. So, solid beams become I-beams, box-beams, tubes, etc., as can be seen on almost any bridge, tall building, and of course, airplane. People may be fooled into thinking that the vertical portion of an I beam offers much rigidity, when its real function is as a web to hold the top and bottom flange in their relative positions so that they can do the real work of resisting those bending forces.

By changing to a more sophisticated profile than just the square solid beam, individual spars and stingers can sometimes be lightened. Using a thinner, rectangular piece on the vertical can sometimes be accomplished if the reduced stiffness is fortified by gluing to the covering. So ribs and stringers, should they run the risk of buckling under tension, say tissue shrinkage, should be glued or doped to the tissue to help keep them straight.

Should, during shrinkage of the covering, you notice that the ribs are starting to buckle, get some thinner on the paper and rub some dope through the paper onto the ring ribs, to secure the paper and the rib before the thinners dry. You may be able to save the situation if you're quick, so do watch while the shrinkage, from water or dope, occurs. I did save a set of wings this way, once.

I use flanges. Many aircraft parts, in order to be easily manufactured out of metal, are often stamped out of, or extruded into, thin sheets and a flange is attached or moulded. A capped rib has flanges, top and bottom. If my bulkheads are too thin, I'll flange along the inside cutout, or relief. The efficiency of strategically placed flanges can result in huge weight savings while still maintaining adequate strength. Flanging often places the material right where you want it — at the outside surface of our construction member.

Weak bulkheads or formers will crush inward under excessive force (hand squeeze, cartwheel landing). Failure will begin as a crack or split starting at the inside relief or cutout. Gluing a flange around the inside edge of the relief can prevent that crack from ever beginning and will greatly raise the failure loads.

Sometimes, placing cyano-glue in strategically chosen spots or edges can strengthen pieces, which are too weak. Remember how difficult it is to work wood which has cyano-glue on it, not to mention its weight; so do be judicious with its application

Simple structures or members: When examining a member for stiffness, there are a couple of figures, or proportions, to remember, although many people's instinct will tell them the same thing. For a construction member to retain its strength in compression, i t must resist buckling. When the ratio of its length-to-its-thickness gets too large, the tendency to buckle increases -- the member fails as a column -- it is too skinny. The same thing happens to sheet material if it's too thin. That doesn't mean that it loses all strength but that it loses much or most of it. So, when a stick or a sheet becomes longer than eight times its thickness, it begins the tendency to buckle, until around twenty times the thickness, it is as wobbly as it can get and cannot be counted on as a column or a rigid, compression member.

So width counts – it adds stability -- maybe something to consider if deciding to go with thicker, lighter material, or skinnier, harder material. The skinnier stuff may need additional support, the softer stuff may be prone to crushing -- no free lunches -- but you can seek advantages. And now consider the use of a flange, which can add to the thickness without adding that much to the bulk. Hooray for complex cross-sections. Consider the difference between the stiffness of a corrugated sheet of metal, and that same sheet flattened out. In some ways, the sheet has been made effectively thicker with the corrugations.

Of course, all that instability stuff doesn't apply to anything in tension. You won't find the bottom of my wings loaded up with spars - I rely mostly on the tissue, which is quite strong in tension. So, what's in tension and what's in compression? Simplified a little, if you apply a bending load to a simple beam, it will resist the bending forces by having half of its material in tension, and the other half in compression. The material furthest away from the centre (the neutral axis through the length of the beam) will carry almost all the load and only after its failure, does the inside material play an appreciable role. Since the inside material can resist even less than the outside material, failure of the skin, or outside surface, often means total failure. The integrity of the outside surface is important. And, those fibres down the middle at the neutral axis, are neither in tension nor compression, and add nothing substantial to the strength of the beam other than their own stiffness.

When the beam does bend, as do our components and even wings, the material in compression distorts by squishing a little, and the material in tension stretches a little, and the bend occurs. Without those little distortions, there would be no bending until the point of failure. If you picture this, you'll understand why the material furthest from the axis, at the outside surface, takes the highest load and distorts the most and why if those outside fibres fail, those inside of them, closer to the axis, will have to take the entire load, and with less resistive leverage are likely to immediately fail. The crack is progressive and instantly becomes a break.

If you think that width is important for the stability of a compression member, say a fuselage upright, depth of beam is even more important. If you have a beam with a rectangular cross section, do place it on its edge to get that depth. The basic material resistance calculation is based on the square of the distance from the neutral axis. This means that the fibres, which are twice as far away from the neutral axis can resist four times the force before failure than fibers, only half as distant can. And now, the full implications of the value of an I-beam should be evident. And similarly, how the value of adding flanges, permitting very much thinner material to be used, should be recognizable.

Fortunately, the parts of a beam that are under tension follow the same rule: the forces and resistance depend upon that same square-of-the-distance from the neutral axis, only pulling instead of compressing. Wood tends to have the same resistance in tension as in compression, but concrete and stonework don't -- hence the need for reinforcement (rebar) or engineered shapes as used in the arches in the Roman aqueducts from thousands of years ago. But, as mentioned earlier, paper is quite strong in tension. As long as the paper is taught and repaired, there is little need for bottom spars other than the L.E. and T.E.

And that square of in our formula - don't be afraid of that. We use the square often: if you double the measurements of your wing, you will quadruple its area, and if you double the airspeed, you will quadruple most aerodynamic effects like lift. Moments of inertia (the effects of a long or short nose on a glider) use the distance-squared. So don't get weirded-out. You don't have to calculate things out - the idea is to realize the importance of things.

I am not, in this treatise, suggesting that we calculate our stress analysis with numbers - only that we have a realistic idea of important. parameters of force and resistance. As modelers, we do develop a feel for the materials we use and their strengths and weaknesses, and we can add that developed sensitivity to these physical considerations to help refine our structures in a logical way; in other words. and I think this is where that beautiful term comes in -- to guestimate.

Complex structures: Structures made up of more than one member. The reason we use shear webs and spacers is that if all the pieces can be adequately stabilized in position, the entire structure can act in concert, as a whole unit. If the pieces are allowed to shift, slide, or buckle in relationship to one another, compromising the integrity of the unit, its failure loads will be much lower - it will break or deform earlier. For example, hold a phone book in front of you as if to read the cover, in your left hand by the spine, and bend the pages back and forth with your right hand, and they slide. one page against another (in shear) and the book bends easily. Now, still holding the spine with your left hand, grip the open edge of the book firmly in your right hand so that the pages cannot slide, and the book no longer bends - it has become a unit, structurally. As a unit, all the pieces are subject to that same calculation with the square of the distance from the neutral axis of the unit (beam).

In the case of wings, if all properly stabilized, the whole wing can be treated as a beam, using the same parameters of comparing the square of the distances from the neutral axis to get an idea of where to place what material to be most effective. I am not a fan of sunken spars - unless something specific is trying to be achieved. Spars at the surface, at max camber. will offer the greatest strength.

Of course, the spars must remain resolutely in position relative to one another. To prevent local buckling of the spar, rib pitching has to be close enough. Webs can help in preventing buckling as well as sliding (shear), and they don't have to be very strong --they are only there to stabilize, not to share the load. The stabilizing muscles along an aging spine are not strong, but they must be constantly employed.

And, to reiterate, if the parts are sufficiently stabilized so that the whole wing acts as a beam, the individual members are to be treated as members and not beams in themselves. The entire member will either be in tension or compression. Spars with rectangular cross section will be most valuable if placed flat, rather than on edge as a beam, and as close to the wing's surface as possible, keeping it as distant as possible from the wing's neutral axis. Remember that the formula is -- cross sectional area x distance x distance, commonly called "the moment of inertia", should you hear the term in a discussion on structures. Moment of inertia will typically be heard in discussions about how long to make a glider's nose, or how light does that stab or those wing tips really have to be.

For a few years, I worked on a line of A-2s, which had fully sheeted wings, and I wanted to reinforce the top sheeting (1/16 61b stock). I didn't wish to sink a spar below the sheeting because the notch would weaken the already thin-wing ribs, and I wanted to keep all the material as distant as possible from the neutral axis from maximum strength. I ended up letting in a 1/16 20 Ib stock wedge (wide at the root, narrow at the tip) to the top sheeting. The ribs weren't any thinner, didn't need notching, and I pitched (spaced) the ribs a little closer to make doubly sure the sheeting wouldn't buckle. The sheeting became the spar, and the most efficient one possible. In fact, the wing had become a total monocoque structure, which has the most efficient distribution of material.

One difficulty that is prone to glider wings (under-cambered) is to prevent reflexing of the wing so it flattens and loses its camber and its effective depth as a beam. I placed several glider wings between two chairs and sat on them until they broke. In every case the camber flattened and the wing broke right away - but not until the camber flattened. It is similar to bending a steel measuring tape. It doesn't bend until it flattens, and then it bends pretty easily. And, the forces causing the flattening are severe and difficult to resist. Capping thin, curved ribs might be very desirable.

The way to think of this is to look down the end of a wing - at the profile, the airfoil with all the spars. The neutral axis will run along the profile, in the direction of the least bending resistance of the wing, somewhere between the top and the bottom, and roughly parallel to the base line.

Establishing the neutral axis of a wing panel is probably the most "iffy" part of the whole process. I haven't actually done one mathematically. I think that if I dredged up all my high school algebra, I could. But up till now, I've estimated it. If a wing has three balsa spars - L.E. and top spar and T.E. - of similar cross section, the axis will lie closer to the two bottom spars because they offer more resistance. But it won't lie very much closer because any change in the distance between neutral axis and a construction member is to be measured as the "square of", to establish its moment. Small change in distance equals big change in resistance. So, even with piling material on, it is difficult to build a strong, thin wing. A slightly fatter one could be just as strong and be very much lighter.

When a spar breaks, or the bottom tissue rips chord-wise, that neutral axis will immediately take a new position, closer to the greatest mass of the remaining parts, everything will now be stressed more, especially those parts closest to the fault which have become more distant from the axis and more alone in assuming the loads, and more subject to deformation.

Should dissimilar materials be used as spars, it gets more complicated. The materials must be compared to the main material (balsa of a given density) for resistance and elasticity (the ability to deform temporarily without permanent change - steel is very elastic, lead is not -- and converted to "equivalents" in balsa area. In the drawings and calculations, a balsa spar of larger cross sectional area would represent a spruce spar. It does get quite a bit more complicated, but for rubber scale, I am usually looking for the lightest stuff - the heaviest would be a medium balsa spar.

Fuselages: I became a little distressed while laying down stringer after stringer, all in effort to nearly reproduce that round fuselage cross section, common to WW II aircraft, and thinking of the weight of all this material. Couldn't some material be removed or done without? Duration ships get along with a square or diamond shaped fuselage that has four longerons — four longerons! And they use bigger rubber. And now, this F-4U was going to require twenty-four longerons in the nose - just to make the shape - it certainly wasn't for needed strength. These scale ships are hugely overbuilt. Surely..... something could be removed without compromising the needed strength.

Oddly enough, the primary limitation to reducing fuselage stringers and longerons seems to be the pull of the covering - shrunken tissue. I want taught tissue but I don't want the starved-horse syndrome. The stringers will sag between formers if: the formers are too widely spaced or the stringers are too thin and/or too few - both are expressions of a too-strong tissue. The solutions can involve using a weaker-pulling tissue, tightening the spacing of the formers, or using more stringers or stronger stringers. Whichever combinations of those procedures you choose might depend on if you have different tissue or dope, or if your formers are already determined and you don't wish to draw new ones, or if you have stiffer, stringer material. My last Peanut had some 1/16 x 1/32 stringers, placed on edge and firmly attached to the tissue to resist any buckling.

Many fuselages are constructed using keels. These keels are often heavier than needed. The F4U from that W.W.11 book had huge keels, which I pared down, once I had the framework in my hand and realized that something had to go. Later models used keels of stringer-size (or marginally larger) but I started with a temporary structure tying the keels together, with diagonals and verticals *(1/4* x *1/16),* which were fairly easy to cut away once the frame had its own stability. I guess it's like interior scaffolding but only two-dimensional.

Often, much material is invested in the bulkheads and formers. I am convinced that with the use of laminations, so that the grain is always in the right direction, the scale, curved, characteristic shapes can still be retained but made lighter. Because I don't want to laminate more than two layers (the shape becomes inconsistent or deformed), a thickness of only *1/16"* will be developed, which is insufficiently strong for a full former on anything larger than Peanut Scale. The laminations would have to serve as a flange to a normal style of former, cut from sheet.

Note that laminating a *1/16"* sq former outline, braced inside with a triangle if *1/16"* sq, is adequate for a Peanut sized model, and is very light and sophisticated. There are no notches - all the stringers are floated on the outside. Important bulkheads would have to be bigger and stronger, or somehow fortified. (I have tried pure laminations as formers on a larger ship, but I'll leave that for a later posting.)

If only a flange is to be made with laminations, and not the entire former, perhaps the outline of the former is not the best place for a flange. Flanging the cutout in the center of the former would permit a narrower former, made with thinner wood. As a bulkhead is crushed, the break begins at the inside cutout edge, as the piece collapses inward. A laminated flange there would prevent (within reason) that break from starting.

My latest project is a double-sized version of the F-4U out of that Fighters of WW II book. This is a big plane with a wingspan of 42", a root chord of 9" (largest I've ever dealt with) and a nose width of 4". Since I only use soft balsa in my scale ships, it will never weigh very much - which is the point. All my bulkheads and formers have been reduced to .." wide, flanged on the inside with .," x *1/16",* which was easy to do. But, whereas I did use *1/8"* thick bulkheads in the nose, all of the formers from the mid-wing point aft are only *1/16"* thick, yet are sufficiently strong with the inside flange. The rubber also has nice contact spots on the smooth flanges.

All the longerons are *1/8"* sq soft. Only four notches were cut into the formers - I used four keels. Otherwise, all the bulkheads and formers are notch-less and smooth on the outline - easy to make. The stringers were floated between the keels, packed or relieved when needed for that perfect, flowing outline, and were lined up by eye during the gluing. This is a fairly easy process and the results are most rewarding.

My tendency has been to use sheeting on these metal ships where ever the weight can be afforded. With rubber ships, that usually means only the cowling. The F-4U was easy - no compound curves, although merely wrapping a cylindrical shape in sheet can produce an ugly, starved-horse shape if you are not careful. It is possible to pull the sheet too tightly between the formers, and do avoid shrinking glues which can pull the sheeting in toward the former - no cellulose glues (Ambroid).

I have never liked the task, and I'm not that fussy about the results either, of planking. So, all my cowlings are sheet balsa -- even the ones with fancy shapes - if I have to mould them.

With balsa sheet wrapping, the sheet, forming a monocoque structure, can take all the loads with no interior structure, in principle. Sometimes I have to use a keel, or some rudimentary stick structure, just to locate and fix the nose. My F-4U has no structure just forward of the wing. The cylindrical cowl is all that's needed. Now, just in order to make the cowl with my hands, and to properly position it, I may find that I do need some sort of keel, or maybe keys, or something more to help accomplish this task of dexterity - lots of careful finger-tip work.

Almost any cowl, such as a Cessna or Spitfire, can be made with three pieces of moulded balsa sheet (one for the top and two for the more curved bottom), with a standard style of nosepiece, plug and bearing.

Moulding balsa sheet may be easier than you think - but it is still a task, not onerous, thankfully, and the results can be entirely pleasing. Only A grain balsa is suitable for any wrapping. A wooden (or could be foam) plug, or male mould, is carved to the exact shape needed, minus the thickness of the wrapping, which is always *1/32"* - strong enough for any sized rubber scale ship - the shape will provide the strength. Any localized reinforcement can be provided with moulded doublers, although there is usually no need.
Choose the most flexible piece of soft wood you can find and it has to be softened with water. Even a soaking in boiling water is usually not quite enough softening, so household ammonia can be added. Ammonia dissolves the lignin (if I'm not mistaken) that holds the wood fibres together. Add a small amount, say 5% to the water and immerse the balsa. Watch for some of the loosened fibres to be collecting on the bottom, and occasionally check the wood for flexibility. The more ammonia, the quicker all this happens. I have never over-soaked a piece, but I imagine it can be done, judging from what collects beneath. I would like to supply a formula with what percent of ammonia to add for how much time, but I don't have these figures.

The softened balsa can then be wrapped, pulling and pushing here and there to help, without splitting the balsa, with a roll of cloth material, maybe an inch or inch-and-a-half wide. Just do one piece and mould and wrap as much of the shape as you can. I have a feeling that heating really does help, rather than air-drying; so stick it in the oven (300 degrees for 15 min. will probably do). When perfectly dry, unwrap it and see mow much of the shape you've managed to successfully mould. Use another piece of balsa and mould those parts of the shape which are not yet moulded - as I said, I have managed with three pieces. When all the pieces are moulded and dry, slip them all on the mould, overlapping, and decide where the best place for the seams should be so that only properly moulded portions will be cut and used to fit together. Make the cuts with a dimensionless cutter (I can never find one, so try a #11 blade with a new, long point) and cut both adjoining pieces at once, on the mould, so that they do fit one another.

If you know you will use a support structure (keels or something) under the moulded sheeting you will probably want to try to mould and cut and join your pieces with the seams directly over the structure. The cowlings I have produced in this manner are the most beautiful parts of my planes. Once, for a shadow Peanut scale (outlines only with single surface wings) I made a Found Brothers cabin plane, which included fat, hollowed, balsa wheels and a moulded cowling, which weighed only 2 grams and flew for two minutes on *.020* x *.020* rubber. The plane was so light and reliable, and thus, virtually unbreakable, that I flew it through countless events and presentations for the next twenty-five years - the most reliable and long-lived plane I ever had.

One extensively moulded plane, still on the board, is a Douglas B-26 (really long nacelles) also with a wingspan of 42" The entire fuselage, from the main trailing edge forward, including the inboard wing panels and both nacelles are fully, moulded sheet balsa. Open structures are on the outboard wing panels, aft fuselage, and tail feathers. The weight of all the finished components, all assembled except the tail parts and minus the propellers and thrust bearings, sits at *120* grams -4- .. oz. The plane will never fly much because to save weight, the aft fuselage and tail are made super-light with condenser tissue. It won't take too many landings, no matter how gentle, to mangle those tail parts. That's a very impressive weight, for the appearance of the plane, but still I am used to things with less than half that wing loading, so I have my doubts. Maybe I shouldn't because a test glide (tail taped on) was relatively slow and flat. Maybe I'm apprehensive at the scale of the project and the edges I'm pushing. Still it has to be a challenge or it isn't much fun.