PEAK OF FLIGHT

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3355 Fillmore Ridge Heights Colorado Springs, Colorado 80907-9024 USA
www.ApogeeRockets.com e-mail: orders@apogeerockets.com Phone: 719-535-9335 Fax: 719-534-9050

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PEAK OF FLIGHT

How to design a nose cone canopy

By Tim Van Milligan

In this article, I thought I'd take you behind the scenes and show how a new product is designed and produced. I wanted to give you a glimpse of the effort that goes into creating a product, just in case you're wondering why we're not releasing things faster.

Previously, in Peak-of-Flight Newsletter 407 (www.ApogeeRockets.com/Education/Downloads/Newsletter407.pdf) it was mentioned that I was a little hesitant on getting overly enthusiastic about 3D printing. The reason is that the quality of the printed parts is not where I'd like to see them. But there is some new technology on the horizon that is going to change all that. Because of that, I have been preparing in my own mind on how it may change the model rocket industry. Can you imagine what you could do on your own if you could create your own parts? It is going to be really exciting!

As part of my preparation, I decided to learn a new Computer Aided Design (CAD) program. Things have changed from the twenty-something years ago when I worked at Estes, where we used our modeling skills and literally 'modeling clay' to design complex nose cone shapes. But a lot has changed since then, and computer modeling has gotten a lot better.

To be honest, I'm still an old-school guy, relying on modeling skills and basic drafting skills to make complex parts. It seems daunting to try to learn a new program. But because of the radical way that 3D printing is going to change the industry, I figured that either I invest the time to learn a new CAD program, or get passed by technology.

I did some research into software, and started out with the free 3D modeling software called 123D Design from Autodesk. My local public library had a tutorial class that showed how to use it, so I took it. They also had several YouTube videos that covered the basics of moving things around and creating different shapes. I even hired a private tutor to get me up the learning curve as quickly as possible.

Designing in a 3D environment is a completely different mind-set than what I learned with a pencil and a piece of paper method. The way I learned design was basically "drafting." In essence, just draw exact shapes. You put down on paper exactly what you want the final product to look like. By contrast, in 3D modeling you start with a geometric object and hack off what you don't want to be there. It is like sculpting a block of granite. So instead of building up one piece at a time, the philosophy in the 3D world is often to take away from a larger shape.

I'm still trying to wrap my mind around this difference. I think this is my biggest impediment to learning quickly, because I have to unlearn my old approaches to solving problems.

After almost two months of intense study, I discovered that the software had too many limitations. I couldn't easily make the type of parts that I wanted. For example, I couldn't figure out how to make a true parabolic nose cone, like the ones we sell at Apogee (https://www.apogeerockets.com/Building_Supplies/Nose_Cones/Low_Mid_Power_Nose_Cones/PNC-18A). That doesn't mean it can't do it, but I couldn't figure out how to make it work.

I was really frustrated. This was my worst fear being realized: investing a lot of time learning a new computer program, and then finding out it couldn't do what I wanted. I couldn't create a basic rocket component very easily, let alone something complex or swoopy with a more organic shape. It was a major mental set-back. I felt a little panic setting in. Maybe it was just me and I was too old to learn.

After my last class at the public library where I vented my frustration, the instructor said that I might look into anoth-

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Newsletter Staff

Writer: Tim Van Milligan
Layout/CoverArtist: Chris Duran
Proofreader: Michelle Mason

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er software from AutoDesk called Fusion 360. While it isn't a free program, he said that it had a lot more capabilities.

So the next day I downloaded the trial version (http://www.autodesk.com/products/fusion-360/overview) and gave it a try. In one respect, it has a lot of the same navigation features of the 123D Design program, so I was able to move around on the screen without too much trouble and I could make things called "primitives" (boxes, spheres, cylinders and other simple geometric shapes) pretty easily. Because of this, I had to admit that not everything was a waste of time when I was investing in the learning of the free CAD program. So I did feel a little better.

But the Fusion 360 program is a professional CAD software, and it has a lot more buttons and features. In all honesty, it is still a daunting program to learn. In one respect, it is like learning a foreign language because all the terminology is unique. I'm still trying to learn it, and I feel like I'm still a baby in the whole process. So don't come asking me for help if you plan to learn it yourself. Fortunately, the folks at AutoDesk do respond to questions. Plus YouTube has changed the way we approach learning. There are hundreds and hundreds of videos available that walk you through the features of the program.

After about three weeks of working my way through the tutorials and watching hours and hours of instructional videos, I could design a true parabolic nose cone. Note that I wasn't trying to create a new nose cone, I just wanted to duplicate on the computer the PNC-18A nose cones that we already sell here at Apogee. It still took me several hours to make the design, but I felt encouraged.

Why admit all this to you? I'm not really sure. Really — admitting that I'm not half as smart as you might think I should be (being a rocket scientist and all…) is probably pretty stupid. Let's just say that I have fallen behind changes in technology and that it only took me 22 years to admit it. Its only now I'm making a concerted effort to catch up.

This whole story of my frustrations learning a new CAD program leads to this article. Now that I could design a nose cone with a defined shape, I wanted to try making something more organic - where the object isn't defined by simple geometric shapes.

For this next excursion into CAD education, I choose to make a canopy for a nose cone. I thought that making a rocket that looked like a jet fighter would be a worthy goal. ***Figure 1*** shows the final product, where the vacuum-formed canopy is attached to the nose cone of a rocket. The photo shows a Snarky rocket kit

Figure 1: Canopy attached to Snarky rocket kit

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(https://www.apogeerockets.com/Rocket_Kits/Skill_Level_4_Kits/Snarky_Rocket_Kit) with the canopy on it.

The Fusion 360 software has two modes of design: modeling and sculpting. Modeling is the traditional method of 3D design where you're working with standard shapes (blocks, cylinders, spheres, cones, etc). The sculpting mode is more fluid, more like taking a lump of clay and stretching it into the shape you want.

Figure 2 shows how the process of creating the canopy started. You can see the lump of material (the blue piece) that I dumped into the 3D environment. The approach is to mold the material so it takes the shape of a tear-drop shaped canopy on the nose cone.

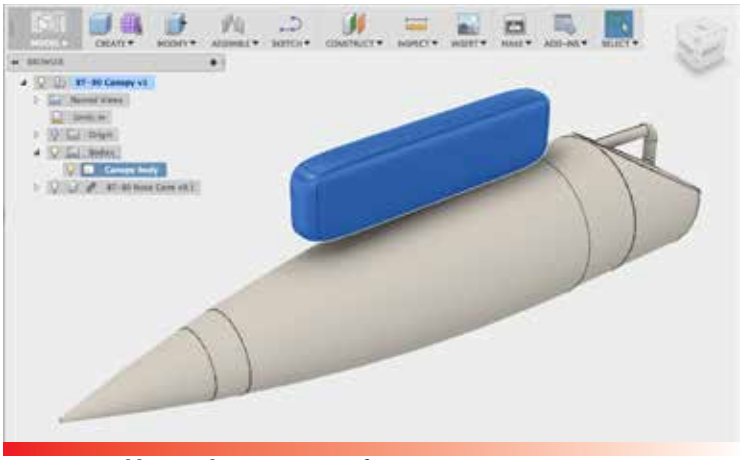

Figure 2: Molding with Fusion 360 software

Actually, the process started with the creation of the nose cone itself. Creating the nose cone was the hardest part, because all the dimensions have to match the actual nose cone that I had available (the https://www.apogeerockets.com/Building_Supplies/Nose_Cones/Low_Mid_Power_Nose_Cones/PNC-56A_BT-70). Fortunately, you only have to do it one time. Once it is made, the file can be used in any future rocket designs.

If you look closely at the drawing, it actually shows a different nose cone, the PNC-66A (https://www.apogeerockets.com/Building_Supplies/Nose_Cones/Low_Mid_Power_Nose_Cones/PNC-66A_BT-80). The reason for this is that I didn't originally intend to write an article about the process, so I didn't take screen shots of the computer at the time. For this article, I didn't want to recreate the same piece from scratch, so I decided to start a new product to fit a different size nose cone.

That gets to a question that I've already been asked about the canopy (https://www.apogeerockets.com/Building-Supplies/Misc-Hardware/Vacuum-Formed-Canopy-PNC-56A), which is: "will it fit other nose cones or body tubes?" The answer is "probably not." As you'll see in this article, the canopy was sculpted to match the specific curvature of the nose cone. So putting it on a different nose cone is going to leave gaps around the base perimeter.

The other question I've already been asked is if I could make a canopy that fits a nose cone made by a different manufacturer. The answer is that I could, but only if I had the exact dimensions of that nose cone. Unfortunately, I'd need the original blueprints of those nose cones. And since they are from a

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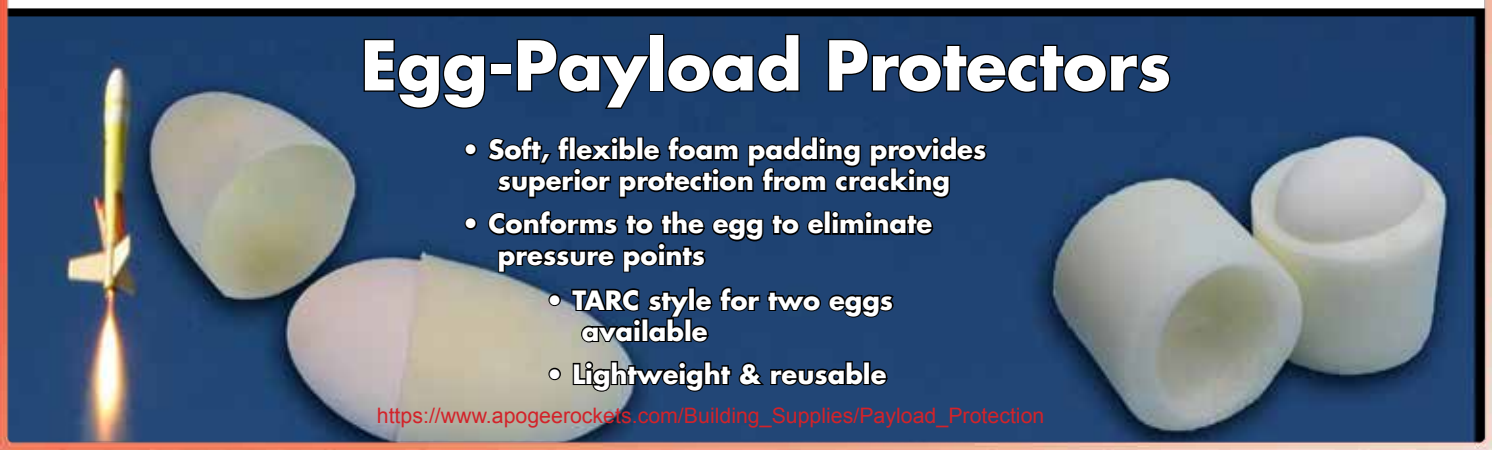

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different manufacturer, I don't have them. In practical terms, I can only make canopy shapes for the nose cones that I have exact dimensions for.

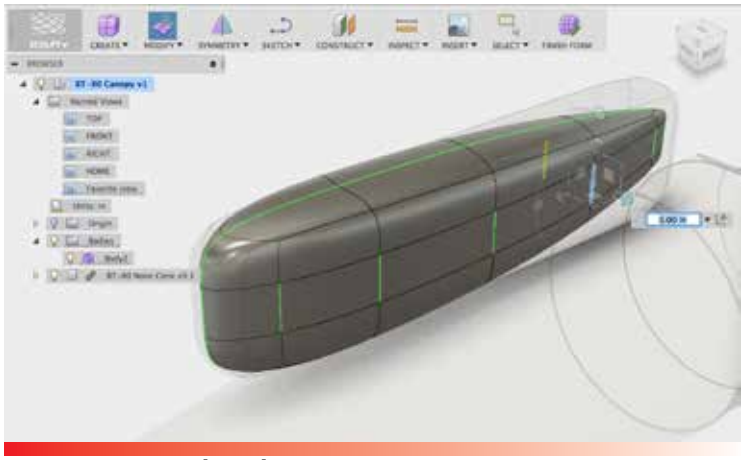

Figure 3: Beginning the sculpting process

In ***Figure 3***, the sculpting process has begun. The technology that Fusion 360 uses is called "T-spline curves." It is pretty slick, if you ask me. I don't know how old this technology is, because I haven't been following the CAD software industry for the last 20 years, but "we never had this kind of stuff when I was a kid."

Essentially, the Fusion 360 software breaks up the surface into rectangular regions and allows you to grab and tug the edges and corners around until you get a shape that you like. This is what is shown in Figure 3. I've highlighted a single edge (shown in blue), and you can tug it to any position you want, like it was made out of clay. This does remind me of the way I learned to make canopies when I worked as a rocket designer at Estes in 1991. We used real clay to make prototype rockets. You can still do this if you want, and I recommend the Fix-It Epoxy Clay (https://www.apogeerockets.com/Building_Supplies/Epoxy_Clay/FIX-IT_Epoxy_Clay) because it hardens like a rock when it cures.

The advantage over real clay is that in the 3D modeling world you can select to make the object perfectly symmetrical (which are shown by the green lines in Figure 3). So if you pull outward on the clay on one side of the object, the other side also exactly matches the same surface shape. This is a real time-saving feature, and everything is perfectly symmetrical when you're done.

Sculpting isn't really hard. In fact, when I was going through the tutorials on how to use the software, one of the very first lessons was about sculpting. What you can do with it is really powerful, so they encourage you to learn it quickly.

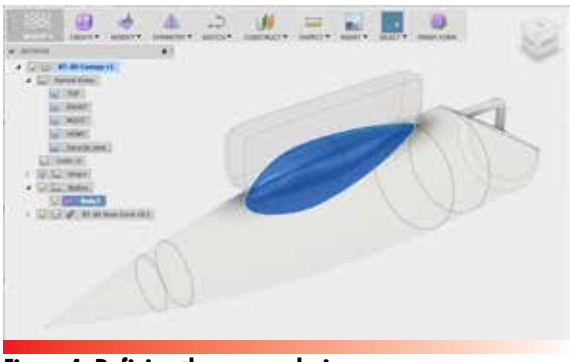

Figure 4: Refining the canopy design

Figure 4 shows a more refined revision of the sculpted canopy (the blue piece). You can also see the silhouette of the original blob of sculpting material, as well as where it passes through the nose cone.

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I did make a mistake during the process, which was to make the part symmetrical around the long axis. So the bottom surface is a mirror image of the top side that would be exposed to the air stream. You can really notice this in ***Figure 4***, but not so much in ***Figure 5***.

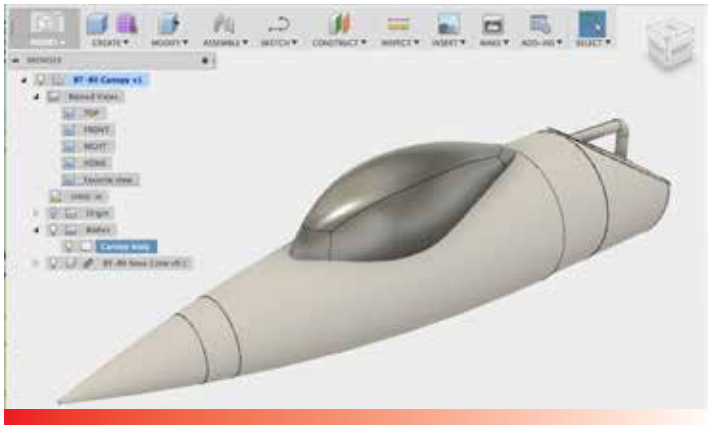

Figure 5: Complex curve revealed at the intersection of the canopy and nose cone

In ***Figure 5***, the surface of both the canopy and the nose cone is opaque, and you can really see how the canopy will look on the rocket. Notice the complex curve that the edge of the canopy makes where it intersects the surface of the nose cone. Trying to draw this in a 2D drawing would be very difficult to do, but it is readily apparent in the 3D image.

At this point, the only concern that I have is that there are no "undercuts" where the canopy meets the surface of the nose cone. An undercut would be created if you played a fabric over the canopy, and you'd have to tuck it in around the edges to get it to conform to the surface of the canopy. Think of trying to lay a piece of fabric over a sphere…

Since this is eventually going to be a vacuum-formed plastic part, I can't have any undercuts around the part, because the soft plastic would envelope the part. This would make it nearly impossible to remove the plastic off the mold, because the mold would be enclosed (partially) inside the plastic sheet instead of just under it.

Because I had the part symmetrical top-and-bottom, this undercut was a big concern. If I had time, I would have just started over with the design. But what I did was just to tilt the front end of the canopy so that the mid-plane line would be just above the surface of the nose cone. It was an easy work-around solution.

Figure 6 shows the next step. The shape of the canopy is done at this point, and now we're thinking more of how the actual vacuum-form mold will look. You don't need the entire nose cone for the mold, as it would have undercuts in it. You only need a little bit of surface so that you

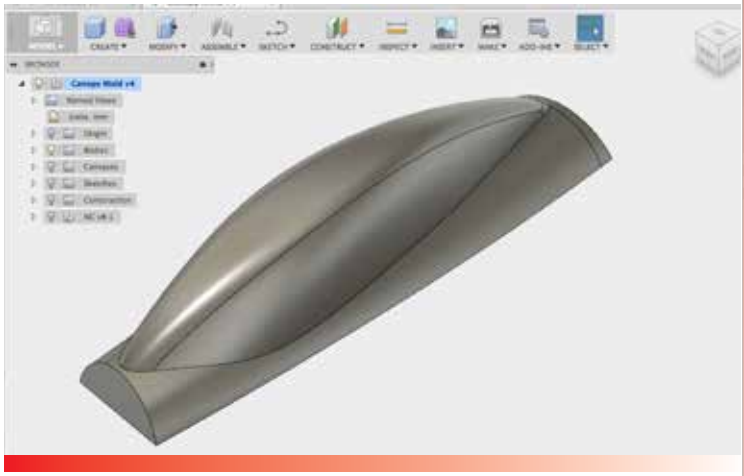

Figure 6: Completed canopy as a solid shape

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have a sharp edge where the canopy meets the surface of the nose cone. Essentially, I merged the solid canopy with the solid nose cone, making it one part.

Then, I cut away the parts of the nose cone that I don't need for the mold. As I mentioned previously, when designing in 3D, you often cut away the parts of the object that you don't need. This is a good example of what I mean by that.

You'll notice that this canopy is longer than shown in Figure 5. The reason is that it is the BT-70 version for the PNC-56A nose cone.

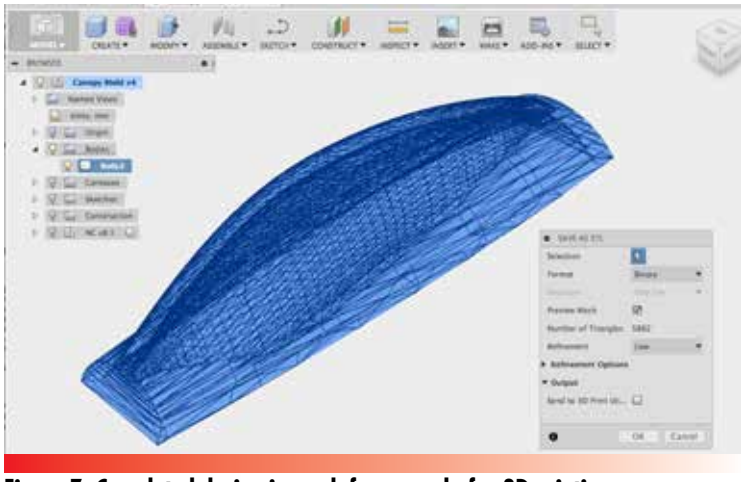

Figure 7: Completed design in mesh form, ready for 3D printing

Figure 7 is where the design is complete, and now it is turned into mesh so that it can be sent to a 3D printer. This is the easiest part of the process, as all you have to do is save it as an STL file format.

I don't currently own a 3D printer, so I send the .stl file to a friend that does have one. As an alternative, you may have one of those maker-hubs in your town that has a 3D printer that you can use.

Figure 8: 3D printed part

Figure 8 shows the 3D printed part that I got back from the printer. In general, the part looks really good from a standpoint of the overall shape.

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Figure 9 shows a close-up view of the surface of the 3D printed part. You can see it has a stair-step like surface that is created by the extruder head on the printer.

Figure 9: Close up of the 3D Printed part

The extruder is a lot like a hot-melt glue gun. It squeezes out a thin ribbon of liquid plastic onto a movable table. The head moves around in a pattern laying down a strip of plastic. As it completes one layer, the table moves down a tiny amount and the head lays down another layer of plastic. The stair-step pattern occurs because it the plastic is squished as it comes out of the extruder head, and it has a very small thickness. The layers aren't perfect which gives this stair-step pattern.

At this point, the mold is not usable. If you tried to vacuum-form plastic over the top of this, you'd get the same stair-step pattern. It isn't very aerodynamic, and it just looks rustic. To get a good part, the surface must be smooth. The smoother it is, the better for vacuum-forming. You can see how the process of vacuum-forming works in our YouTube video: https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_189

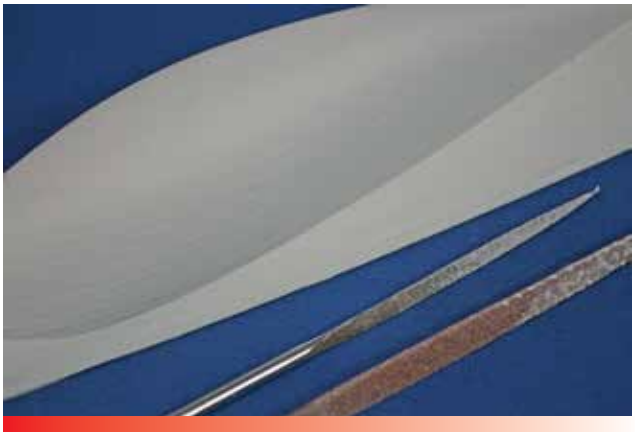

Figure 10: Begin to sand the ridges out of the 3D printed part

Figure 10 shows the first step after getting the 3D part back from the printer. Basically, you just sand it down so that it is smooth. I've found that files work a little better than sandpaper because the plastic is a bit gummy. The files seem to work a little better at cutting through the gummy plastic. But with enough effort, sandpaper would work OK too.

You can still see some ridges in the plastic, and to fill them, I treat it like I would if it was a spiral in a paper tube. I use sanding primer laid on very thick. In ***Figure 11***, you can see brush strokes in the primer, because I just paint it on rather than spraying it on. I just want it on very very thick.

When the primer is dry, it is sanded smooth. But in real life, it takes several applications of primer to get a smooth surface. This is actually the longest part of the process and the most te-

Figure 11: Applying sandal primer to further smooth ridges

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dious. I hate it. I can't tell you how much I despise it. I'd say that it is the main reason I don't make a lot of new vacuum-form parts, because the molds are so monotonous to produce. The day that the surface quality of 3D printed parts improves will be a day that I dance with joy because I won't have to do this step ever again.

On the last couple of coats, I put the primer paint on by spraying it with a paint gun so that it goes on smoother. Then I use very fine grit sandpaper to get it as smooth as possible.

I use primer paint rather than some of the epoxy-like resins made for smoothing 3D printed parts because it sands easier. Those resins don't seem to fill the stair-steps any better than primer, so they still take multiple coats. And it is harder to sand it smooth between coats, so there is more work involved.

Figure 12 shows the final part after it has been smoothed by multiple coats of primer paint. This is where your modeling skills will shine. I think you should have a easier time making smooth parts than people that have never built a rocket, because the techniques are exactly the same as making an aerodynamic part.

Figure 12: Smoothing process complete

Unfortunately, I can't put this smooth part directly into the vacuum-form machine here at Apogee. The reason is that the heat of the machine that softens the plastic sheet would also soften the plastic of the mold. Also, I'm sure you know what happens to a painted surface if you heat it up a couple hundred degrees, like what would happen in a vacuum-form machine. The paint would blister and melt. It would then stick to the plastic being draped over the mold. It would be ruined.

Because of this, I need to duplicate the mold out of a material that can take the excess heat inside a vacuum-form oven. I use polyurethane material. But in order to use that, I have to make a rubber mold of the canopy mold.

The exact details of making a silicone rubber mold are described in Apogee Technical Publication #12 (https://www.apogeerockets.com/Rocket_Books_Videos/Pamphlets_Reports/Tech_Pub_12).

But the process begins by building a simple box around the object to be molded. This is seen in ***Figure 13***.

Figure 13: Molding box

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The box is just there to contain the liquid silicone rubber and hold it while it hardens.

Figure 14 and ***15*** show the silicone RTV rubber being mixed and poured into the mold box.

Figure 14: Silicone RTV rubber being mixed

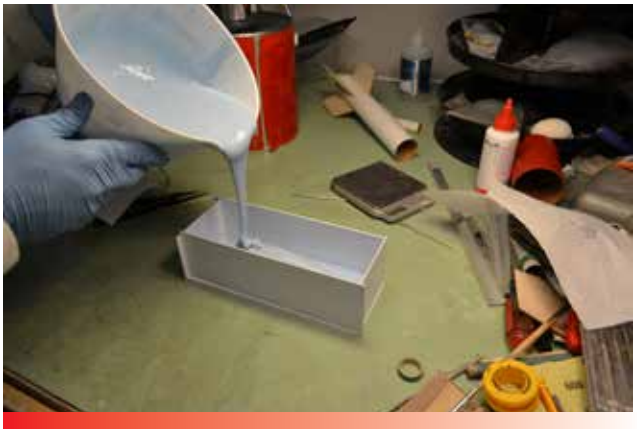

Figure 15: Pouring rubber into molding box

Figure 16: Pouring rubber into molding box

The rubber takes at least 24 hours to cure. In colder climates, like here during the winter months, it takes even longer. I personally let it sit for 48 hours before I take the mold box apart. This is easy to do, because the silicone rubber doesn't really stick to the box or the part inside.

Figure 16 is what the mold looks like after the canopy piece is pulled out of it.

At this stage of the process, the liquid urethane resin can be poured directly into the silicone mold. This part goes fast, as it takes only an hour for the resin to cure.

Figure 17 shows the resin mold that is the duplicate of the original 3D printed part. The difference is that it can take the heat of the vacuum-former's oven.

What is not shown in ***Figure 17*** are the holes that I'll drill around the perimeter of the canopy. These holes are so that the vacuum in the machine can pull air out from under the plastic so

Figure 17: Completed

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that it is snug and tight against the tight corners where the canopy meets the nose cone portion of the mold. You can see these holes as dimples in the plastic sheet once it is molded. You'll see them if you look closely at ***Figure 19***.

Figure 18: Vacuum forming the molds

Our tray in the vacuum-form machine is pretty big, and because I don't want to waste plastic, I'll make a lot of duplicates of the mold out of resin. The silicone rubber mold shown in ***Figure 16*** can be reused multiple times to make other urethane resin pieces.

Figure 18 shows the tray with eight identical canopy molds sitting on it. This way, I can make a lot of parts at single time.

Vacuum-forming is a fast process. You heat the plastic sheet for a little while (about 40 seconds in this situation) and it becomes soft. Then the plastic is draped directly over the molds, and a vacuum system under the tray sucks the plastic down tight against the molds. Then you wait a minute for the plastic to cool and solidify,

Figure 19: Cutting the canopy out of the plastic sheeting

and you can take it out of the machine.

The individual parts are then cut out of the sheet and packed up for you, the customer.

Figure 19 shows how I cut the canopy out of the sheet of plastic. You don't cut all the way through; you just score the plastic lightly and bend it back-and-forth until it cracks along the score line. There is also a video on the Apogee web site that shows how to cut it out and install it on the nose cone. See: https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_191

Figure 20 is the final canopy as it is cut from the plastic sheet.

The most anticipated moment of the process is when you test fit the part to the nose cone, which is shown in ***Figure 21***.

You can tell you've done a good job when you look around the perimeter of the part where it meets the nose cone, and there aren't any gaps. That means you've done a really good job in making the part and cutting it from the sheet. When things fit right, you don't

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Figure 20: Final canopy once cut from plastic sheeting

need much glue to attach it to the rocket, and there isn't much filler needed to smooth out the edges. In this case, if you want to make it look more organic (smooth and feathered-out edges at the joint line), I'd recommend the Fix-It Epoxy Clay that I mentioned earlier in this article.

Conclusion

I started this article by explaining the laborious process that I had to take to learn how to use a modern CAD software. I'll have to admit that getting over that learning hump is an ordeal, as I'm still struggling in the process of figuring out what all the buttons in the software do. But after seeing the results and experiencing how well this one single part fit on the nose cone, I'm glad that I went through the hassle and the time-investment to learn it.

I'll also admit that this first nose cone canopy took several days to design - because I was still figuring out the Fusion 360 CAD software. And while the first-time through the design process took a long time, the second one (for the PNC-66A nose cone) went significantly quicker. I was ready to hit the print button to send it to the 3D printer after only a couple of hours of work.

In conclusion, I hope you got a sense of what I go through when I design a new product like this particular piece. If you liked this article, please let us know by sending us a testimonial or making a comment on the canopy installation video that I mentioned previously.

Figure 21: Canopy easily aligns to nosecone