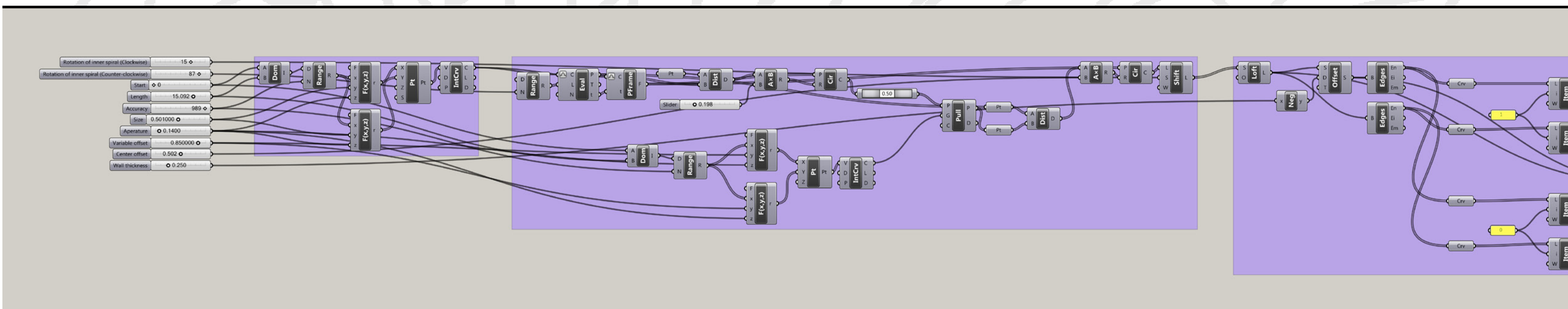
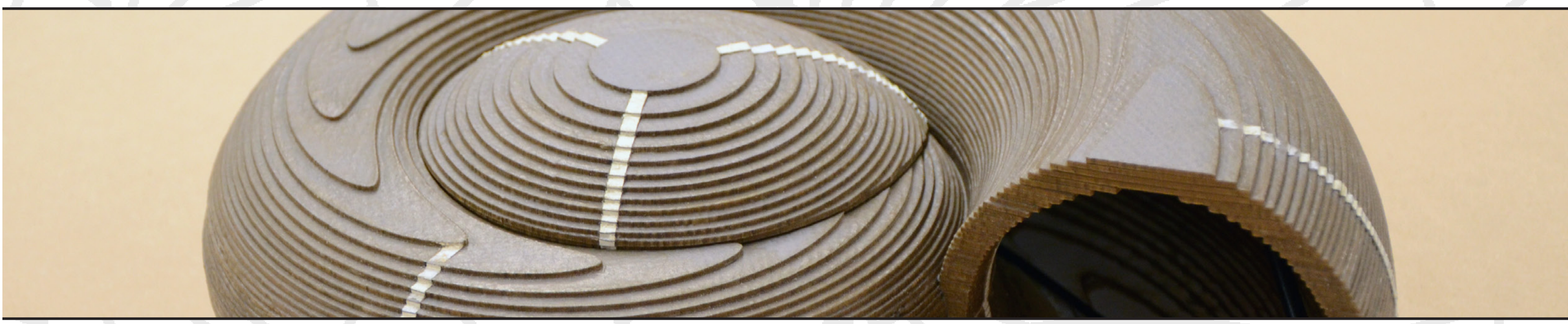
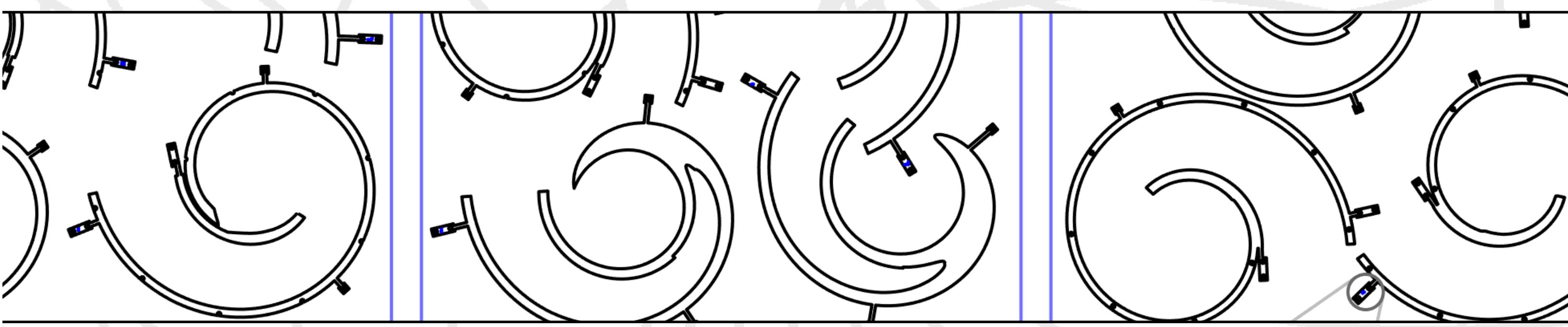
Slow Protoyping an Audio Recording Device







By Carlo Sammarco

In support of Lisa Tolentino's Ph.D. research

Arizona State University - 2012

Introduction

Rapid Prototyping (RP) technologies offer designers and manufacturers the ability to make objects with greater speed, precision and ease than ever before. Having used RP technologies for several years, and coming from a traditional background rooted in the hand made, I am aware of how, when using RP technologies, time is increasingly compressed throughout the process of developing a prototype. “Slow Prototyping” explores an alternative to this compression.

Design is not necessarily a rapid or linear activity. The development of a prototype requires time, often involving several iterations as a design is refined. Manual methods of object making offer me time to digest what I am doing. It is through labor and time that my mind and body learn from each other. Doing and thinking in fact complement one another.

I saw project that follows as an opportunity to slow down the prototyping process. I was curious how the slow pace of a manual process might affect the design of the object. I also saw an opportunity to reconsider the RP process from the ground up. I wanted to appropriate prototyping technologies on my own terms, borrowing from concepts that made sense to me. In doing so, I might better understand current RP technologies.

This project uses concepts developed in fields ranging from “early” rapid prototyping to tool and die manufacturing and even printmaking. I found that in solving the logistics of a layer-based building process, I came across solutions very similar to what have already been established in commercial RP systems. In this sense, certain principles are universal. What follows is an account of the project, and hopefully a reference for future projects.

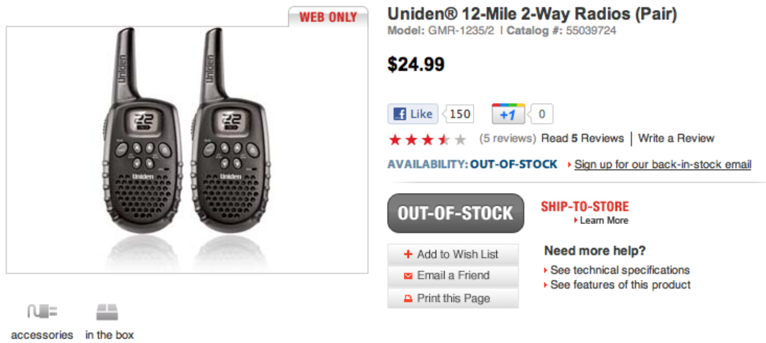
The goal

Lisa Tolentino, a Ph.D. candidate in the Arts, Media and Engineering program at Arizona State University, approached me with the goal of creating housing for a handheld, wireless audio recording device. This device would be used by Lisa in her research which looks at the social interaction between children. The recording device would be used along with other devices in a motion-capture environment. The device should:

- Conceal the recording device
- Provide access to turn the recording device on and off and to change batteries
- Be ergonomically comfortable for a wide range of hands
- Be able to withstand abuse by children

The constant

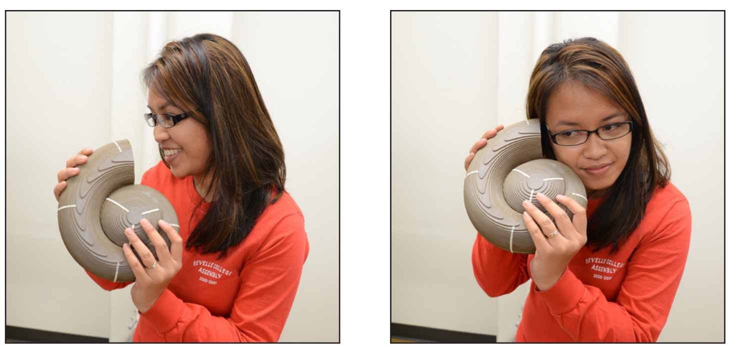
When Lisa originally approached me about this project, she presented to me the walkie-talkie she was planning to use in the system. This was our starting point, the one constant from which our design began. We needed to design a form that could accommodate this walkie-talkie.



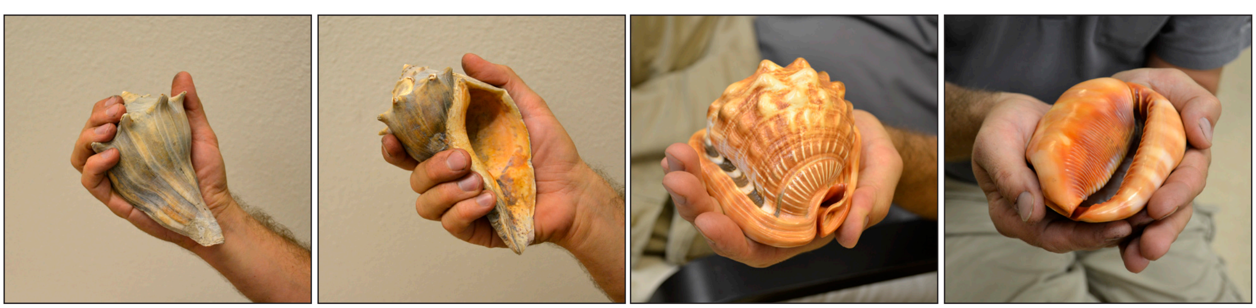
The initial walkie-talkie

Initial form finding

Lisa's initial ideas for the form were inspired by the act of speaking into something. These included a plush toy in the form of a stingray, a squeaky toy and a starfish. We then considered basing the design on a sea shell, both because of its generous shape and because of its associations with sound, as both a speaker and a microphone.



Lisa brought some shells she had collected from her travels overseas. These were amazing! They were beautiful in their surfacing and texture. Moreover, it was astonishing to hold them in our hands. It's hard to believe these *weren't* made for the human hand. The tactile and ergonomic qualities of these shells remained a source of inspiration for us throughout the project.

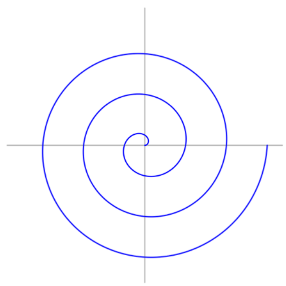


Shells from Lisa's collection

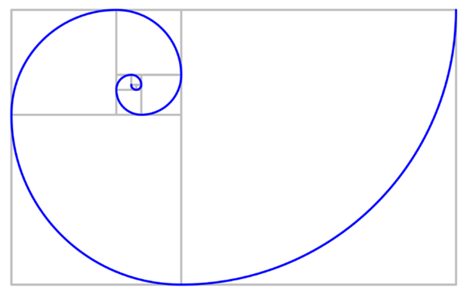
In order to accommodate fabrication, I needed to simplify the shell shape. I started from scratch, considering alternative models for our underlying spiral geometry.

I briefly considered an Archimedean spiral because it is easy to model with its constant offset from the center. Additionally, the Archimedean spiral is part of most modeling software's basic tools. However, we ultimately chose a Logarithmic spiral instead because it provides a more interesting shape in its cross-sectional variation and it seemed more ergonomic in its ability to accommodate a variety of hand sizes and positions.

Archimedean

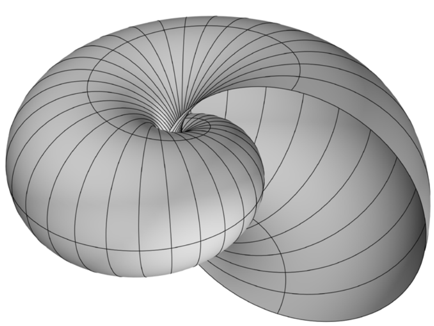


Logarithmic

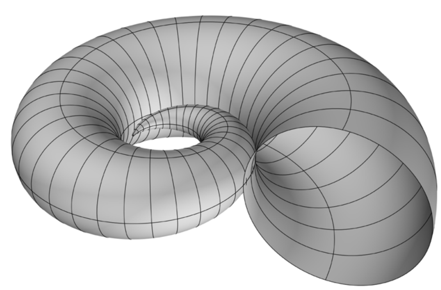


The logarithmic shape proved to be more challenging to model than I first though. I found some scripts which created very basic variations on the structure, but we needed more control over how the shape would be defined (particularly for the purpose of accommodating a wall thickness). For these reasons, I eventually created a parametric model.

Which way should the tail of the spiral go? Did we want an "innie" or an "outie"? We decided to go with an outie. This would keep the entrance to the shell unfettered. It also created a natural area in which to integrate a lid.



Innie



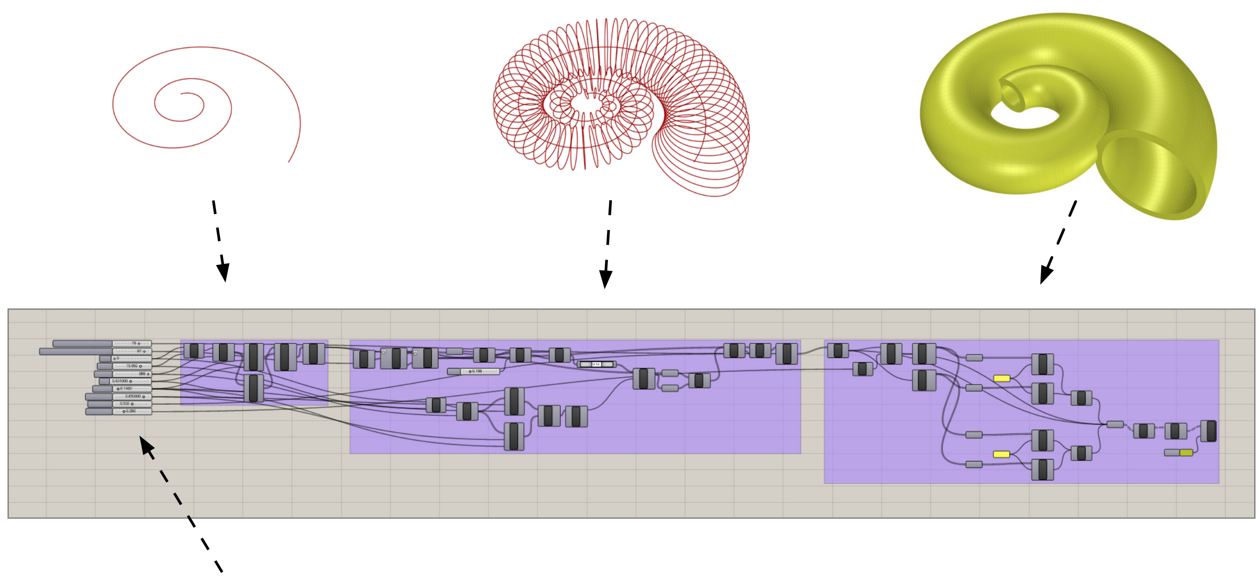
Outie

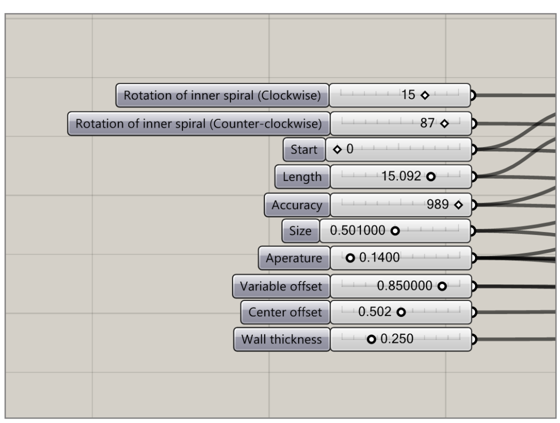
Creating a parametric model

Rhinoceros 3D was used as the basic 3D modeling platform. While the entire design could have been realized through traditional, explicit modeling, I decided to work within a parametric environment, as the number of variables could be fixed and a parametric model would allow us to make changes to these variables quickly. I used Grasshopper, a Rhino plug-in, for the parametric modeling.

The main steps for creating the parametric model involved defining a base spiral, creating a series of perpendicular circles on that spiral, creating a lofted surface through the perpendicular circles, and offsetting a surface from the original surface, resulting in a solid model.

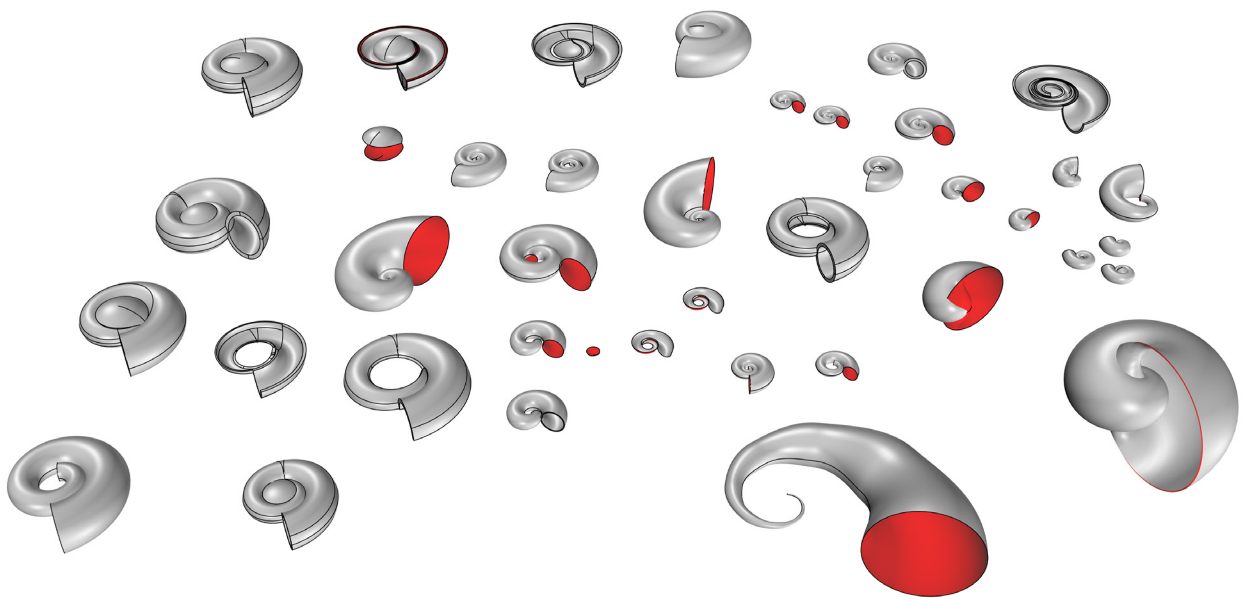
Below are a few screenshots from the definition I wrote for the shell…



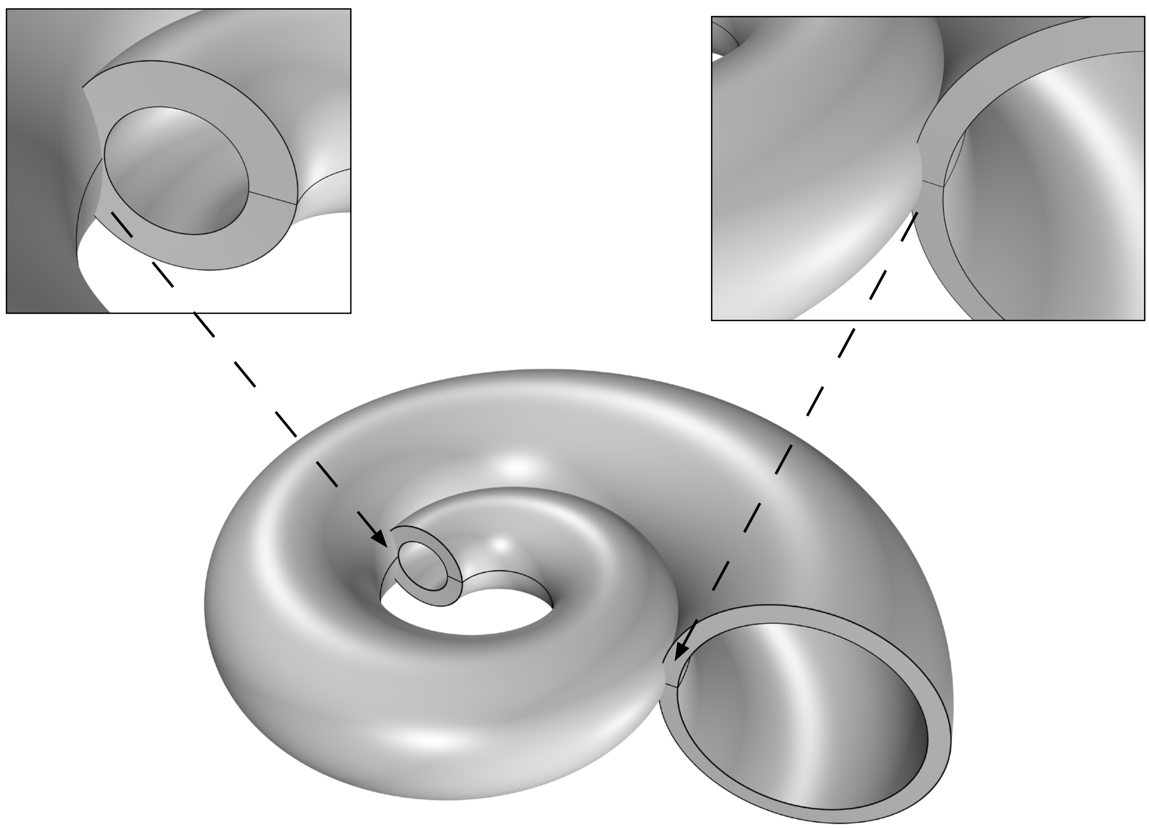


Parametric variables for the model

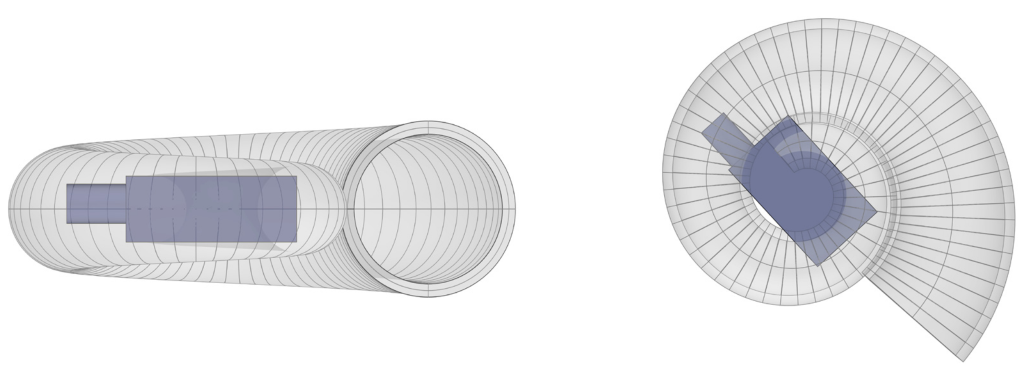
Below are some preliminary variations as we narrowed down the size and shape of our shell. These models were derived from the Grasshopper definition and in some cases were further edited manually in Rhino.



A particular concern for the geometry related to how the wall of the shell intersected itself as it progressed through its spiral. There needed to be overlap, but not so much that the wall was breached. This proved difficult to achieve as the offset is continuously changing. I'm sure this could have been defined mathematically in the definition itself, but my math skills only carry me so far! The parametric model proved invaluable in achieving this aspect among a host of inter-related parameters.

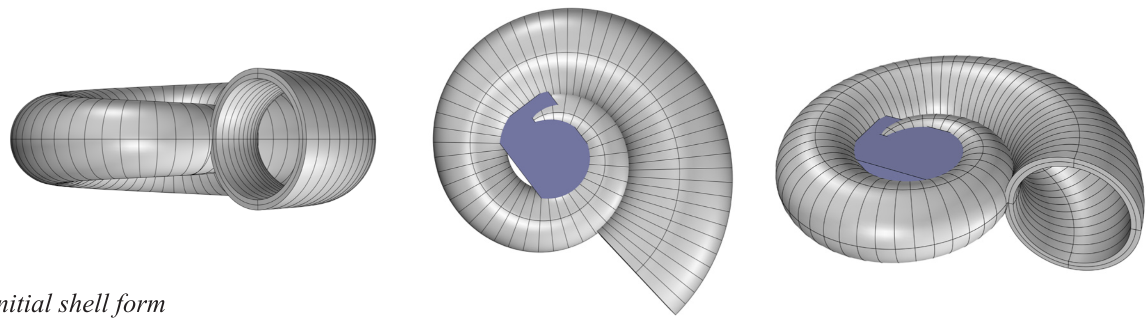


With the general variables set, the next stage was to approximate a scale model of the walkie-talkie. The scale of the shell form was then tweaked, ensuring that the walkie-talkie was contained within its volume.

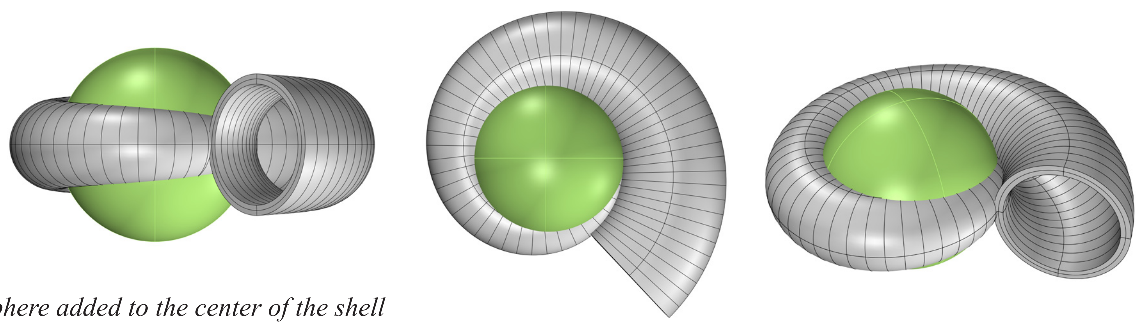


Side and top views showing position of the walkie-talkie

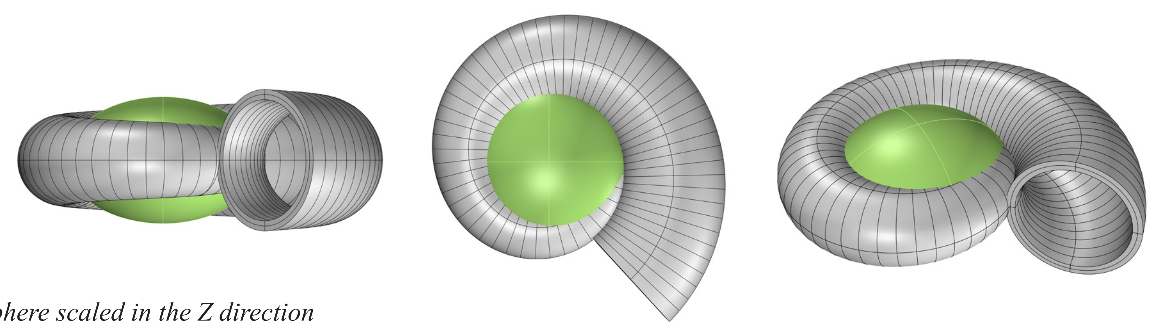
Below is a summary of the steps involved in modeling the lid...



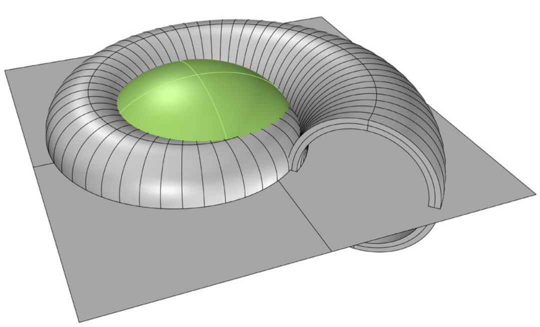
Initial shell form



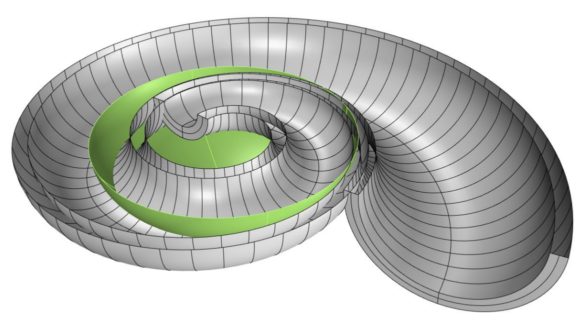
Sphere added to the center of the shell



Sphere scaled in the Z direction



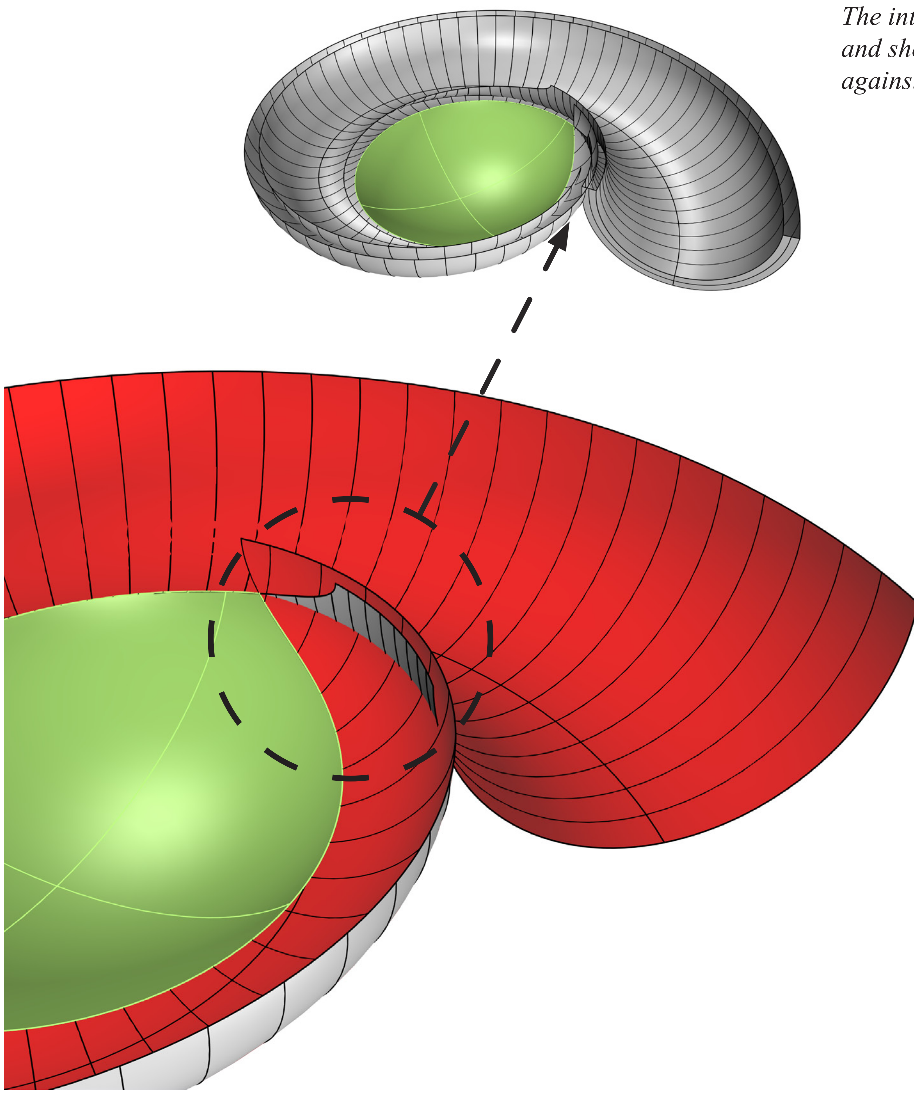
A trimming plane is established.



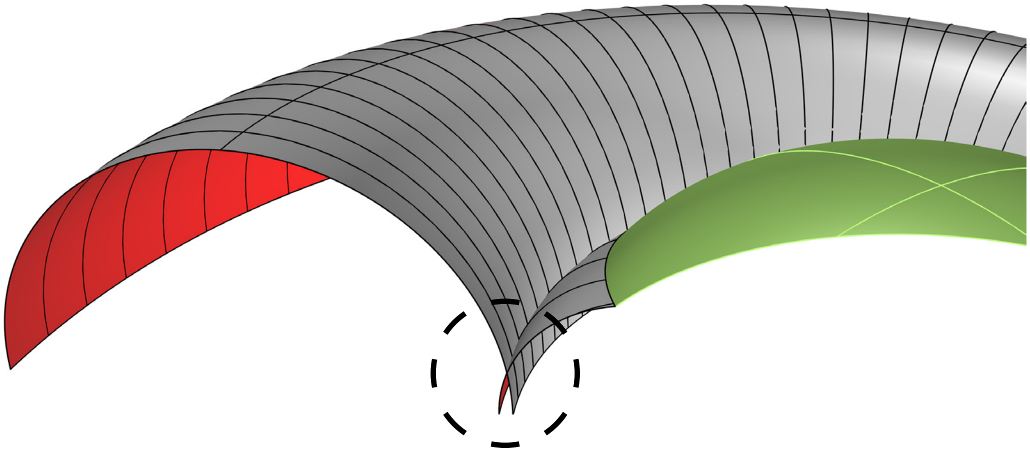
After trimming, half the lid and shell remain.

The most difficult aspect to modeling became apparent when negotiating how to trim away the overlap of the form's outer shell. This was difficult because this entire outer structure was defined by a single surface. Rhino, and most other modelling programs for that matter, can not find self intersections of a surface. Furthermore, some of Rhino's tools, like ExtractIsocurve did not solve the problem, since the intersection did not lie perfectly parallel to the surface's UV directions and was in fact curved.

The intersecting areas between the lid and shell after trimming against one against the other.

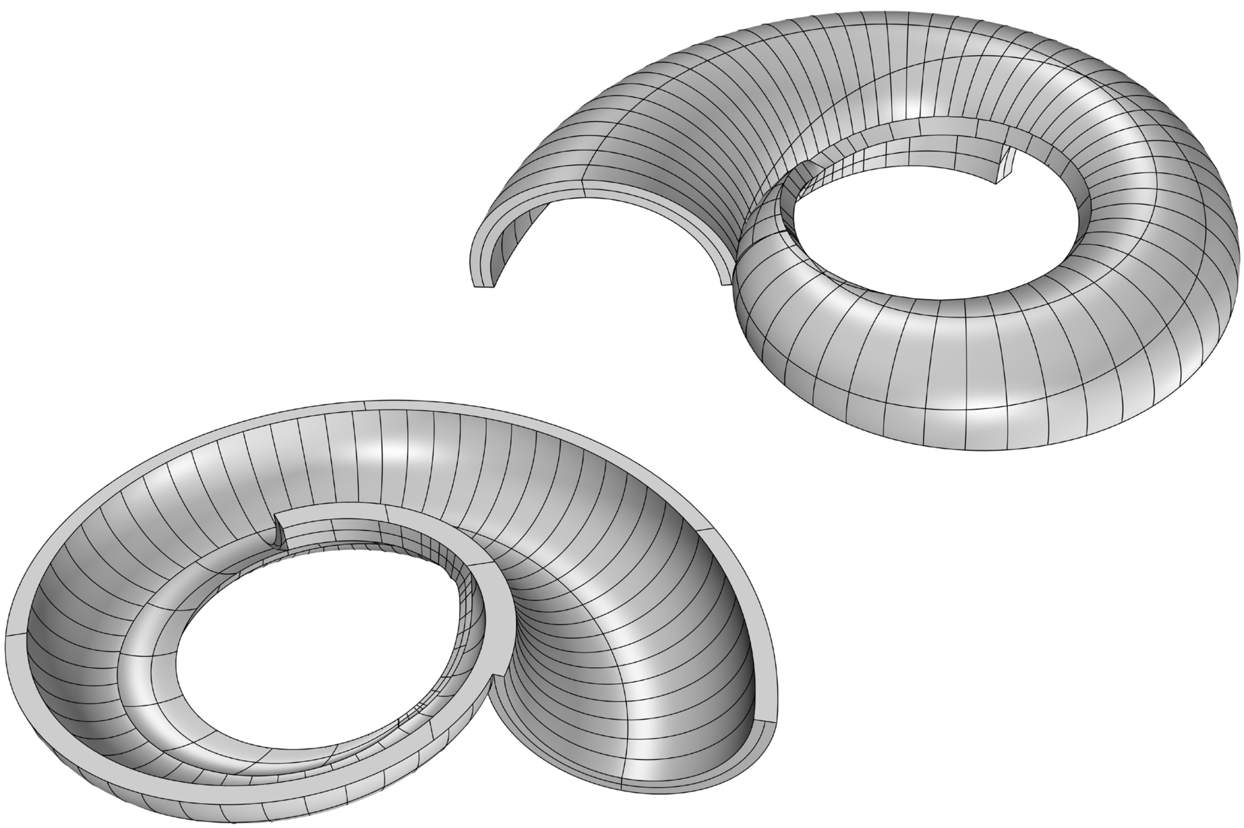


Detailed view; back faces have been rendered in red and the inner shell surface has been hidden for illustrative purposes. Note the problematic self intersecting surface.



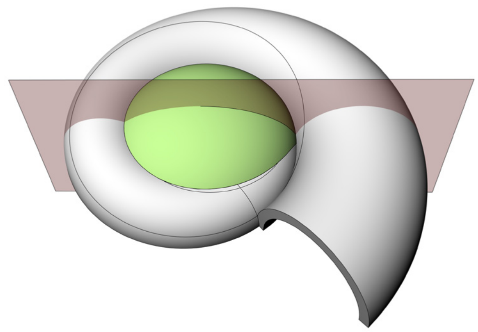
Flipped view of the above showing the outer aspect of the shape. The geometry has been clipped to give a cross-section, again highlighting the problematic self-intersecting surface.

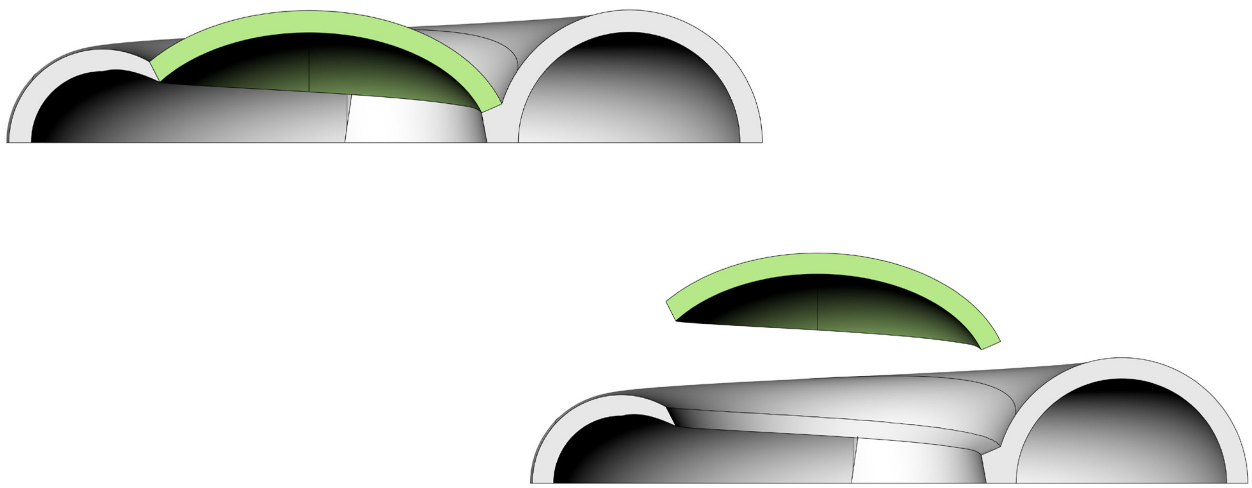
Several strategies were combined to solve the self-intersecting problem. The result was a watertight solid model, which allowed for reliable boolean operations in later stages of modeling.



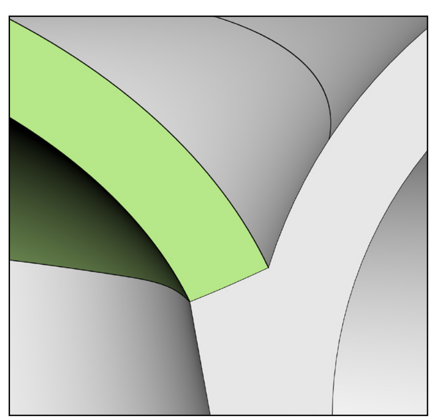
The completed shell.

The interface between lid and body was chamfered. This angled area creates a natural stop, ensuring that the lid self-centers as it is seated...





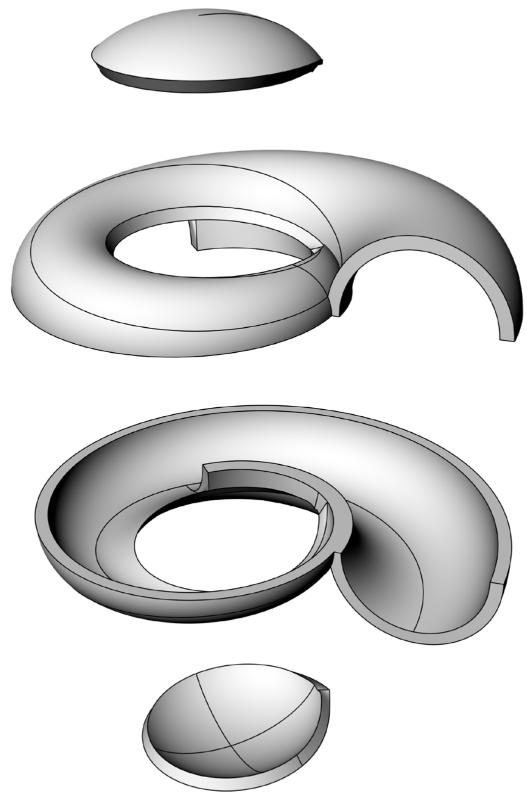
Cross-section view of the body and lid interface.



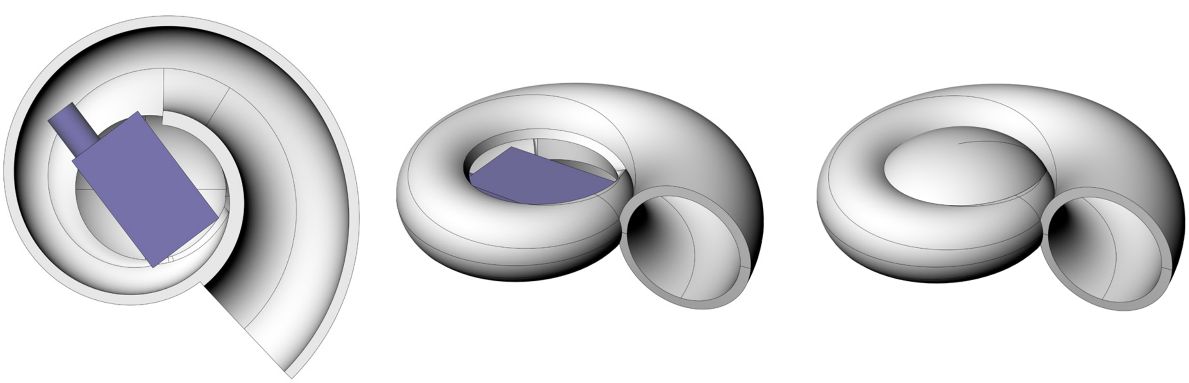
Detail of the chamfered body and lid.

Version 1 - Fabrication considerations

In our first version, we tried to address the challenges of the design and fabrication of the object. This included the logistics of assembly, the geometry of the lid, and the registration system as described below...

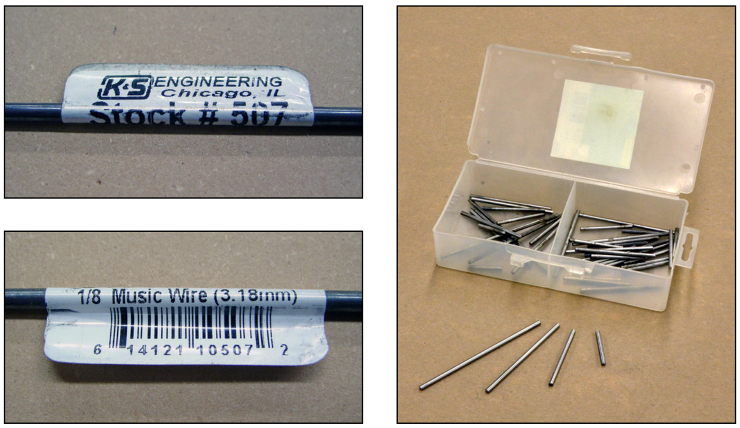


Exploded view of the assembly showing the four discrete parts.

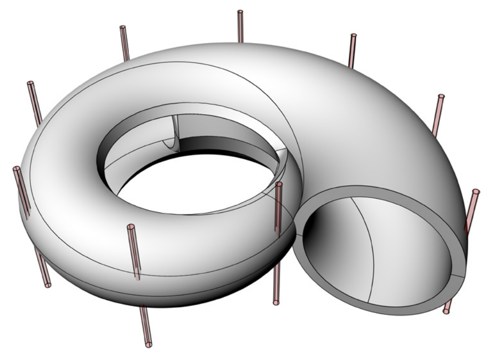


Views showing location of the walkie-talkie in the final shell and with lid in place.

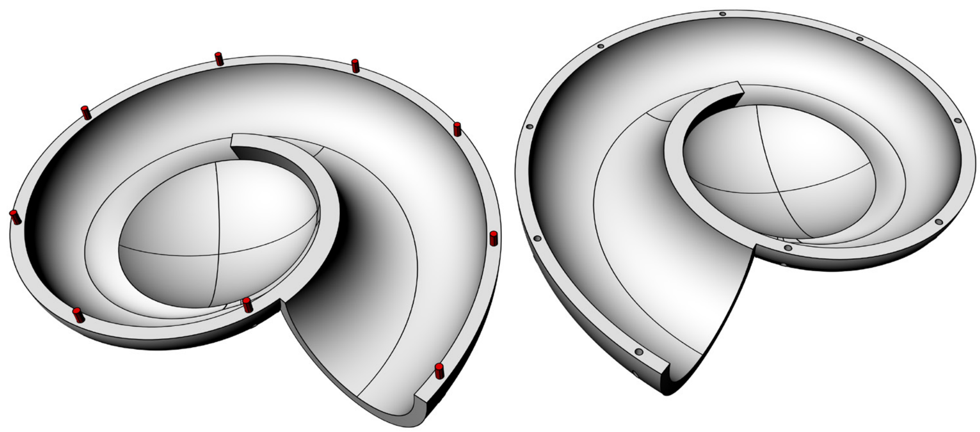
The two halves of the shell were designed to be intersected by registration pins. These pins would act as a fastener, holding both sides together after assembly through a press-fit, providing a tight, semi-permanent hold. The pins we chose were made from 1/8” music wire which we purchased locally at Industrial Metal Sales. This material was surprisingly consistent in diameter (consistency being a good thing when dealing with registration!). The metal was cut down to required lengths with a hack saw, then ground to final length with a bench grinder and belt sander. A slight chamfer at the ends of the pins was added to help guide the layers during assembly.



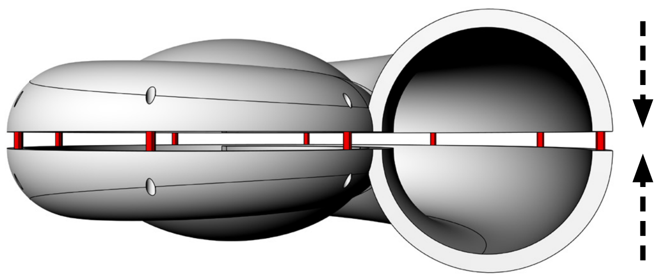
Registration pins cut to a variety of lengths.



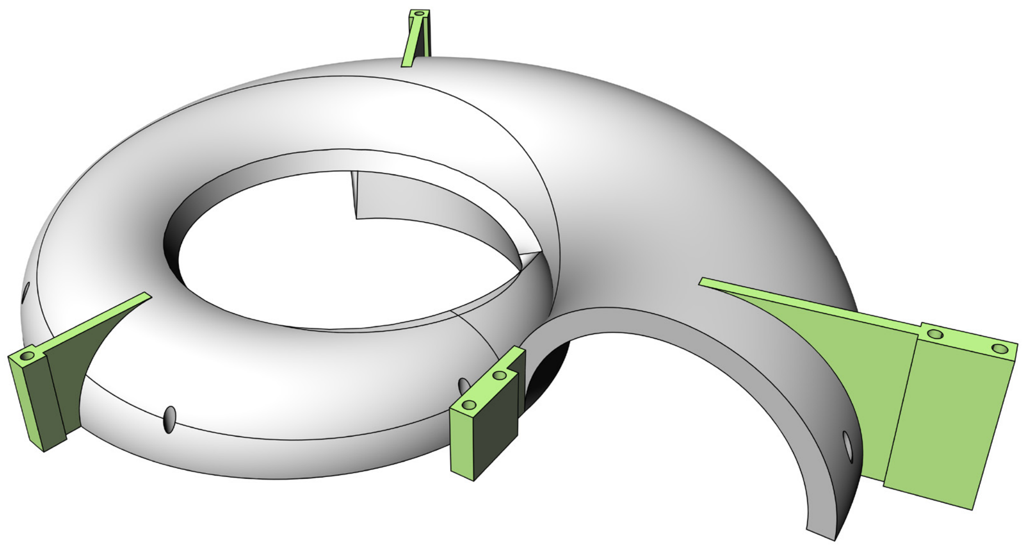
Cylinders of the same diameter as our pins were used for boolean subtraction from both halves of the shell body.



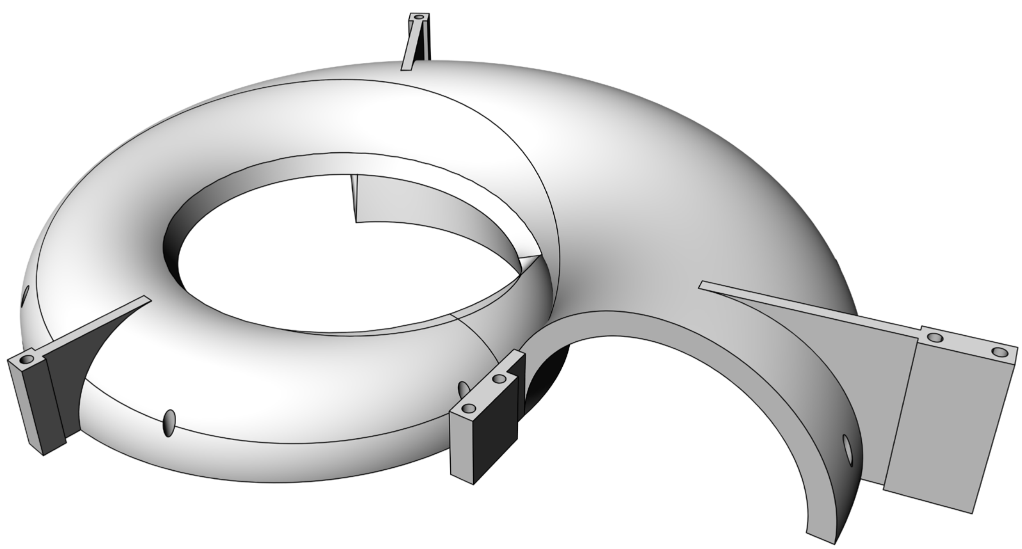
Mock-up showing the resulting holes for the pins and the pins (shown in red). Pins are approximately 0.5” in total length. Registration holes on each half of the body are about 0.35” deep, ensuring the pins do not poke through when fully seated. Individually, the pins fit somewhat loose; when used in unison, they fit quite tightly.



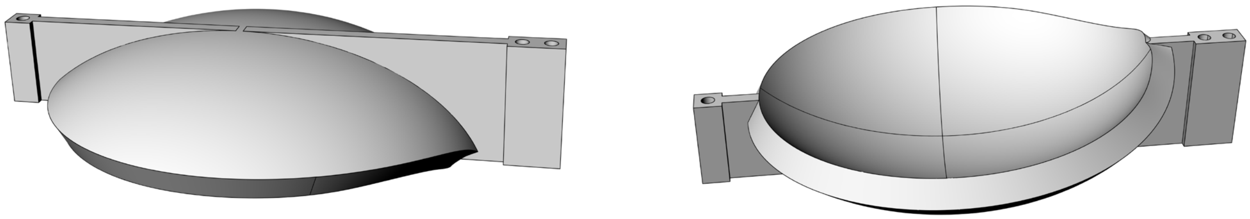
I needed some way to register all the different layers using a common set of points. This was accomplished by creating extensions from the shell which ensured contact with as many layers as possible. I call these “registration tabs”, though the first thing I thought of when I saw them was flying buttresses on a Gothic cathedral. These tabs were boolean joined to become part of the geometry prior to sectioning. They would be manually removed with an Exacto blade after glue-up.



Registration tabs highlighted in green.



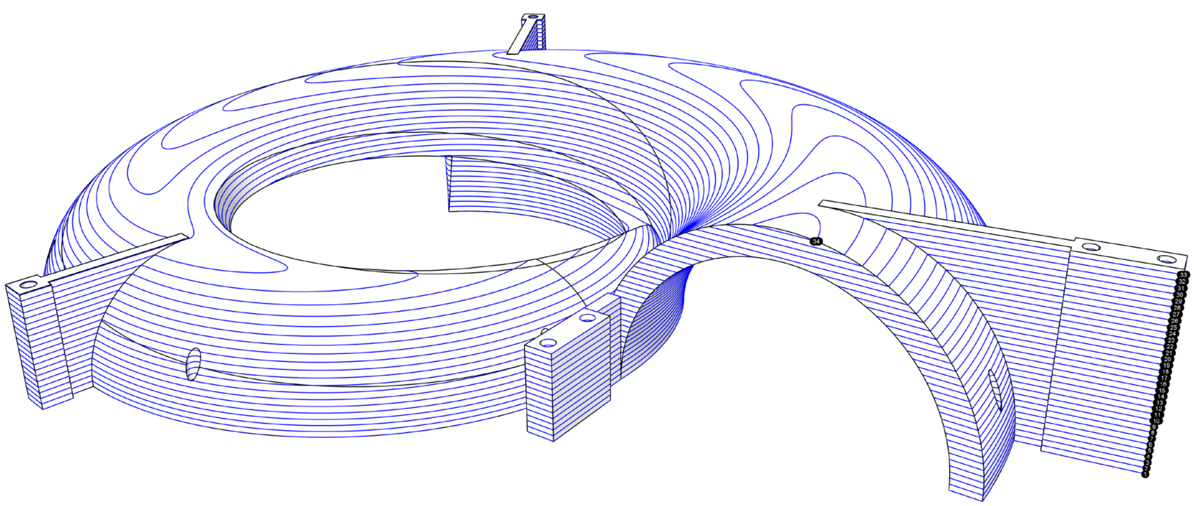
One half of the shell, booleaned and ready for sectioning.

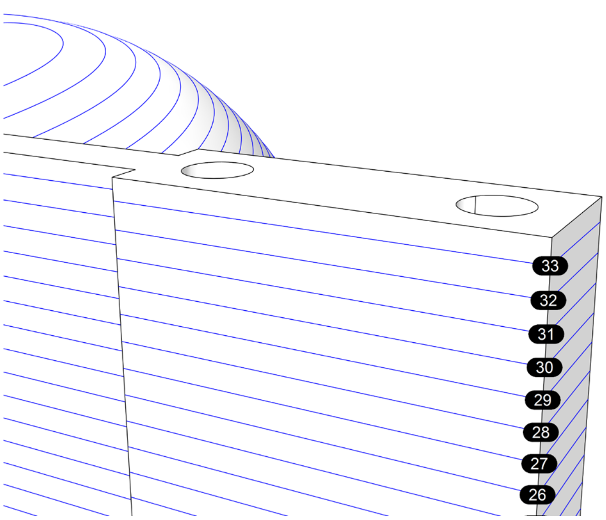


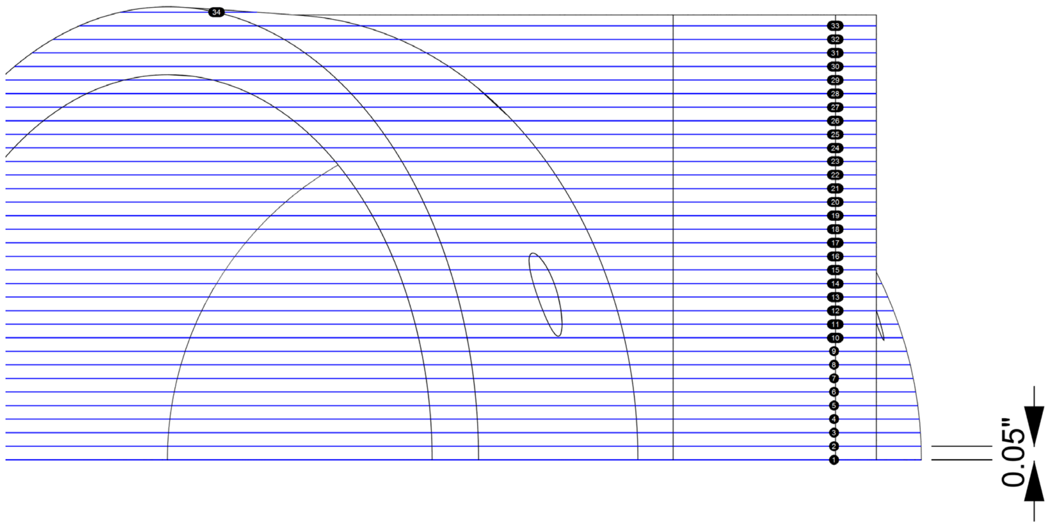
One of the two lids, ready for cross-sectioning (top and bottom views). Note that the registration tabs do not breach the inner walls of the geometry.

Cross-Sectioning the model

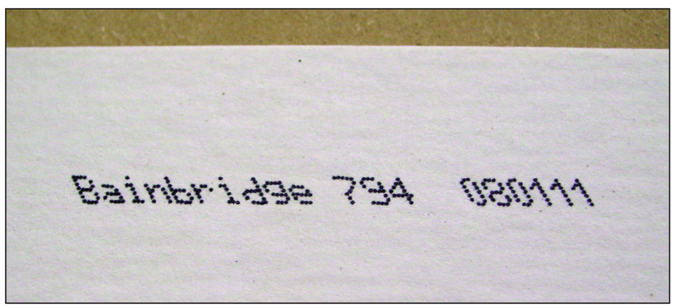
Cross-sectioning was done using Rhino's "Contour" command. Contours were labeled manually using a number for each layer (34 layers for each half of the body).



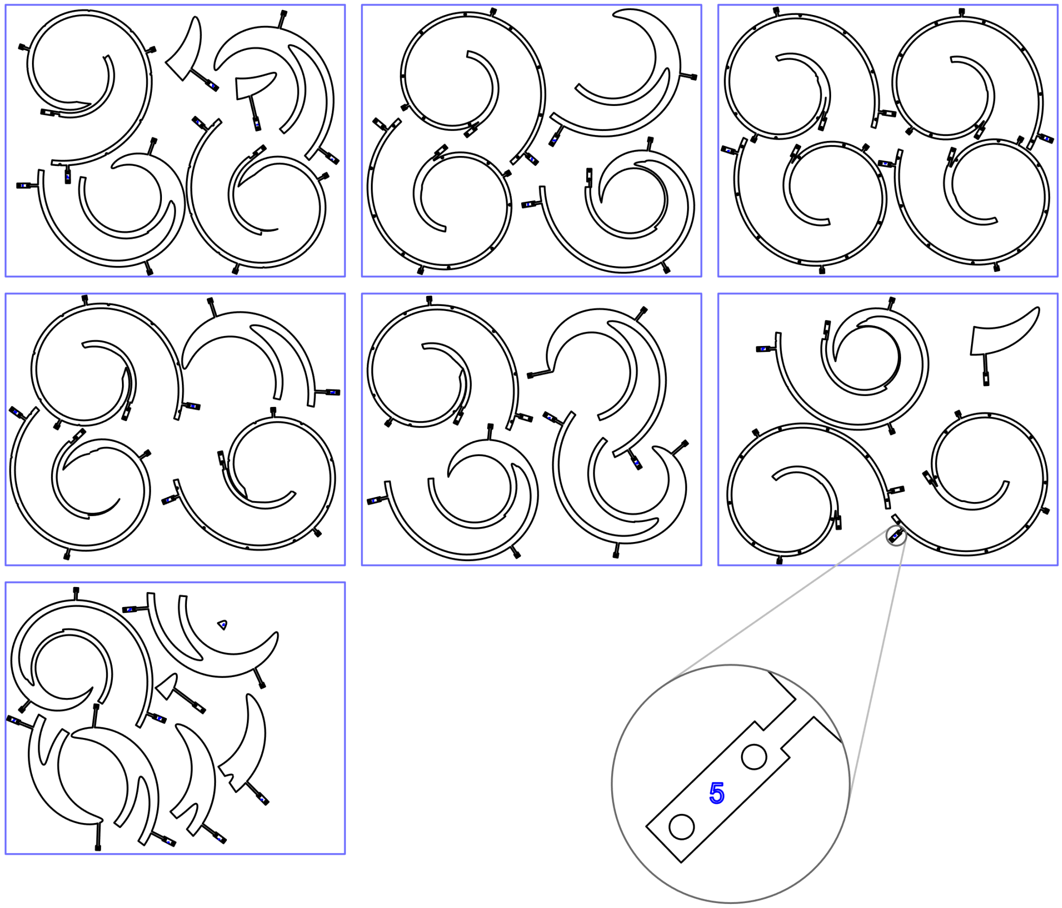




Spacing for the contours was determined by the thickness of the material. In this case, our Mat Board was 0.05" thick…



Mat Board is Warm Grey 794 by Bainbridge, purchased locally at Utrecht.



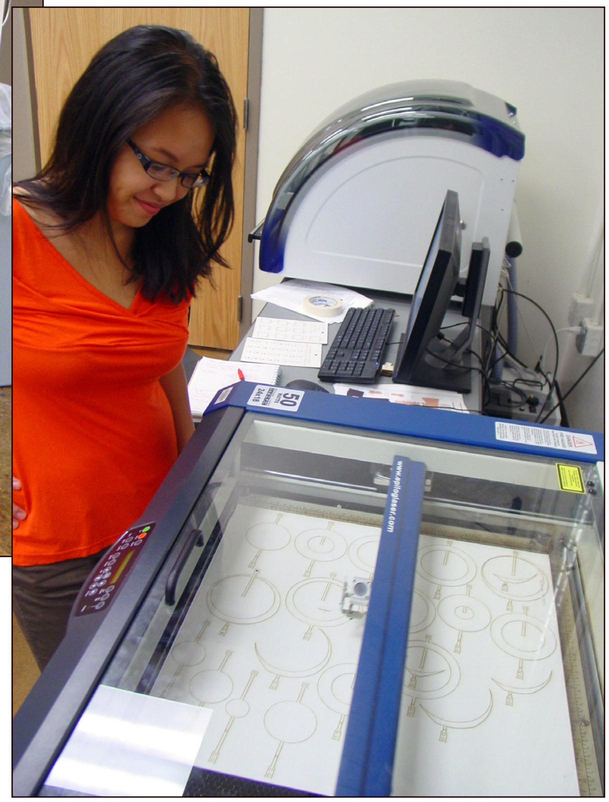
The 34 layers for the one of the body's halves, laid out after sectioning and ready for laser cutting (rectangles are 20 x 16"). Detail shows the numbering system applied to the tabs.

Material Considerations

This object is primarily intended for children. As such, we were looking for something lightweight, warm to the touch and resistant to knocks and drops. Mat Board was chosen as it provided many of these qualities. Also, it was available in relatively thin format, giving us decent resolution compared to alternative materials like Masonite or MDF.

Laser Cutting

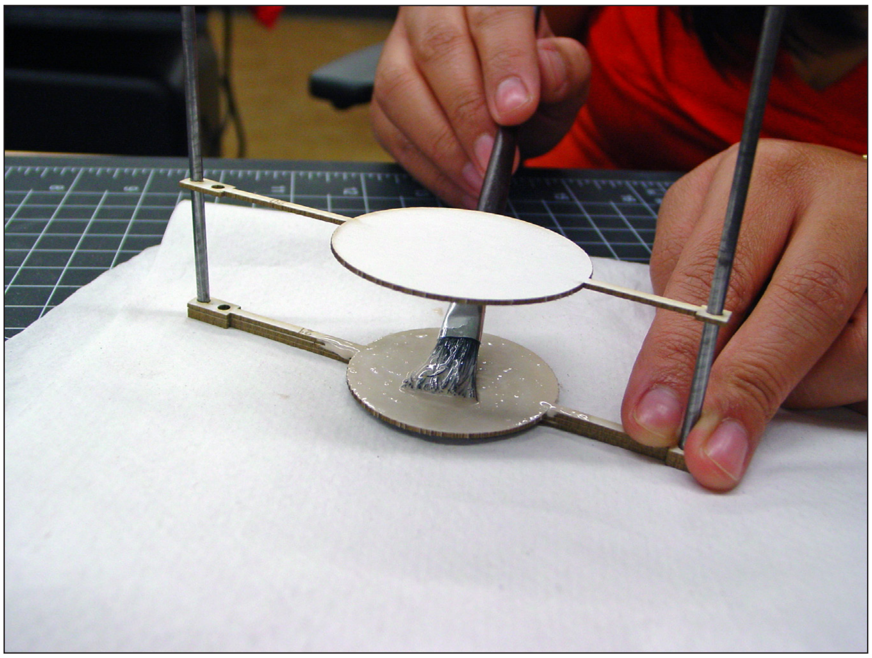
Cutting was done on an Epilog Helix 50 watt model. No surprises here really. This technology is pretty mature at this point. It worked as advertised… which was a good thing!

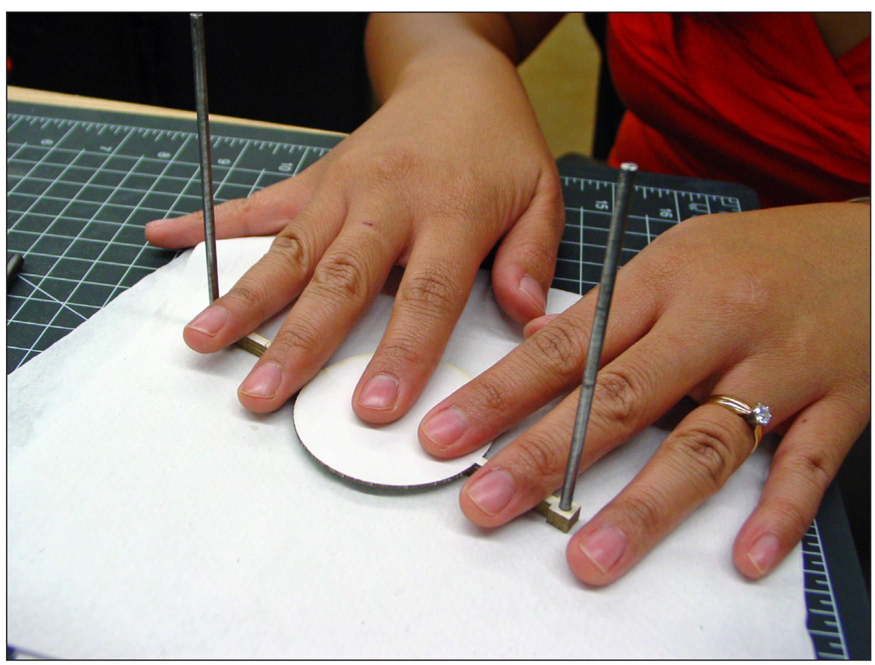


Glue up of pieces

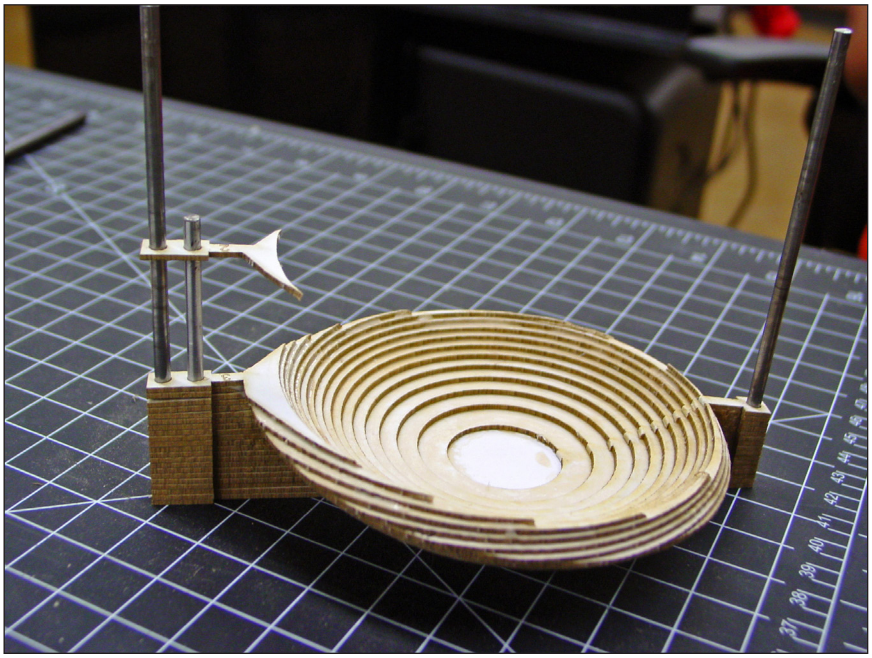
Before gluing, we organized the parts based on their stacking order.

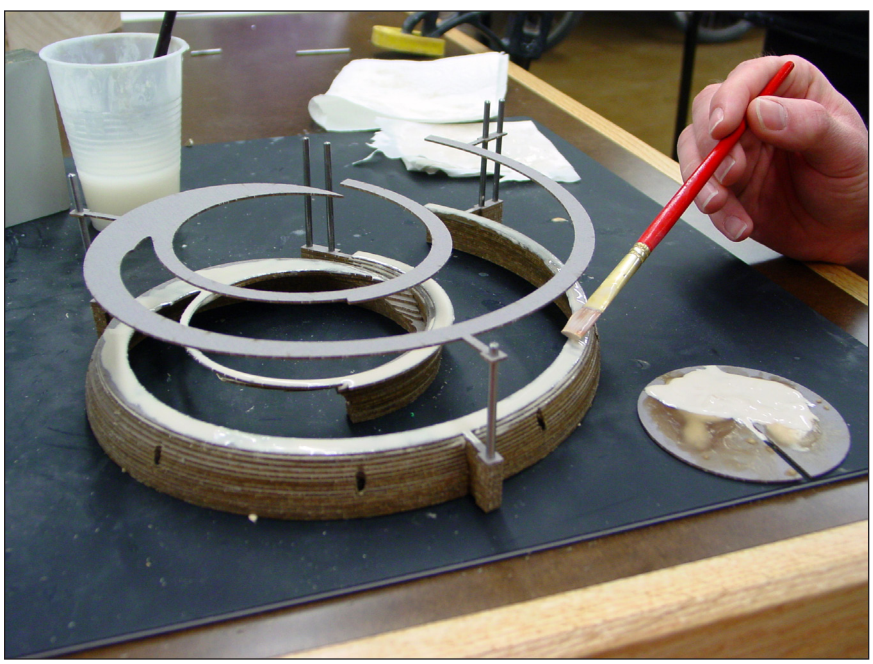
We then intersected the registration holes of each part with the last and evenly applied glue in between the layers using a brush before applying pressure. Excess glue that squeezed out was regularly cleaned using a damp, clean brush. Try gluing two flat surfaces with wood glue. The glue creates a thin film, allowing the pieces to slip and move making placement inexact. The registration pins really helped. They were in fact essential.





The contour sections run higher on one side of the lid design than the other. We chose to use 2 pins for registration on this higher side, as using just one wouldn't have been enough for registration of the final layers…





Glue considerations

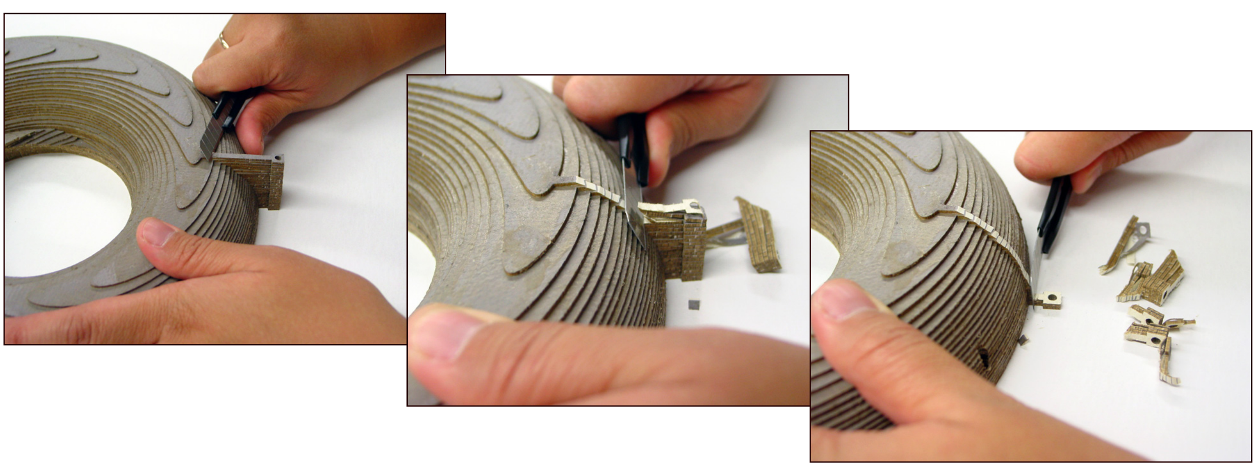
As for glue, we considered using cyanoacrylate (a.k.a. crazy glue). While crazy glue sets up quickly, it doesn't penetrate the surface. It creates a superficial bond between the Mat Board layers. Additionally, there is no easy way to distribute cyanoacrylate evenly and its working time is too short.

We chose Titebond III. It is affordable, waterproof when dry and provides a long working time. It also cleans up with water, making it easy to work with. The glue was evenly applied to each layer using brushes. As we were quite liberal with our glue usage, we did a lot of wiping off. This naturally left residue on the entire surface. Ultimately, this created a very durable surface (perhaps a rare case where being messy is a good thing?).

De-cubing

The term “de-cubing” was coined in the 90’s by a company called Helisys to describe the process of removing support material from a 3D prototyping process called Laminated Object Manufacturing (LOM). This system used a paper or plastic laminate with an adhesive; the laminate was cut, glued and stacked one layer at a time. The space surrounding the part was cut as a grid. This “negative space” provided a support during the layering process. It was cut in a grid like pattern to facilitate removal of the unwanted volume after the process was completed. The image below shows the de-cubing process in action (image courtesy of Cubic Technologies, Inc.).

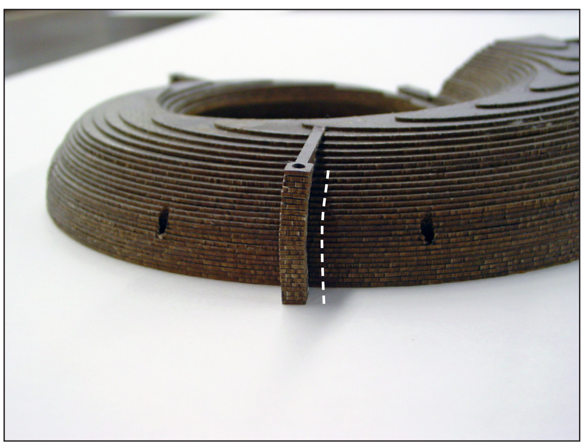
In our case we used an Exacto blade and steady hands to shave away our registration tabs…



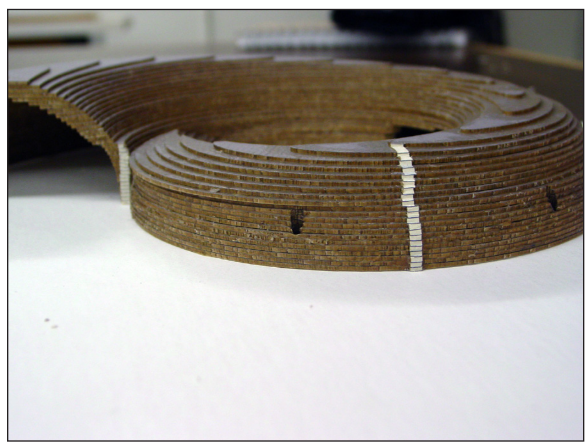
Impressions

The process took a long time! The stacking and gluing alone took about 7 hours for the body and another 3 for the lid. That was with two people working and only for half the object. This is definitely not "rapid" prototyping! Despite the labor, or perhaps because of it, the resulting object has a warmth to it that resides somewhere between the cool mechanical world of prototyping and the warmth associated with more traditional fabrication techniques. The object is surprisingly light and resilient too, thanks in part to the exterior coating provided by the wood glue. This might be a paper product, but it doesn't really feel like it. Also, the ridges of the layers provide an unexpected tactile reward to the hands that hold it. This is an object that wants to be held.

As for the process, there were a number of issues I noticed, particularly with the registration system. Namely it wasn't rigid enough. There were only three sets of registration pins for the entire lid… far too few. Also, there was no external reference for these pins. As such, there was a noticeable drifting as the layers were stacked, almost as if the object was slightly skewed. Finally, our registration system didn't account for the flexibility of the material. This became an issue in some of the internal areas of the layers of the body. What we really needed was registration points on the inside areas and a more rigid system (which is the whole point of a registration system!). These issues were addressed in the revised version.



Note the gradual curving of the layers along the registration tab from top to bottom.



An abrupt shift in the layers is visible half way up the object.

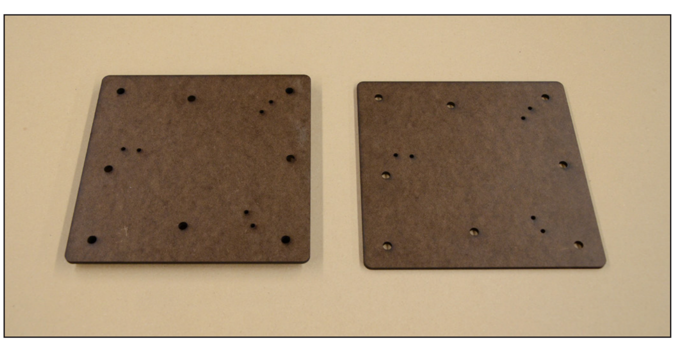
Version 2 - Design and Fabrication revisions

For the revised version, we reconsidered our registration process. We designed a registration plate, independent of the object, which consisted of two pieces of 3/16" Masonite. This plate would provide a reference plane for locating the registration pins prior to stacking the layers. Using two boards spaced far enough apart would minimize flexing of the registration pins.

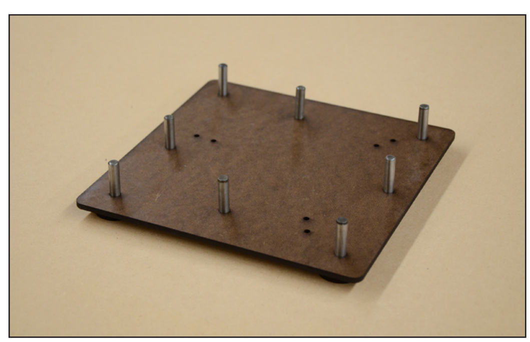
The two Masonite boards were registered to each other using ¼" precision ground steel dowel pins. Dowel pins are used as locator pins in the tool and die industry and can be purchased inexpensively through Grainger or other industrial suppliers. We stacked round spacers around the dowel pins that kept the offset between the two boards consistent. The entire registration assembly snapped together very tightly.

Additionally, we added two pins for each registration tab, and also increased the number of tabs.

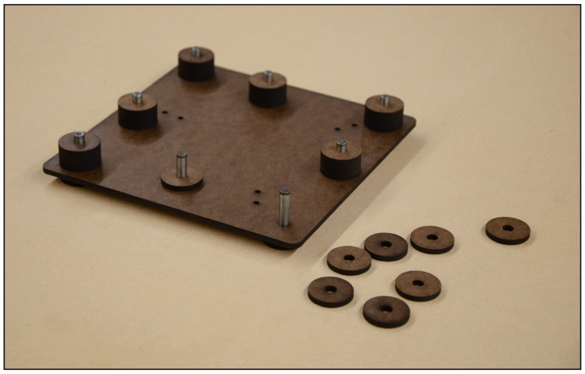
1/4" precision ground steel dowel pins.



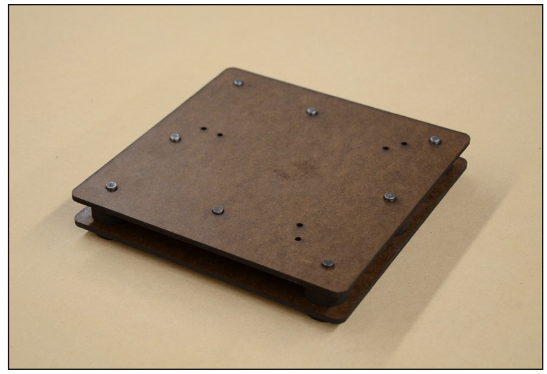
The two Masonite sheets.



Dowels fit tightly into the Masonite.

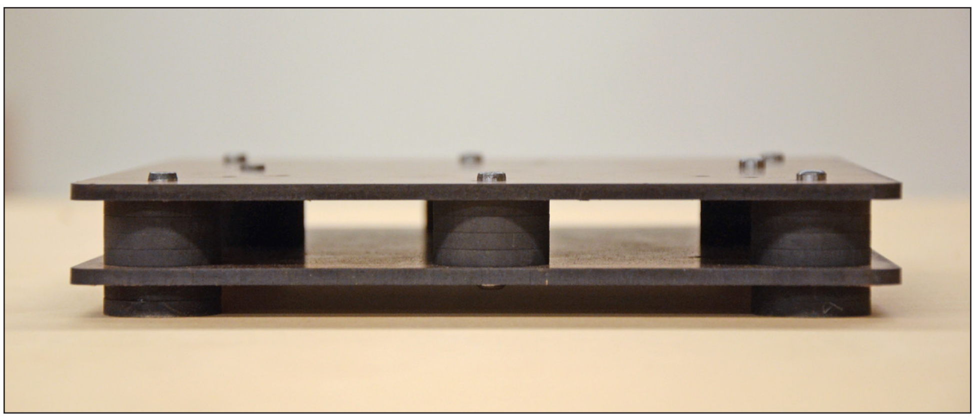


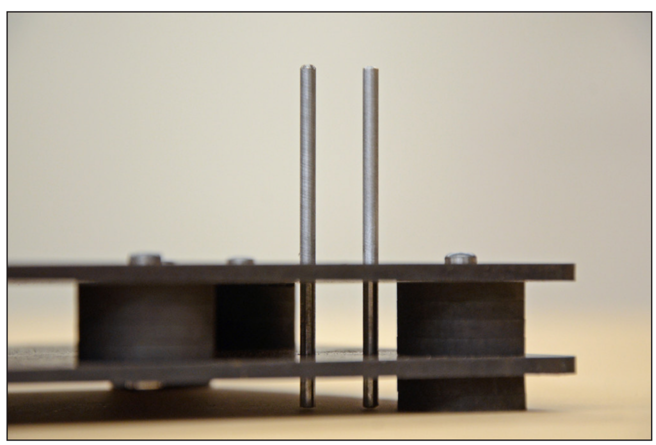
Spacers fit loosely around the dowels.



The registration platform after assembly.

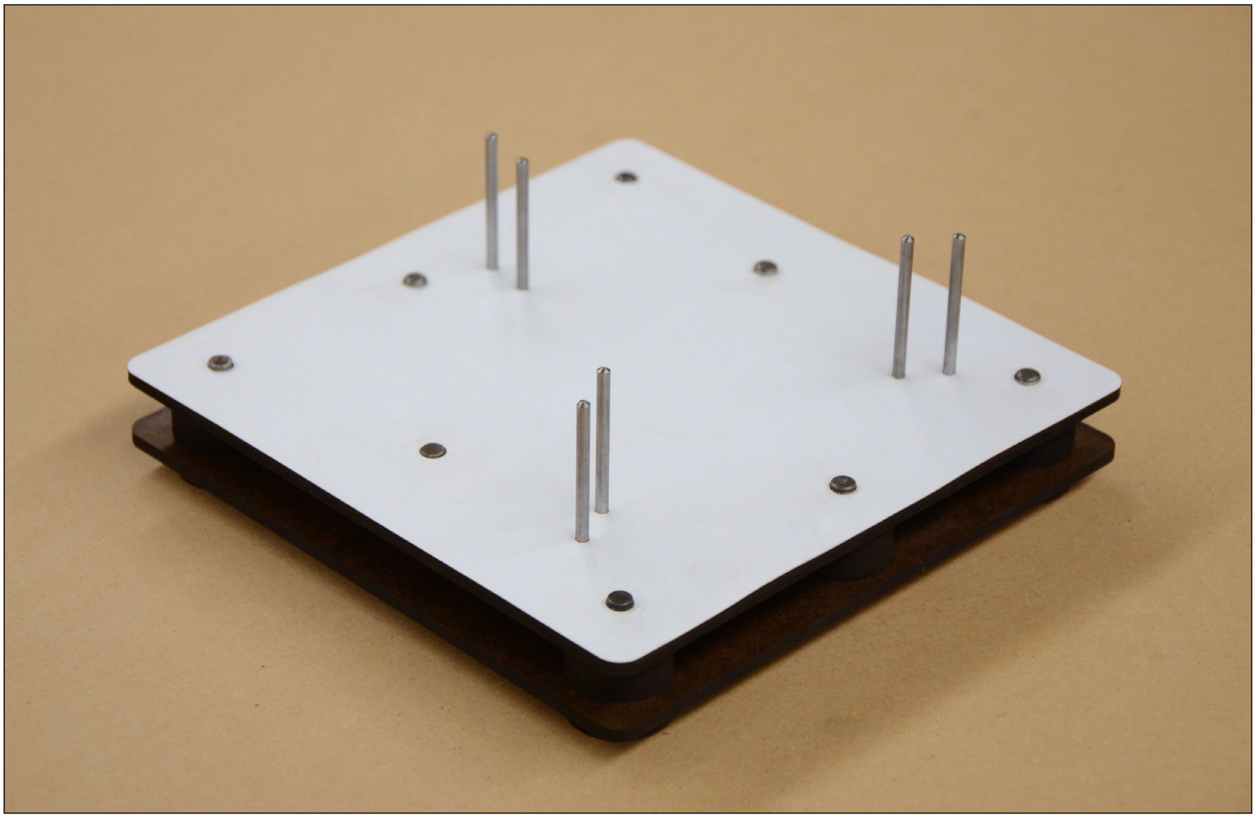
A single spacer was added to each of the four corners on the bottom of the registration assembly. This allowed the registration pins to fully protrude through the base when the assembly sat on the table. This small protrusion proved very helpful as we periodically needed to remove the pins to free the object and clean up glue on the underside.



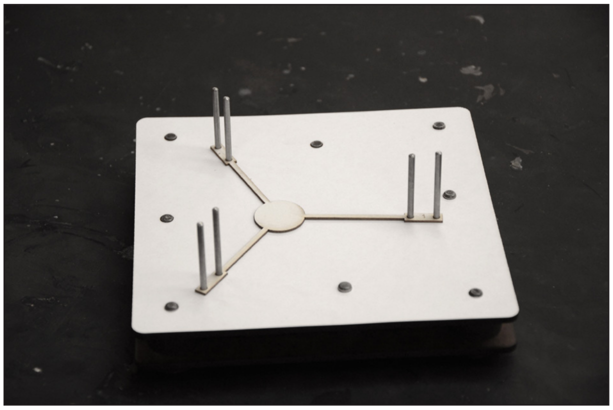


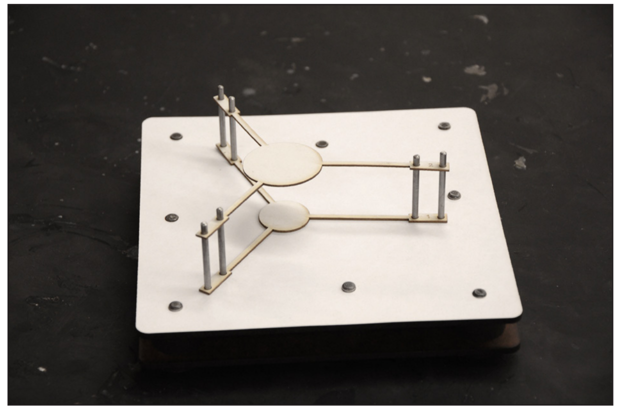
Registration pins fully protrude for easy removal from the bottom.

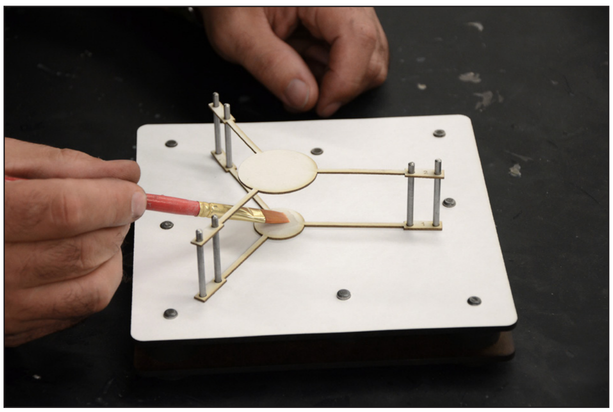
Another refinement concerned how to isolate the first few layers from the registration platform during gluing. We initially had some problems as the matt board tended to stick to the Masonite due to the liberal application of glue. To remedy this, we laser cut from paper the same hole-pattern as the dowel pins and registration pins. This paper was laid down and was changed periodically for the first few layers of assembly until the bottom layers were dry…

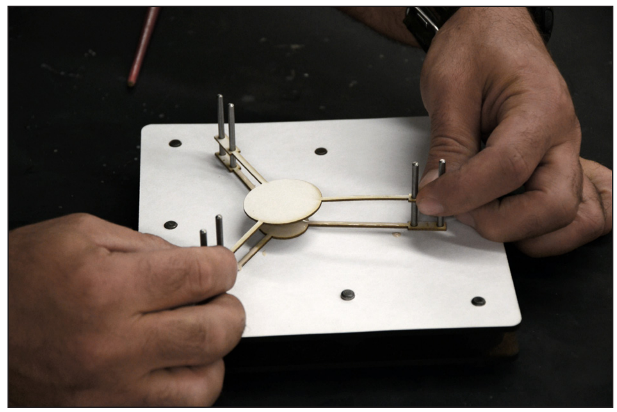


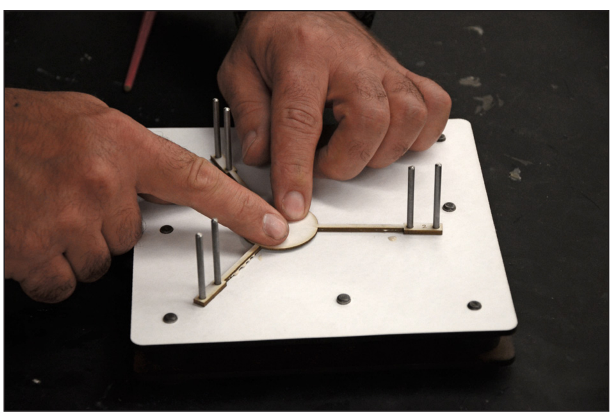
Below is the chronology involved in layering each section using the registration assembly…

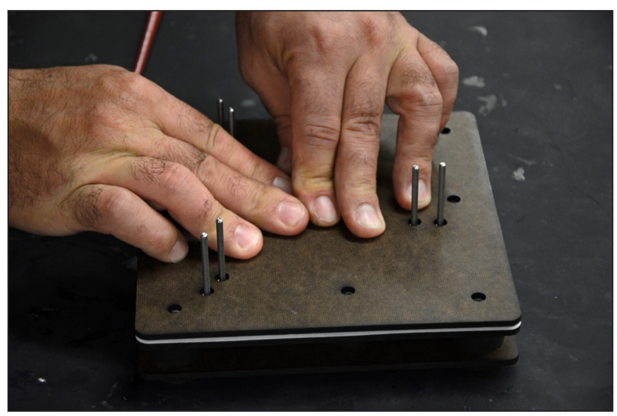

First section is registered


Second section is lined up

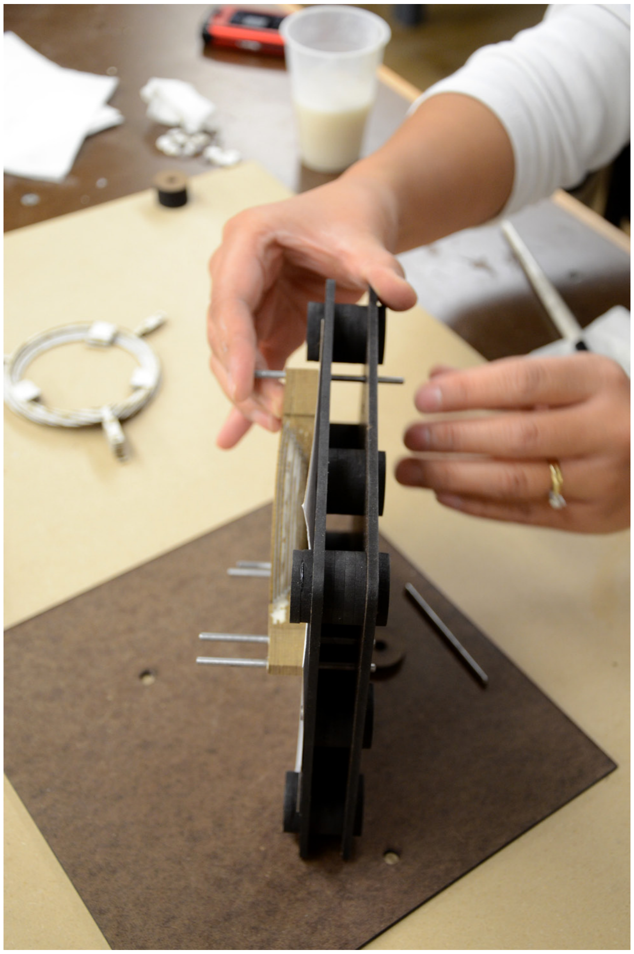

Glue is applied with a brush


Top section is lowered

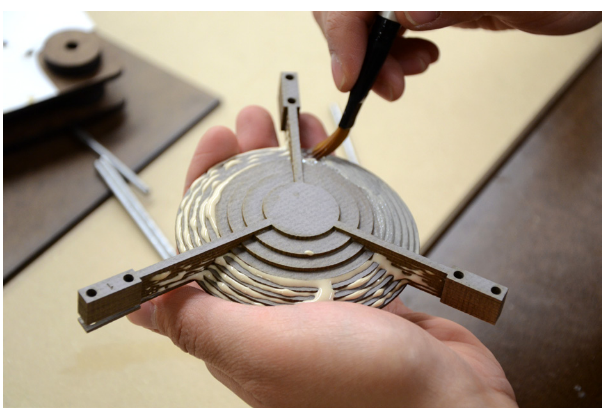

Pressure is applied lightly by hand


Equal pressure is applied using a "plunger". This plunger is an additional piece of Masonite with holes cut, allowing it to slide down through the registration pins.

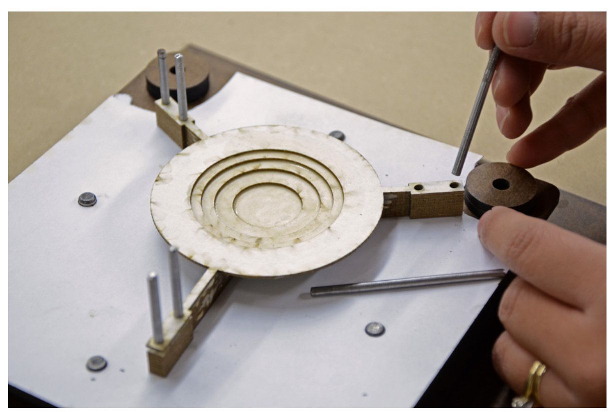
We removed the registration pins during the initial first few layers of assembly so that we could wipe off any excess glue and also to replace the resist paper so that it didn't stick to the bottom layers of the assembly.




The pins where pulled through the bottom of the registration assembly. This placed the registration tabs in compression, ensuring that the layers didn't separate while the glue was setting.



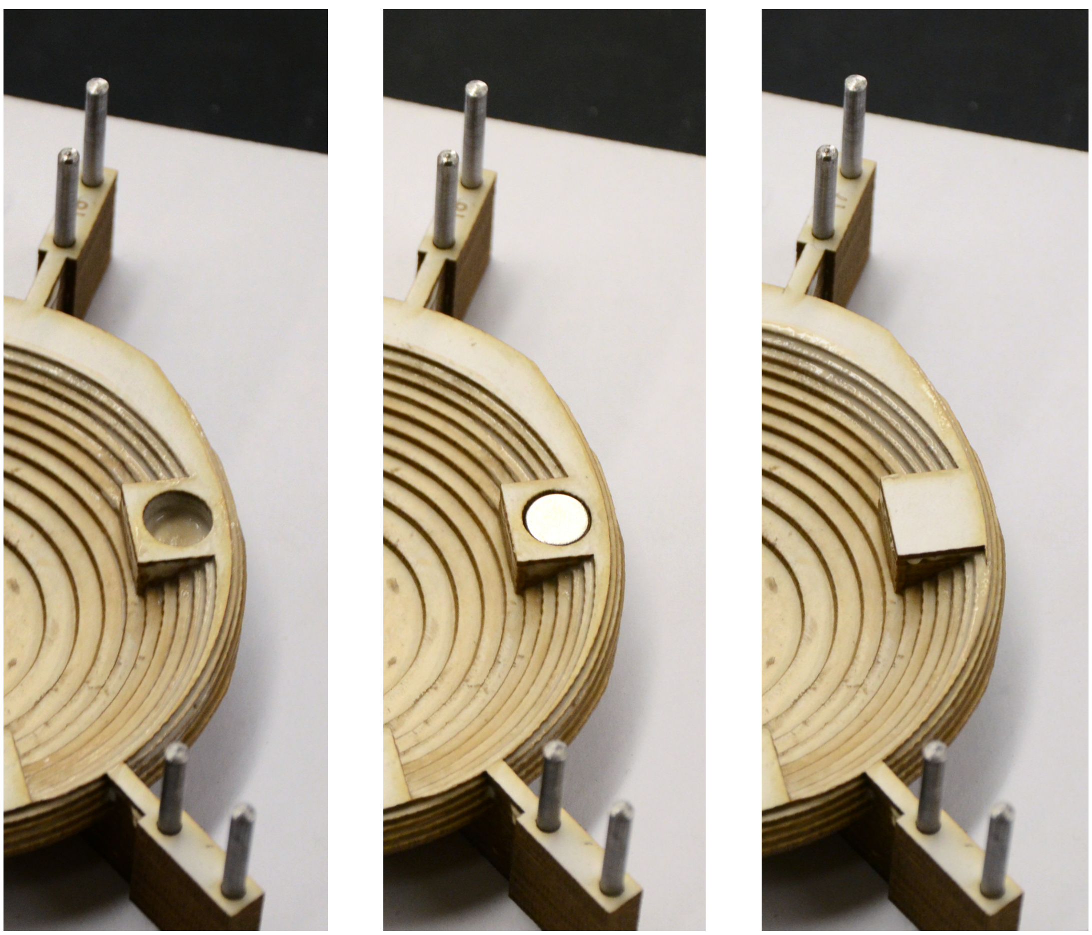
A brush was used to wipe off any excess glue.



To replace the pins, we inserted them from the top, again ensuring compression of the layers.

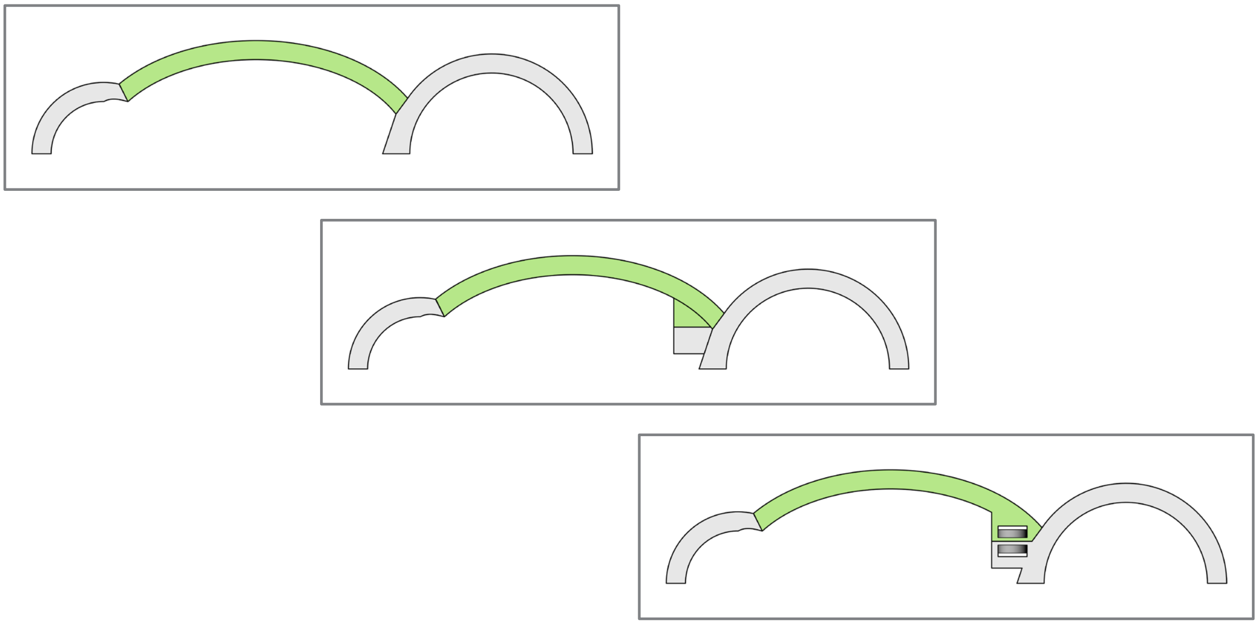
The lid was designed to snap top the body using magnets (of the rare earth variety, purchased at "Woodcraft"). For these, we provided three compartments on both the lid and body. These compartments became part of the virtual models and were sectioned along with everything else during laser cutting. The magnets were then embedded during the layering process when we reach the appropriate layers. When complete, the magnets were completely embedded and concealed within the structure.

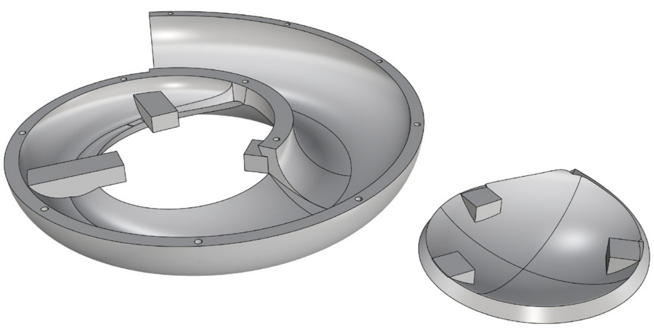
Due to the space requirements of the walkie-talkies, we were restricted to three magnet pockets (i.e. three in the lid; three in the body). If we had to redo this, I might consider adding a fourth set, or perhaps doubling up the magnets in each pocket to increase their strength. In the end, three worked fine, considering that the lid's edge sits slightly recessed in the body and isn't going anywhere unless it is willfully pried apart.

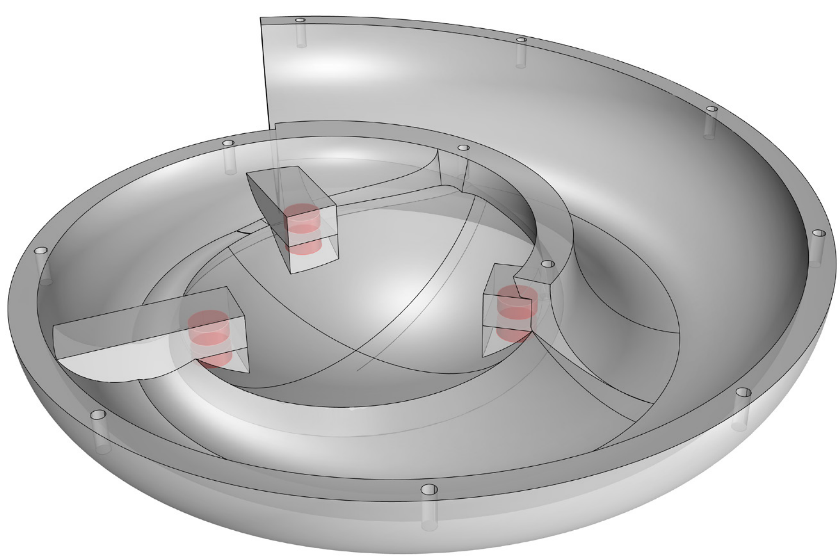


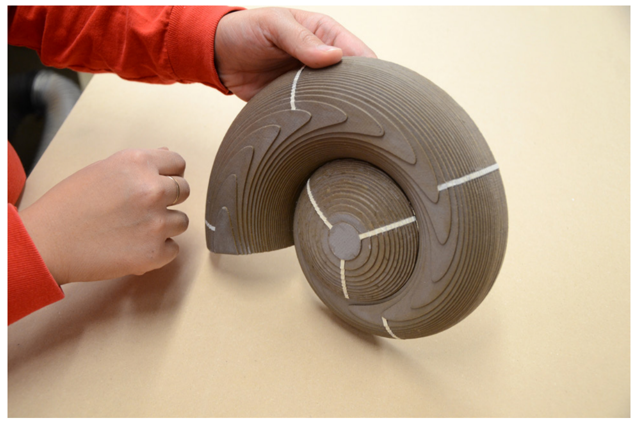
Embedding a magnet during the stacking of the layers.

The magnet compartments were modeled by adding enough volume to fully encompass the magnets. These volumes were then boolean unioned to the respective body and lid, as shown below...



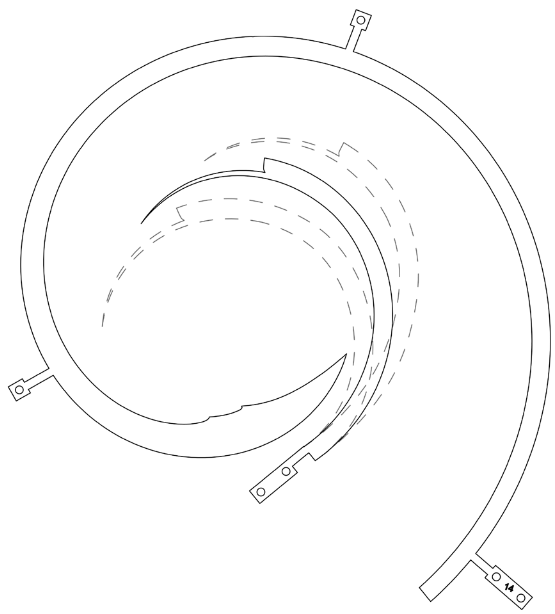




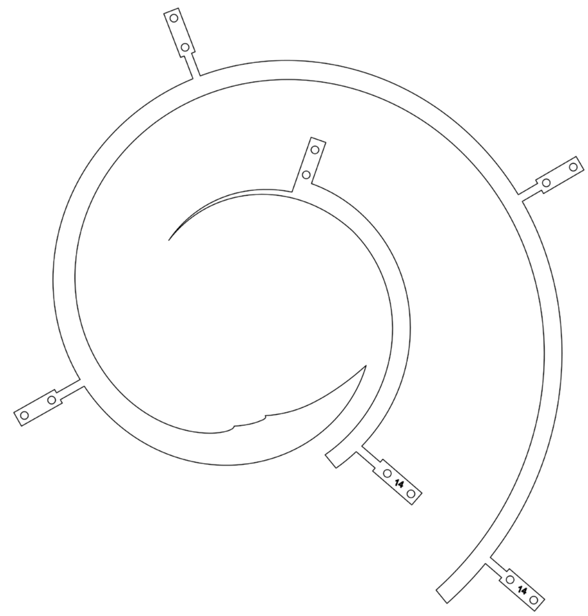


Front and rear views of the body/lid interface.
The rectangular elements house the magnets.

During the stacking process for the main body, we encountered an island area which resulted from the curved design of the body. In our first version, this island had not been specifically addressed. We noticed there was considerable flex in the Mat Board, making placement during gluing inexact. In re-designing the registration assembly for the main body, we added an additional registration tab to this inside area. We increased the number of pins for all tabs to two, further decreasing the chance for misalignment. We also increased the number of tabs on the outside of the form. These changes greatly improved stiffness and registration in the second version.

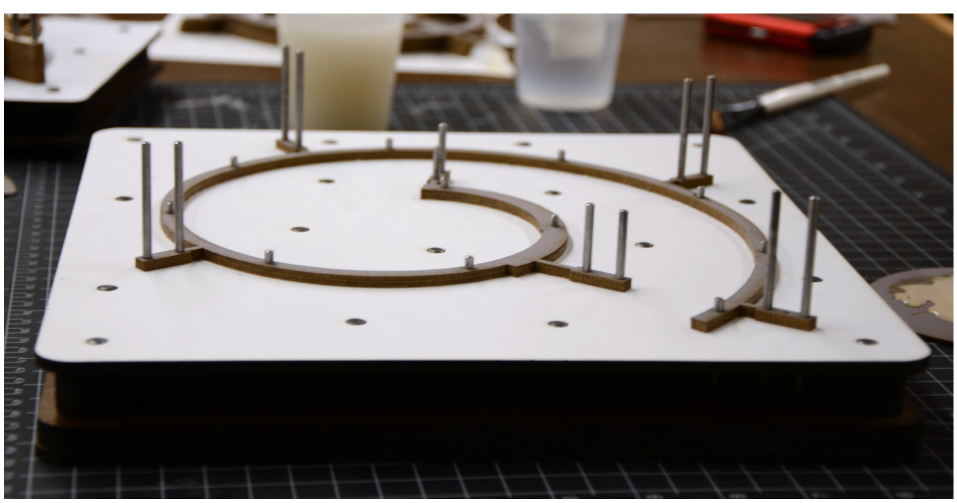


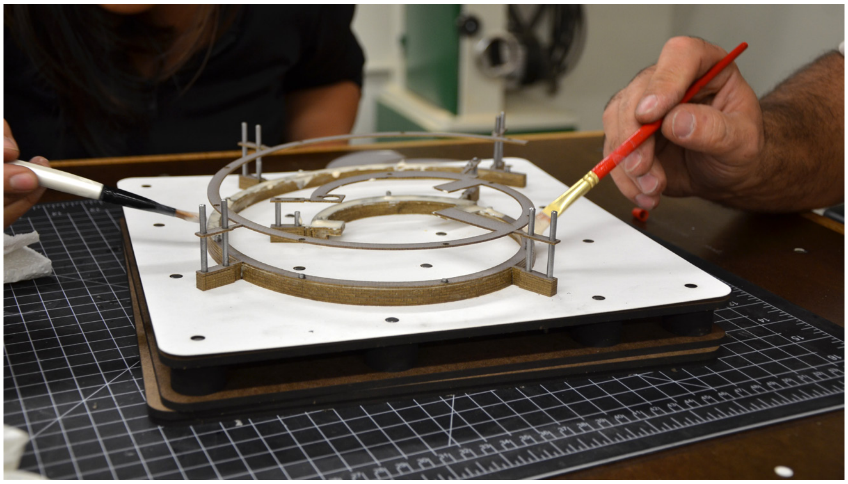
First version



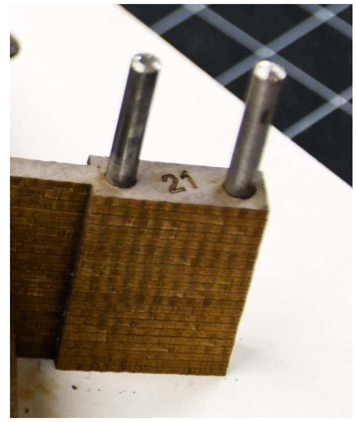
Second version

Also, we realized that the holes which would eventually be used to register the two completed halves of the body could also be used during the early stages of the layering process as additional registration holes. These can be seen as the short pins intersecting the Mat Board layers in the image below...

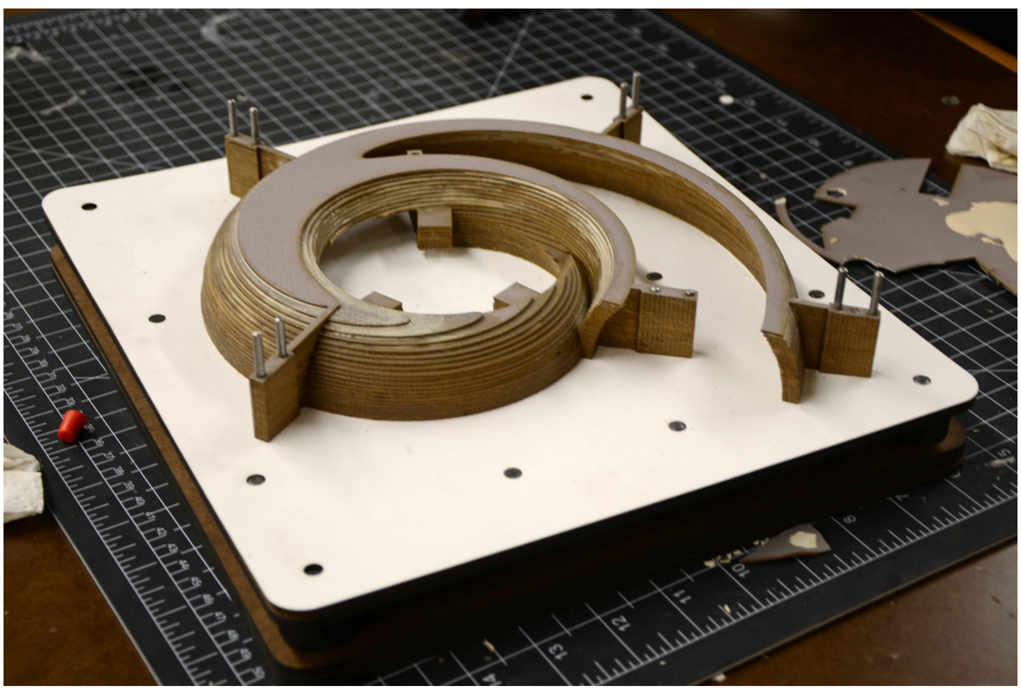




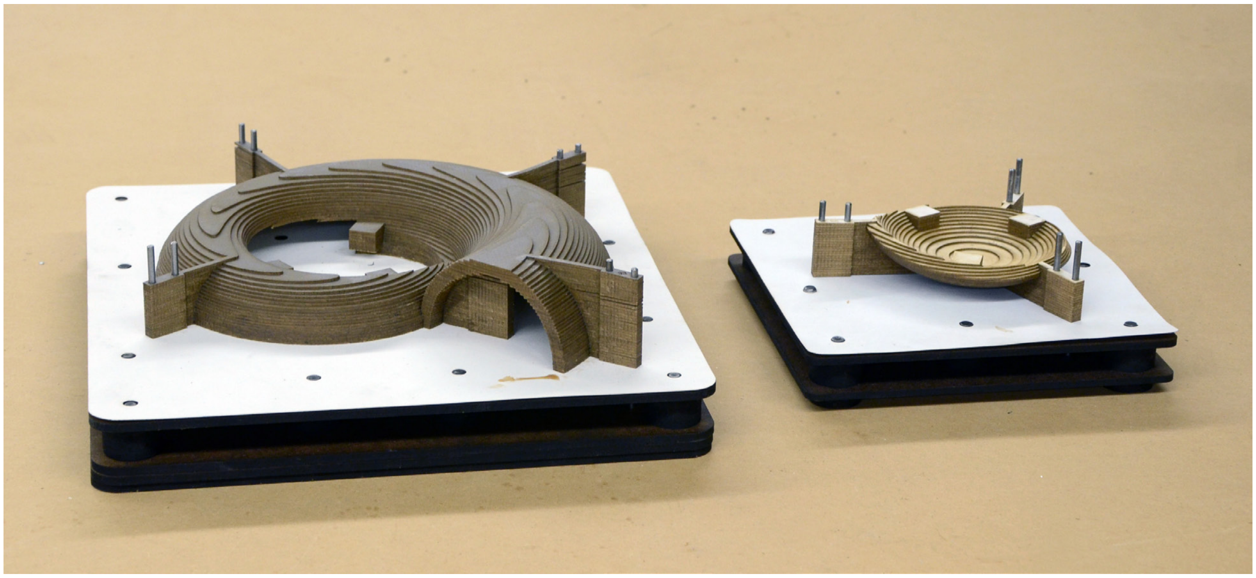
Applying glue to one of the body parts during the early stages. Working in tandem was the only way to ensure good glue application before the glue set.



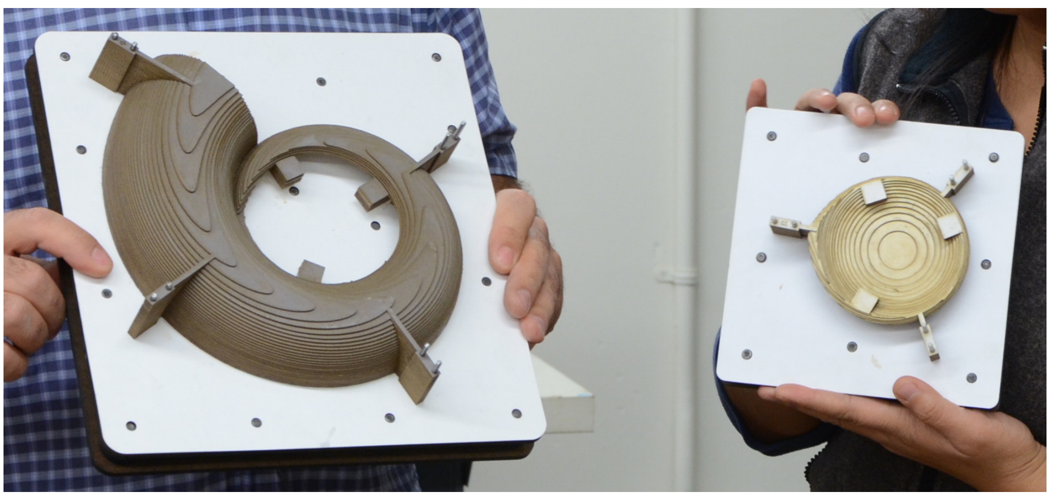
Detail of a registration tab with the current layer number visible.



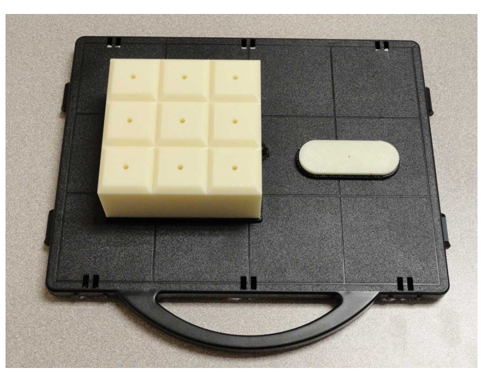
One of the two body parts nearing completion.

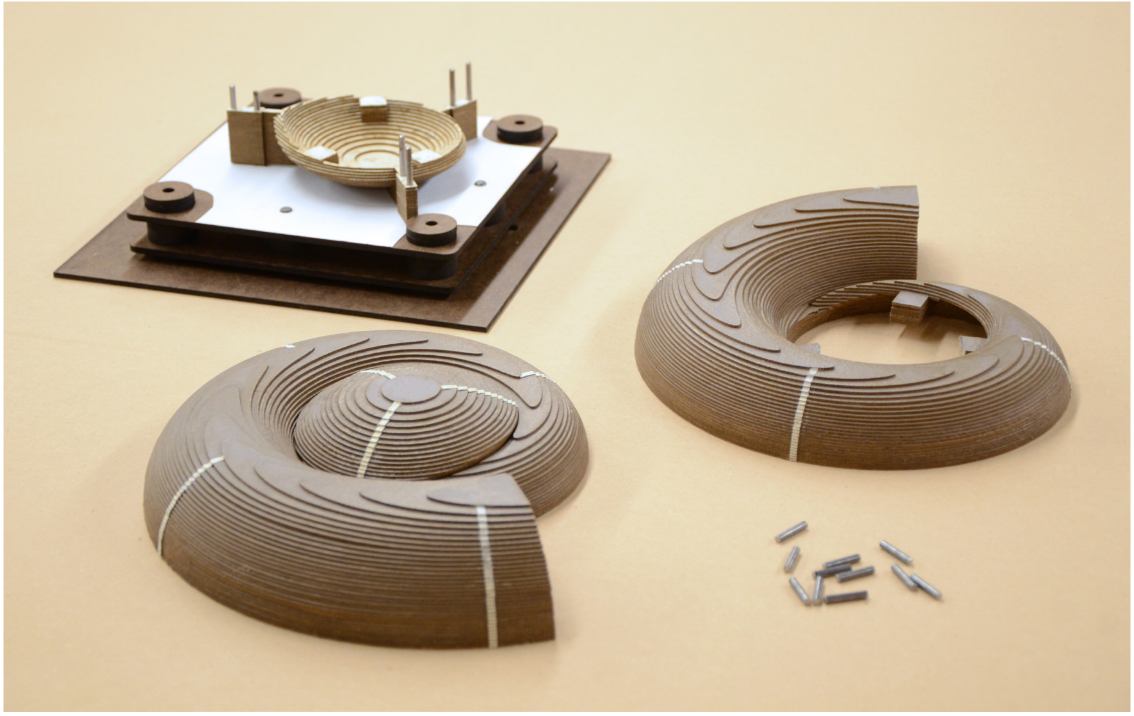


The body and lid completed and still attached to their build plates.



When we finished gluing the layers, we left the parts attached to the build plates so they could fully cure and dry evenly. I then realized how this resembles the build plates used for Stratasys' FDM system, shown below...

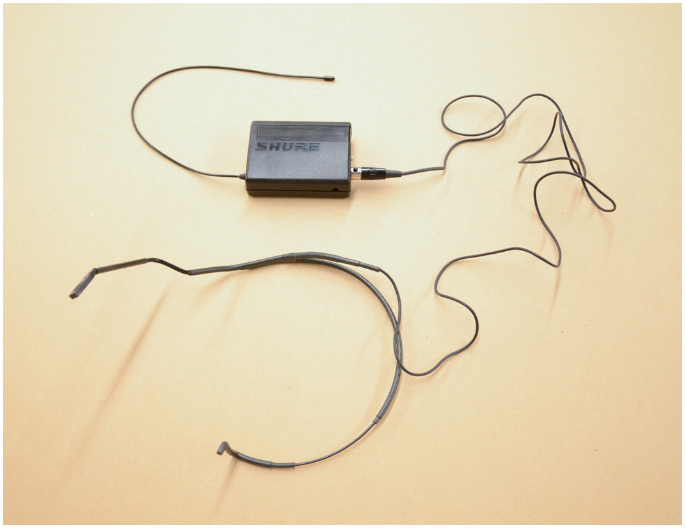




Two lids and two bodies along with guide pins, ready for assembly!

Assembly

After some initial testing, Lisa decided to forgo the original walkie-talkies in favor of a wireless microphone which provided better sound quality. Luckily, this unit fit into our design with just a slight modification to the magnet housings of the main body.

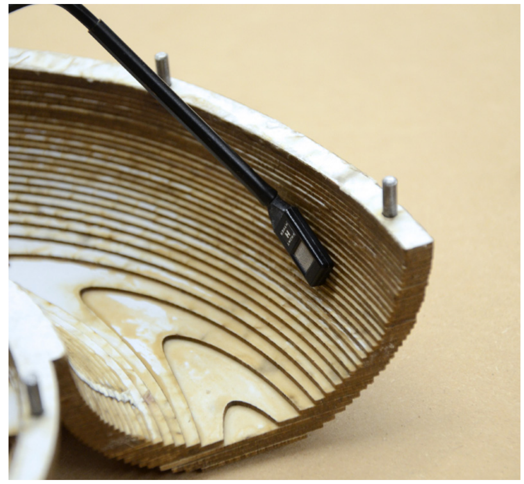


The final electronics used.

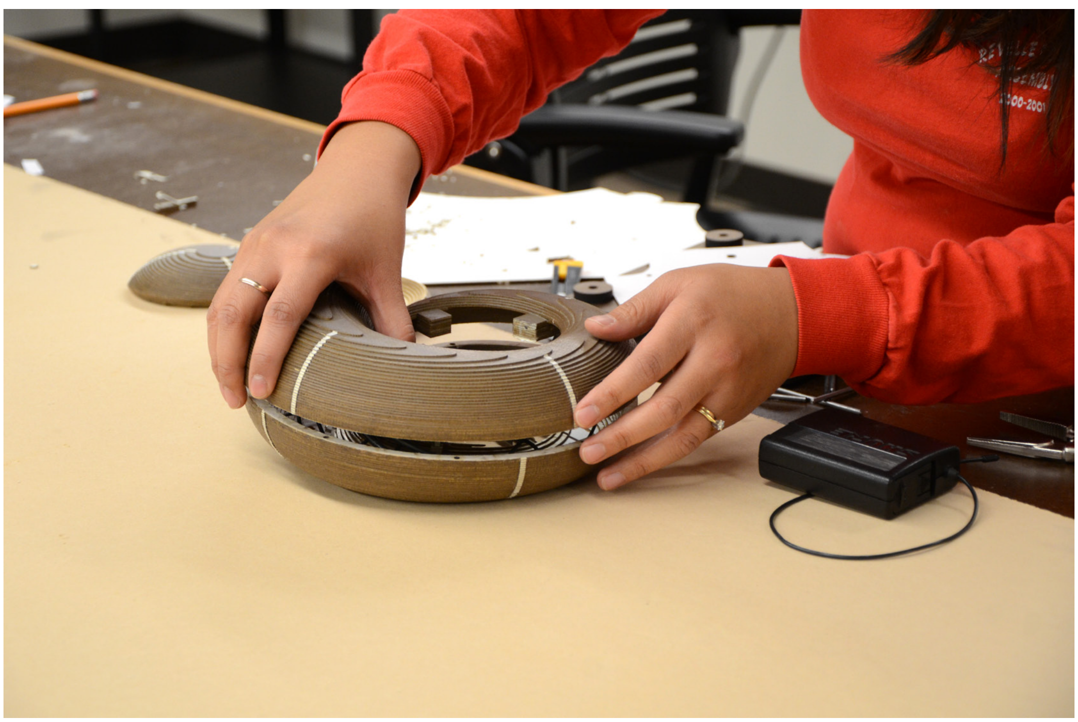
Final assembly was pretty straight forward. We started off by installing our guide pins...

Installing guide pins for the body.

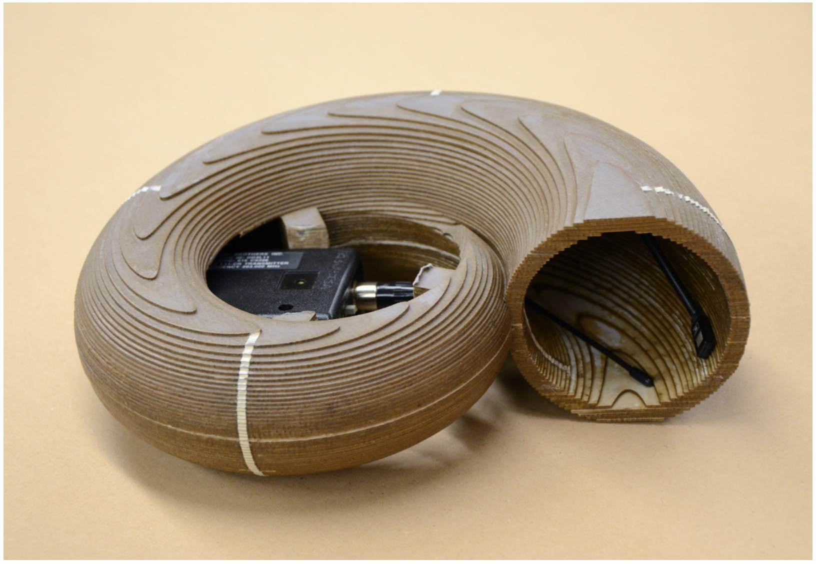
Next, the headset from the wireless system was positioned. This fit perfectly (almost as if it had been designed for this shape!).

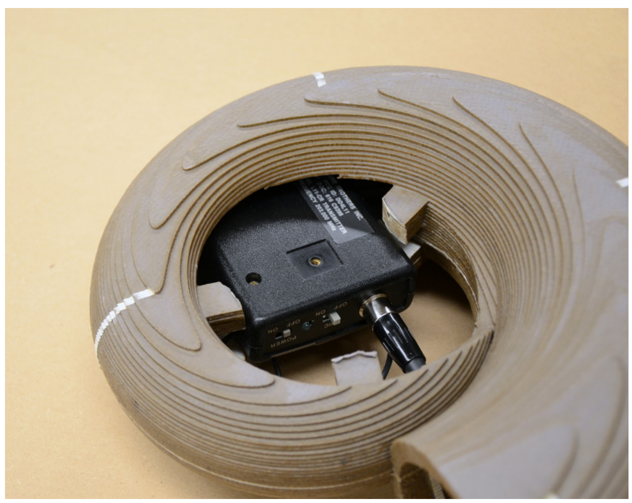



The two halves were then press-fit together



With the halves joined and the lids in place, the system was assembled and ready for use.








Thanks to the variable thickness of the body, the final object can accomodate a variety of hand sizes and position. Ergonomics, together with the tactile qualities of the stepped surfaces, result in an object that wants to be held!