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APOGEE

PEAK OF FLIGHT

NEWSLETTER

Man vs. Mother Nature

Are Composite Materials Stronger than Wood?

By Tim Van Milligan

I was digging through my archives, and I came across this article that I wrote in 1993. It is still useful today as it was years ago.

"If you're not using composites, you're getting beat by people who are." That was a quote out of a catalog from a company which specializes in selling composite materials to competition model airplane fliers. In most respects, the quotation is true.

But I've always wondered, just how much benefit is the average modeler getting out of the use of composites. I started thinking about this several years ago, so at that time, I dug out one of my old engineering textbooks that had a chart in it comparing the strength-to-weight ratios of several materials. Table 1 is that chart, with one exception; I added the data on balsa wood, because that is still the material of choice for model rocketeers, and competitive fliers in particular.

To make sense of the table, you need to know what all the Greek symbols mean. Column 1 is the type of material. Column 2 shows "σ_{avg}" for each material. Sigma (σ) is the symbol representing the maximum applied load per unit area that the material can withstand without failing.

There are three types of stresses being average here to obtain the average value shown in the table. Figures 1 shows these types of stresses, and what would happen to the material under destructive failure.

Stress is independent of the material used. That is, two different materials (i.e., steel and wood) will have the same internal stresses if they have the same physical size and are being acted on by identical forces.

Table 1

Sheet material (1)	σ, kips/in^2 average (2)	ρ, lb/ in^3 (3)	E(10^3) kips/in^2 (4)	Ratio of weight to weight of 2024-T3 aluminum alloy: Tension: $\frac{\rho_1}{\rho_2}\frac{\sigma_2}{\sigma_1}$ (5)	Bending: $\frac{\rho_1}{\rho_2}\sqrt{\frac{\sigma_2}{\sigma_1}}$ (6)	Buckling: $\frac{\rho_1}{\rho_2}\sqrt[3]{\frac{E_2}{E_1}}$ (7)
Stainless steel	185	0.286	26	1.23	1.72	2.12
Aluminum alloy 2024-T3	66	0.100	10.5	1.00	1.00	1.00
Aluminum alloy 7075-T6	77	0.101	10.4	0.87	0.93	1.01
Magnesium alloy	40	0.065	.5	1.07	0.83	0.77
Graphite/epoxy laminate	30	0.050	2.5	1.10	0.74	0.83
Spruce wood	9.4	0.0156	1.3	1.09	0.42	0.31
Balsa wood	**2.8**	**0.0061**	**.55**	**1.45**	**0.29**	**0.16**

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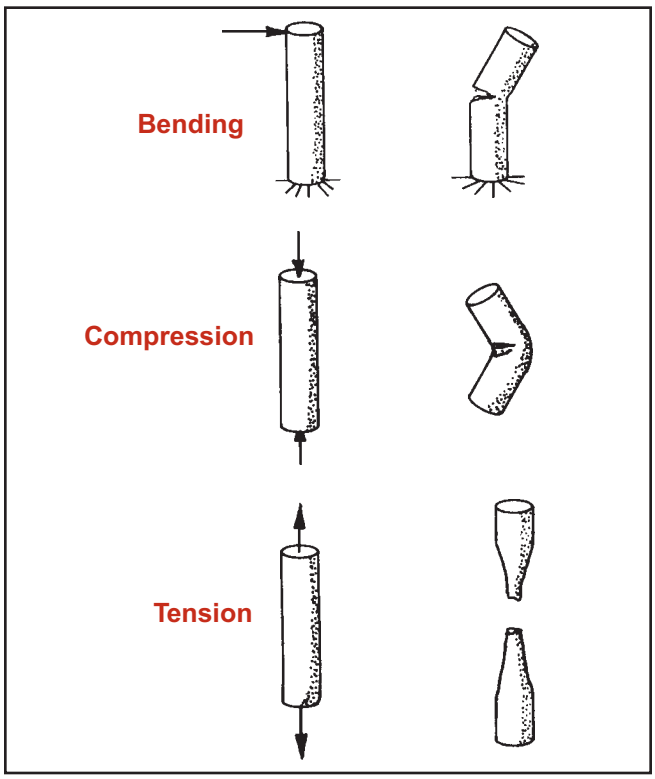

Figure 1: The three types of forces are averaged to give a value for the material's strength.

Column 3 shows the density (ρ) of the material in weight divided by volume. Column 4 shows a property of any material known as the Modulus of Elasticity (E). This describes the material's "stiffness," or ability to resist deformation. The Modulus of Elasticity gives some indication of a material's "strength."

This means a one-inch diameter steel rod is "stronger" than a one-inch diameter wooden rod.

The comparison of the different materials can be seen from columns 5, 6, and 7. These columns compare the given material to an aluminum alloy, known as 2024-T3. The smaller the number (below 1.00) the "stronger" it is when the materials' weights are compared.

In tension, the tables shows all the materials are relatively close in comparison. But when comparing bending strength and buckling strength, the lower density materials have a distinct advantage. As can be seen, both spruce and balsa are "stronger" than aluminum or of a composite made of graphite/epoxy.

The spruce is 2.38 times stronger than an equal weight of aluminum, and 1.76 times stronger and the composite material in bending; 3.22 and 2.68 times stronger for buckling against equal weights of aluminum and composites, respectively.

One example of the superior performance of wood as an Aerospace material is that of the world's largest airplane (built during WWII), the Hughes "Spruce Goose," is made mostly of 'wood.'

One important subject that needs to be addressed is that both wood's and composite material's strength is a direct function of the quality of craftsmanship put into the model rocket being produced. Any wooden or composite could be a piece of garbage if it is thrown together haphazardly. Numerous rockets shred to pieces because of poor workmanship, and it didn't matter what material it was constructed of.

That leads into the next question; where do composites fit into model rocketry when the data show that natural wood fibers have a strength-to-weight ratio advantage?

One area that composites are comparable and most times better is when volume of material is also considered. It takes "less" volume of a composite material to give the same strength to a given part than an equal volume of 'wood.' This is one reason why that in international competition, body tubes are made out of fiberglass/epoxy matrix. It takes very little material to give enough strength to perform the task. Per volume, the strength of composites is incredible!

So the first place that composites would be an excellent candidate as a construction material is anywhere "size" reduction is critical.

The strength of composites comes from the individual fibers in the material matrix. This leads to a very important concept: the strength of any part can be tailored by orienting the fibers in the direction where the greatest strength is required.

One excellent "real world" example of this is the X-29 airplane — without the use of composites, the forward-swept wings would not be able to stay attached to the fuselage at

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high speeds. Using composites to tailor the strength characteristics of individual parts is a second possible use of these materials.

As in the X-29, wings are a good place to use composites in boost- and rocket-glider models. For an excellent detailed treatment of this subject, see Terry L. Dean's *Composite Wing Construction and Design Techniques* in the July 1989 American Spacemodeling.

The one key point to be made in regard to composite wings is that higher aspect ratios are possible with composite wings. This becomes particularly important on larger models (such as "E" RG) that fly at higher Reynold's numbers, where higher aspect ratio wings are more efficient and give improved gliding performance.

Don't limit yourself to just glider wings however, as composites are also suited for helicopter rotor blades (which are in essence "wings".)

If the direction of maximum strength isn't critical, a woven composite cloth, or "mat" can be selected. Using these will give a composite part where strength is constant in any direction. This type of composite would have benefits when making high-strength "skins" for wings, rotors, or fins on high-power vehicles.

Higher impulse models are an exceptional place to use composites. It is with these rockets that modelers can exploit all the claims dealers make about composite materials. That is: reduced weight; because less overall material will achieve the same strength. With high-power rockets, fins really need to be strong, and covering balsa wood with a few layers of epoxy-soaked cloth will make them almost indestructible. The same can be said for nose cones and body tubes.

Where composites really show their greatest utility in the field of rocketry is as a reinforcing material. Field repairs on cracked or split tubes are just a few of the many places that composite cloths can be used. Where localized strength is needed, composites can fill the bill. One example is the fin/body tube joint. Making the fillet with a high-strength material will help keep those fins attached when the rocket takes off , or when it lands extremely hard. The same can be said for wing/fuselage joints on gliders.

But my question still remains; how much benefit is the average modeler getting out of the use of composites? With this question in mind, I decided to do a quick test. Here is the basis for that test. I wanted to see what benefits could be realized by using composites in small boost gliders. The larger the glider model, the easier it is to utilize composite materials, and composites are already being used extensively in the altitude events and in streamer and parachute duration events, so the only event left is the small glider events. These events are still dominated by the use of balsa and other types of woods.

The maximum stress on these types of models is the bending stress created in the wings. So my test would test different spars of a size that would probably be used in average sized boost gliders that use "B" engines.

The methodology for the test was pretty simple. Build a selection of different beams using construction methods that are available to your average type model builder, and load them up and see how they perform.

The test was performed by placing one end of the beam under a heavy block of steel, and hang weights on the other end and see how far it deflects. Table 2 shows the results of that test. The following is some explanation of the data in the chart.

The first beam tested was a piece of plain balsa, with measurements of 1/8" X 1/8" X 10". It had a mass of 0.50 grams, which yields a density of 12.1 lb/ft3 (.0071 lb/in3), which is balsa of average density, but certainly not hard balsa that would probably be used in such a situation. I placed the steel weight on it so that 9.50 inches was cantilevered over the edge of the table. I suspended a plastic tray on the opposite end, and placed weights in it and measured the deflection with increasing mass. I took several measurements with different masses to see if I would get a linear data — which I did. This deflection is column 4 of table 2.

I continued to load the beam until it broke, which occurred with a mass of 35.7 grams. It broke where I expected, at the point where the beam exited the steel weight used to hold it down. From this data, I extrapolated a modulus of elasticity, which is in column 6. Comparing this number to the theoretical average value listed in table 1; and you can see that my number is a little low, but it is generally in the ballpark. The difference could be a variety of causes, but is most likely

Spar Type	Mass (g)	Beam Length (in.)	Deflection (in.) / gram	Breaking Mass	Calc. E (psi)
Plain Balsa 1/8" X 1/8" X 10"	.50	9.50	.0924	35.7 g	.3363 E6
Balsa & 1 Spar Cap 1/8" X 1/8" X 10"	.65	8.50	.0615	35.7 g	
Balsa & 2 Spar Caps 1/8" X 1/8" X 10"	1.20	9.0	.0072	210.4 g	
Plain Spruce 1/8" X 1/8" X 10"	1.00	9.0	.0292		0.8742 E6
Spruce & 1 Spar Cap 1/8" X 1/8" X 10"	1.35	9.0	.0120		
Spruce & 2 Spar Caps 1/8" X 1/8" X 10"	1.60	9.0	.0089		
Graphite/Epoxy Spar 1/8" X 1/8" X 10"	4.20	9.0	.0073		3.506 E6

Table 2: Strengths of spars made by average modelers.

that my experiment was done very quickly, and it was hard to accurately measure the deflection of the beam.

The next step in the experiment was to glue spar caps to the beam, and then to repeat the experiment. The spar cap was made with 1/8" wide graphite tow. A 10 inch long piece had a mass of 0.10 grams. When soaked with thin CA, its mass rose to 0.18 grams. The method of attachment was to place a fresh piece of tow along the beam, and apply the thin CA directly to it. I attempted to squeegee out as much CA as possible before it hardened.

The data for a balsa beam with one spar cap applied to the top surface is shown in row 3. Row 4 is the same test but with spar caps on both the top and bottom.

Rows 5, 6, and 7 is the same test, but with spruce as the wooden part of the beam.

Row 8 is the data for a beam made of graphite/epoxy. The beam was made in a two part mold, with multiple strands of the tow layed in, and then saturated with epoxy. It had a couple of air bubbles in it, but for the most part, it came out square. From the calculated value of the Modulus of Elasticity, you can see that the value is much higher than that of either the balsa or the spruce wood, but MUCH lower than the theoretical value of 58.01E6 found in engineering textbooks.

There are several conclusions from the data collected. First the graphite/epoxy spar is no where near the theoretical strength value. This I expected because the method of spar creation was very prone to being resin rich. This spar wasn't meant to be represented as a typical spar an average modeler might use in a boost glider, but an attempt to get a value of "E" for the spar caps in the other tests. But on the other hand, the spar was very stiff, and I ran out of weights long before the spar was even close to breaking.

The second conclusion is that with two spar caps, the deflection per gram was about equal for both the spruce and balsa beams. This is expected as the graphite is taking up all the load in both cases. But, the balsa spar compressed after being loaded to 210.4 grams, and the spar broke. This may be critical on your models, so you might want to use a different filler between the spar caps. Table 3 lists several materials that are usually sandwiched between skins (or spar caps), and their compression strengths. In this chart, the Balsa was loaded parallel to the grain. In my experiment, the balsa was loaded perpendicular to the grain. Additionally, the data on Rohacell is the low density structural version. Higher densities with higher strengths are available.

As far as how much performance advantage the average modeler will gain from using composites; I would say that even if the composite material wasn't correctly applied, the gain would still be worth the effort. The strength derived from the material is great, and it gets even better if done properly and advance application methods such as vacuum bagging are employed.

Material	Density lb./cu. ft.	Compression Modulus	Crush Strength
Balsa	6.0	5,100 - 16,000	50 - 84
Rohacell 31	2.0	5,120	57
Expanded Polystyrene	2.0	850	20 - 40
Polyurethane Foam	2.0	1,300	16 - 43

Table 3: Core materials that can be used in place of balsa.

My conclusion is this: if a spar were to be used to handle the flight loads on a wing of a boost glider, I would recommend a balsa spar with two spar caps. Is this overkill? Maybe. I built a glider a couple of years ago using a spar with only one spar cap, and it withstood the flight forces just fine. A little bit of work might be needed to be accomplished to find out what flight forces a wing will experience to determine how much reinforcement would be needed.

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