PEAK OF FLIGHT NEWSLETTER

ISSUE 554 / AUGUST 17TH 2021

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HOW 3D PRINTING ALLOWS EXTREME ROCKET DESIGNS

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PEAK OF FLIGHT

How 3D Printing Allows Extreme Rocket Designs

By Tim Van Milligan

When people come to me with article ideas about using 3D printers in model rocketry, they are almost invariably about creating parts to use directly on the rocket. For example, they'll be about making 3D printed fins, nose cones, centering rings, launch lugs, boattails, transitions, etc. They'll even talk about 3D printing the entire rocket in one go. It is only the exceptionally shaped rockets or those that function differently that seem to get my attention (see https://www.apogeerockets.com/Peak-of-Flight/Newsletter482).

In this article, you'll learn the other way that 3D printing can help you make extreme rocket designs, without actually using the printed parts in the rocket.

There are a couple of problems with 3D printed parts. Eventually these problems will be solved when technology improves, but for now, they are limitations. The main problems are excess weight and inferior strength.

As of today, 3D printed parts are relatively weak because they are made from plastic. If they were made from carbon fiber, that would be different. And there are some resins for 3D printers that have embedded carbon fibers in the plastic. But the plastic is the main component of the resin, and as such, it will never be as strong as a similar part made from traditional carbon fiber with an epoxy binder to hold them to shape.

So in order to make the part strong enough, it has to be made thicker. And that simply adds more weight to the rocket, as well as eating up more space inside the rocket.

For most model rockets -- those that are just launched for the fun of it -- these limitations of strength and weight aren't too much of a concern. Most rockets are already being overbuilt as it is, and an overly heavy 3D printed plastic rocket wouldn't be any different. To launch them, you can just use a higher power rocket motor-- and those are readily available.

When I'm talking about extreme designs here, I'm talking about highly efficient rockets, like those used for competition or for setting new altitude records for a specific impulse of a rocket engine. In this case, having extra weight or thick wall parts that take up a lot of space in the design are not desirable features. These types of models require thin-wall tubes with sufficient strength and low mass.

Right now, that means composite materials like thin-wall fiberglass/epoxy tubes, or better yet, carbon fiber/epoxy tubes.

Since 2019, I've been helping my daughters to create and build such rockets in preparation for the World Space Modeling Championships, which this year (2021) will be held in October. The strategy is to remove as much weight as possible by using carbon fiber/epoxy as the primary material. Carbon fiber/epoxy is currently the gold-standard of aerospace materials because if it is done right, the strength-to-weight ratio is phenomenal. It is almost as good as balsa wood (see Peak-of-Flight Newsletter #30 https://www.apogeerockets.com/education/downloads/Newsletter30.pdf). The advantage that composite materials have over balsa is that they are much more uniform, can be made with thinner walls, and their strength can be tailored in different directions.

The big disadvantage is that they can't be easily formed like you can with balsa wood. With balsa, you can shape, sand, and form the wood using common hand tools like a knife, ruler and sandpaper. With carbon fiber parts, you need molds to hold the wet slurry in the right shape until it cures and hardens. They can be cut, but once hardened, it is difficult to modify the molded shape. So you want to try to mold it into shape before it hardens.

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This is where 3D printer technology shines. In my opinion, 3D printers are a game-changer when it comes to producing ultra-light composite structures like carbon fiber components. Not just because you can print the molds so quickly, but also that you're not limited to shapes that have nice straight lines or flat surfaces. You can create swoopy organic and aerodynamic shapes easily with a 3D printer that you would have a hard time duplicating by carving wood or cutting metal to make a mold. I talked about this before in Peak-of-Flight Newsletter issue #408 (https://www.apogeerockets.com/education/downloads/Newsletter408.pdf) where I showed how we make our conformal canopy that attaches to a BT-70 size nose cone (https://www.apogeerockets.com/Building-Supplies/Misc-Hardware/Vacuum-Formed-Canopy-PNC-56A).

The other advantage 3D printers have is how inexpensively the tools can be produced. So if you make a mistake in the dimensions of the part, you're not out a fortune. You can simply modify the CAD drawing in a few seconds, and send it over to the 3D printer like you would if you made a typo in a written school report. It is no longer a make-or-break obstacle that prevents a modeler from "tooling-up" in order to create the optimal rocket design.

I wanted to give you an example of just a couple of parts that I used my in-house 3D printer to create the tools for. The actual parts for the rocket were made in these tools, and therefore were lighter, better shaped, and stronger.

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The first was a hinge support for a helicopter blade. The blade has a curved underside similar to the Rotary Revolution helicopter kit (https://www.apogeerockets.com/Rocket-Kits/Skill-Level-4-Model-Rocket-Kits/Rotary-Revolution). I wanted to attach another section of blade to the tip, so that it would unfold in flight (like a flop-wing glider). The problem is that for a hinge, you need a straight edge that the hinge can fold over. Since the blade was curved, I needed to create a special wedge that was curved and could conform to the underside of the blade on one side, and flat on the opposite surface for the hinge line.

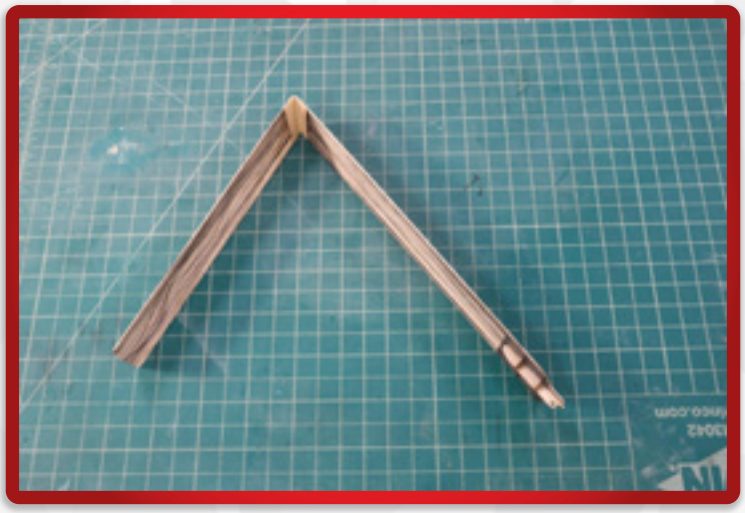

FIGURE 1: THIS HELICOPTER ROTOR BLADE FOLDS IN HALF TO SAVE SPACE INSIDE THE ROCKET. THE HINGE LINE NEEDS TO BE ON A FLAT PLANE.

I first directly 3D printed the part. And that worked just fine. Except that it was too heavy for the rotor blade that I was working on. I needed it to be lighter, like if it could be

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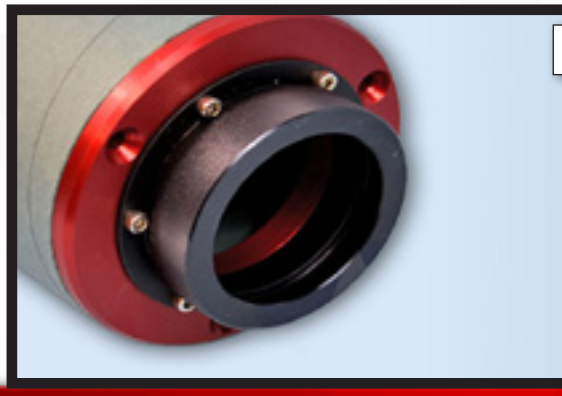

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if it were made from balsa wood. But how do you create something as precise and delicate from balsa wood?

Solution: 3D print a sanding fixture. I just tack-glued a strip of balsa to the flat area recessed into the curved surface of the printed part, and sanded the top of the balsa wood until its upper surface conformed to the sanding fixture. Once it was shaped, it was a simple matter to unstick it from the tool and glue it to the underside of the balsa rotor blade.

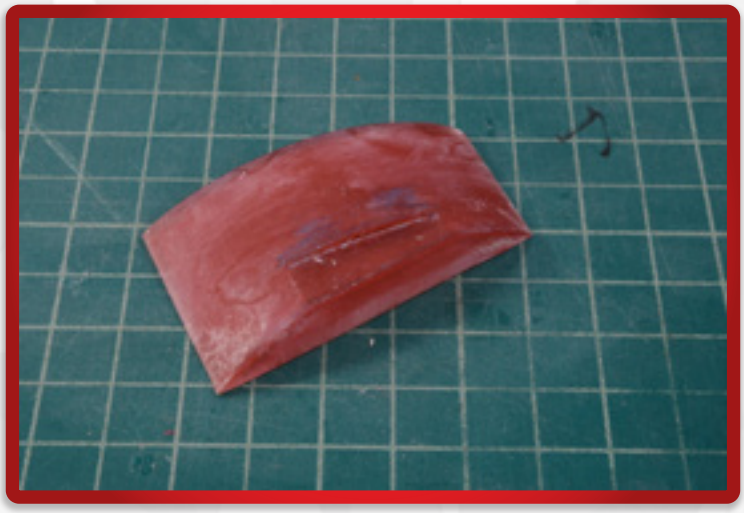

FIGURE 2: 3D PRINTED SANDING FIXTURE FOR THE HINGE PIECE. BALSA WOOD IS TACKED-GLUED ONTO THE FLAT SURFACE AND SANDED DOWN TO MATCH THE CURVATURE OF THE TOP.

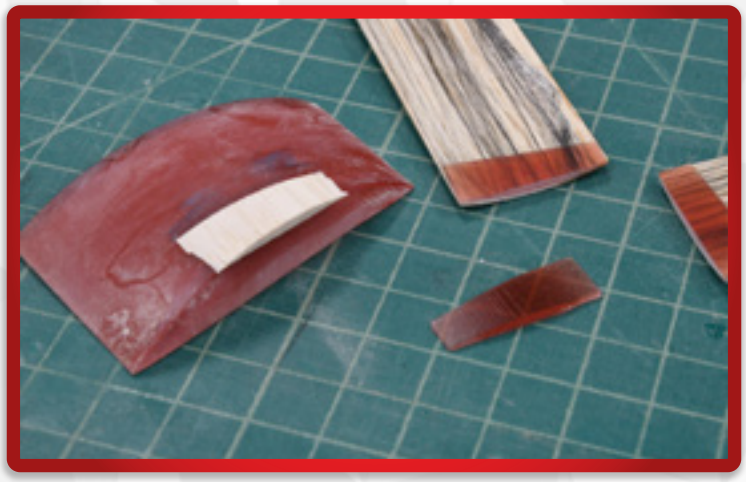

FIGURE 3: THE COMPLETED BALSA WEDGE. ON THE RIGHT ARE SIMILAR PIECES THAT WERE 3D PRINTED. THEY WEIGH OVER 4 TIMES THE BALSA PIECE.

The finished curved balsa wedge weighed ¼ of the mass of the 3D printed part. And they are so simple to make, that I could crank out dozens of them in an hour. And each of them would be just as perfect as the first one.

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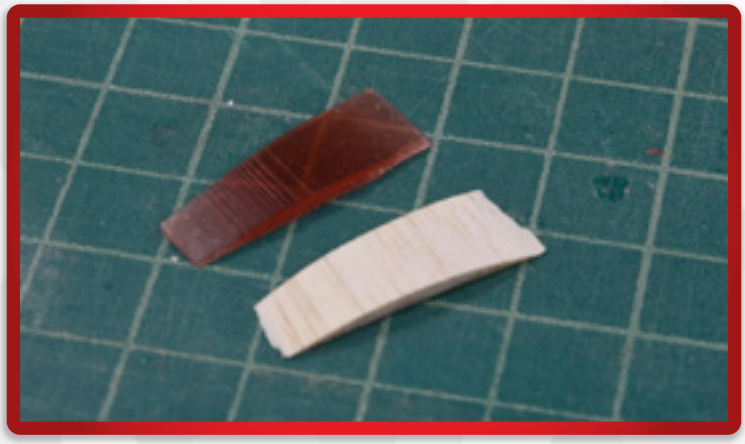

FIGURE 4: THE FINAL BALSA WOOD PIECE IS LIGHTER AND EVEN LOOKS BETTER THAN THE 3D PRINTED PLASTIC PIECE IT REPLACES.

The second 3D printed part is much more involved, because I wanted it to be a mold for carbon fiber centering rings.

The optimal shape of a centering ring that has minimal mass would look like a spoked bicycle wheel. All the material between the stiff spokes can be removed, since its strength isn't needed, and it is just dead weight.

My mold was something that looked like a wheel with 8 spokes. The spokes would be filled with short lengths of carbon fiber tow (tow is unidirectional fibers, which is similar to a ribbon made of thousands of fibers all running in the same direction). The spokes were the easy part to make. The hard part was the inner hub and the outer rim of the wheel. For this I needed to wrap the carbon fiber tow around a dowel that is the right diameter for either the hub or the rim.

FIGURE 5: A CARBON FIBER HOOP WINDING TOOL. THE BUNDLE OF CARBON FIBERS IN THE BOTTOM RIGHT HAS APPROXIMATELY 250-TO-500 INDIVIDUAL STRANDS OF CARBON.

I decided to 3D print a tool for this, even though I could probably have made a dowel from other methods. I just didn't want to take the time to find something the exact diameter I needed for the task.

Once the circular hub and the rim were wrapped, I placed them into the mold along with the spoke. Next went in the liquid epoxy that would bond all the fibers together. My mold was actually a two-part design with a top and bottom. So to make the part, the epoxy was poured in, the two halves of the mold brought together and then clamped closed until the epoxy cured.

After prying open the mold and removing the part, it still needed to be cleaned up to remove the excess epoxy that oozed out past the rim. Clean up was a fairly difficult process for this part, because of how thin it was. The first ones I made were about as thin as a piece of copy paper.

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Trying to sand something so thin is difficult because it is easy to take off too much material and then you end up with a ring that has a flat spot on the edge.

FIGURE 6: (TOP) A TWO-PIECE 3D PRINTED MOLD TO MAKE CARBON FIBER HUB-AND-SPOKE CENTERING RINGS. (BOTTOM) THE TWO-PIECE TOOL THAT IS USED TO TRIM THE MOLDED CENTERING RING TO HAVE THE PERFECT SHAPE AND CORRECT INNER/OUTER DIAMETERS. (BOTTOM-CENTER) A CARBON FIBER CENTERING RING THAT HAS BEEN TRIMMED TO SIZE.

Again, I made a special 2-part tool to help trim it up to a perfect circular shape. It was identical to the two-part mold that the part was created with, but smaller and the exact diameter of the final ring. I could trim off the excess epoxy, and then use the outer surface as a guide to sand off any excess carbon fiber.

FIGURE 7: THIS SHOWS HOW THE 3D PRINTED TRIMMING TOOL SANDWICHES THE CENTERING RING (THE BLACK LINE IN THE MIDDLE) SO THAT THE OUTER EDGE CAN BE SANDED DOWN TO A NEAR PERFECT CIRCLE.

In fact, the tool has an open central portion too, so I could use it to trim the inner edge of the centering ring as well. In this case, I had to use a round file to help trim up the edge.

The finished ring is really lightweight, exceptionally strong and the perfect diameter. It is probably overkill for the strength that I needed, so it probably could have been minimized even more.

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FIGURE 8: THE COMPLETED CARBON FIBER CENTERING RING IS LIGHTER AND STRONGER THAN AN EQUIVALENT RING MADE FROM WOOD OR PAPER.

However, there is more to the story of this ring. It is so thin that gluing it inside the tube is extremely difficult. It would be easy to get it installed crooked in the tube. It is a lot like trying to balance a coin on its edge, except the edge is so thin that it doesn't want to balance.

Yet again… a 3D printed tool came to the rescue. I call this my ring insertion tool. It is a surface that the molded ring nests into so that it is perfectly perpendicular to the inside surface of the outside tube. And then it can be pushed right into the correct position in the tube and bonded into place.

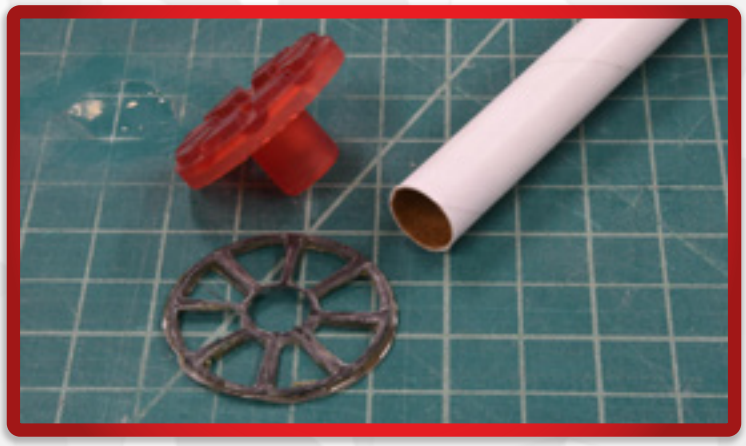

FIGURE 9: THE "PUSHER TOOL" THAT IS USED TO ALIGN THE RING PERPENDICULAR TO THE TUBE, AND HOLD IT IN POSITION UNTIL IT IS BONDED INTO PLACE. THE PUSHER TOOL SLIDES INTO A BODY TUBE TO MAKE IT EASIER TO PUSH THROUGH THE TUBE.

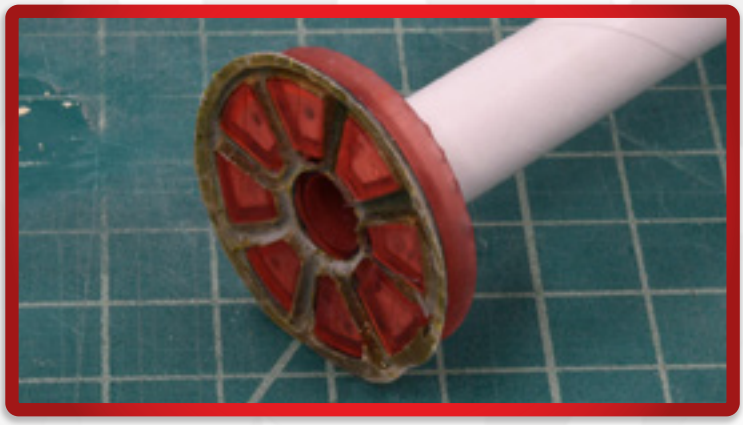

FIGURE 10: THE CARBON FIBER CENTERING RING NESTED INTO THE FACE OF THE PUSHER TOOL,

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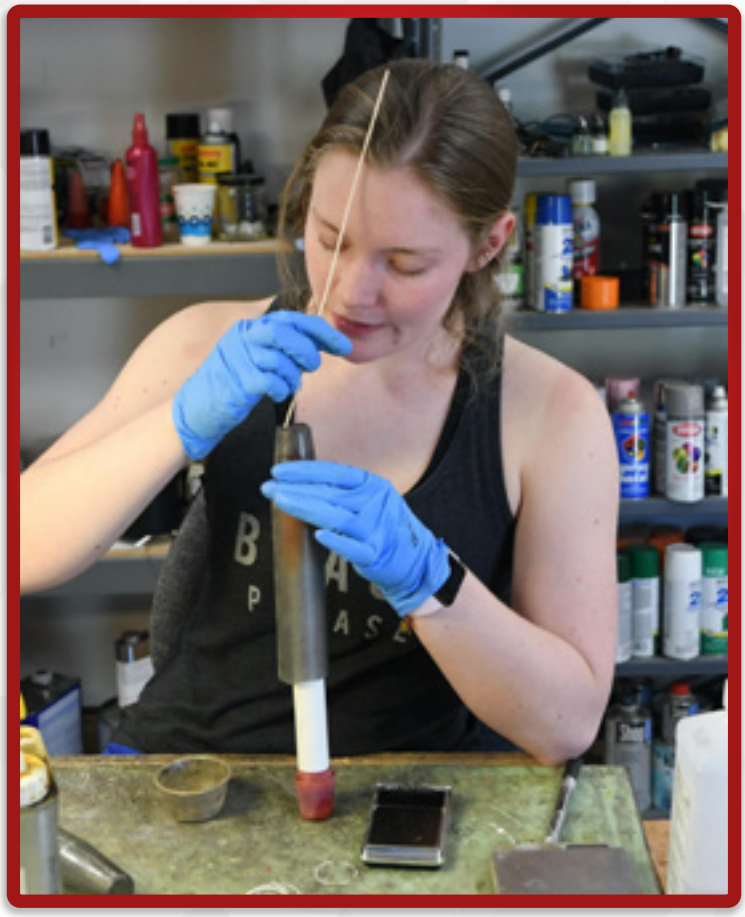

FIGURE 11: ALLISON VAN MILLIGAN USES A PUSHER TOOL TO HOLD A CARBON FIBER RING IN POSITION INSIDE OF A CARBON FIBER TUBE. THE TUBE IS SO THIN THAT YOU ALMOST SEE THROUGH IT.

Since I began seriously experimenting with carbon fiber in 2019, I have learned so much about how to create tools to form it properly. I will be writing more articles and doing how-to videos on making extreme parts. So stay tuned for that in the future.

Eventually, my goal is to revisit the plan of the Bat-wing Glider (https://www.apogeerockets.com/education/downloads/Newsletter08.pdf), and see if I can create a special tool to make the bone structure of the wing totally out of carbon fiber. Then I could lay up the entire skeletal structure of the bat shaped wing in one super-strong piece.

Conclusion

The types of tools that I 3D print for extreme rockets include:

Cutting and sanding jigs - to hold parts while they are shaped with a knife or sandpaper.

Holding fixtures - to keep things aligned until they are permanently glued together. A simple fin jig is an example of this.

Positioning jigs - to push parts into the right locations inside the rocket - where it is difficult to see, and still retain alignment of the parts.

Molds - used to hold the carbon fiber and epoxy in the right shape until the epoxy cures.

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FIGURE 12: ALLISON USES ANOTHER 3D PRINTED TOOL TO TRIM OFF THE EDGES OF TUBES AT THE CORRECT POSITION. THE RED UPRIGHT-STANDING TOOL IN THE MIDDLE IS USED ON THE BACK END OF THE ROCKET TO HELP TRIM THAT END TOO.

I really don't get too excited when someone tells me that they printed a part for their model rocket, like a nose cone, a fin can or even the entire rocket itself. For the most part, those things are pretty generic. But I do get really excited when some modeler tells me that they 3D printed a special tool to make a part for their rocket. Those are the things that I'd like to see and hear about. They say a lot of good things about the designer and tell me that they care about craftsmanship enough to invest time in creating a tool.

Finally, I really encourage you to work with younger modelers to create tools and jigs to help them out. A properly designed jig or fixture is like an extra set of hands that allow those that don't yet have fine motor control of their hands to create exceptional models. I can assure you that they do get excited when they can compare their models to those built by others, and they can see how much stronger and better looking their models are and that they perform better. And best yet, they know deep down that they did it themselves. It wasn't a rocket that was simply printed on a machine. That sense of accomplishment is what I think really helps them stick around in the hobby for a long time.

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. He is an avid rocketry competitor and is Level 3 high power certified. He is often asked what is the biggest rocket he's ever launched. His answer is that before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward an M.S. in Space Technology from the Florida Institute of Technology in Melbourne, Florida. Currently, he is the owner of Apogee Components (http://www.apogeerockets.com) and also the author of the books: Model Rocket Design and Construction, 69 Simple Science Fair Projects with Model Rockets: Aeronautics and publisher of the "Peak-of-Flight" newsletter, a FREE e-zine newsletter about model rockets. You can email him by using the contact form at https://www.apogeerockets.com/Contact.