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Final Design Report:
Compression Molded Composite Component

ME 430
COMP^3
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ABSTRACT

The following final design report outlines the design and fabrication of a carbon fiber compression molded sunglasses case. It intends to guide the development of a future lab activity for a composites undergraduate course at Cal Poly – San Luis Obispo. The activity aims to support an educational investigation in "out-of-autoclave" composites manufacturing methods, such as compression molding, which offer some key benefits over autoclave molding. The methodology behind the creation of a conceptual design, an initial prototype, and a final product is laid out in detail below.

1 – INTRODUCTION

Our selected project incorporates the field of composite compression manufacturing to develop a product and build the foundation for a future Cal Poly lab. Traditionally, the composites lab on Cal Poly's campus has manufactured components using an autoclave methodology, which generally produces 30-50% material stock waste and has lengthy cycle times. By compression molding composite components, production waste and cycle time per component can be reduced drastically, making this manufacturing method suitable for a lab curriculum. Professor Joseph Mello, of the Mechanical Engineering department here at Cal Poly, was our designated head engineer and project sponsor. Quatro Composites, out of Southern California, supported our project, however, they acted as a technical advisor and material supplier rather than an end customer or head sponsor. We worked closely with Dr. Mello and Quatro Composites to develop and test an optimaized manufacturing process for a carbon fiber sunglasses case in the Cal Poly College of Engineering composites lab that will go on to become a lab activity for future engineering students.

2 – BACKGROUND

2.1. Autoclave versus Compression Molding

Autoclave molding is still a common method of molding, especially in the aerospace industry where parts require a high strength-to-weight ratio. An autoclave, pictured in Figure 1, is a heated pressure vessel containing user controlled pressure and vacuum systems.

Figure 1. An industrial size autoclave used for creating composite parts [4]

To autoclave mold a part, a material lay-up is vacuum-bagged to a mold and then placed in an autoclave. The autoclave then heats and pressurizes the part at user-specified values for a specific amount of time. Once the set cycle time is complete the autoclave cools and

depressurizes; the cured part can then be safely removed. This entire process can take hours and, as stated above, produces a lot of waste. The compression molding method is similar to the autoclave method in that sheets of high strength fibers pre-impregnated with resin, also known as pre-preg, are shaped and cured using a mold however, compression molding has its notable differences.

The biggest notable difference between compression molding and use of an autoclave is the use of a heat press to compression mold.

Figure 2. Cal Poly heat press

Just like an autoclave, heat presses must be large enough to encompass the entire mold for the part, but they are much less costly to operate and have a lower cycle time given faster loading and process execution times. Prior to inserting a mold in a press, a compression molded component must have pre-impregnated sheets of fibers laid up in the negative half of a mold, the positive half must then be mated with the negative half, and then the entire mold itself compressed in the preheated press for a specific amount of time. The cycle time for a mold/component is based on the material used as well as the temperature and pressure supplied by the heat press. Once the desired time has been attained, the mold set can be removed from the heat press and the cured part can be withdrawn from the mold halves. The entire compression molding process usually takes less than an hour (in our case, less than 20 minutes), and yields a near net shape part with little waste.

2.2. Previous Compression Molding Findings and Accomplishments

Previous investigations into the composite compression molding science have been performed by various Cal Poly graduate students, and their results helped guide some of our project aspects. [6] Several factors that we wanted to explore while designing our sunglasses case included determining the appropriate fiber to resin ratio, optimal ply count, optimal mold pressure and temperature, and optimal cure time. We determined the thickness, or ply count, required for the sunglasses case based off our engineering design specifications, which are detailed further on in this report. Mold pressure, mold temperature, and component cure time, subsequently, were then determined by the material and ply count.

2.3. Aluminum Mold and Carbon Fiber Material Used

Quatro Composities provided us with an end mill, aluminum blocks and the carbon fiber material necessary to complete our project. The unidirectional fiber material contains 35% resin content, whereas, the bidirectional material contains 42% resin. After receiving molding tutorials from Ken Gamble, of Quatro Composites, we learned that the typical applied pressure used to mold standard compression components was 100 psi material pressure (around 1700 pounds on the press read out for our particular sunglasses case). The cure times varied depending on the temperature of the heat press. The general rule of thumb for cure times is as follows; starting at 250°F allow to cure for one-hour, for every 15°F increase over 250°F, the cure time for the component cuts in half. The cure time for our particular composite set-up was roughly 15-20 minutes.

2.4. Market Research on Existing Products

For research and brainstorming purposes we purchased several sunglasses cases online. A few of these cases came from Oakley and were advertised as being real carbon fiber cases, but upon inspection, we discovered that they were actually made of sheet metal with a carbon fiber print wrap on the outside. The only other carbon fiber case that we found was a soft-case made by RAGGEDedge, that fell short of many of our design requirements. We tested these cases alongside our finalized case to provide bench marks with which we compared our case against.

3 – DESIGN REQUIREMENTS AND SPECIFICATIONS

With the high specific strength and specific stiffness of carbon fiber, we were able to create a case that was both light and strong. These two characteristics don't always go hand-in-hand but for our situation made for an ideal case material. Current sunglasses cases made of fabric, alloys, or synthetic leather are not as durable or reliable (testing allowed us to explore this claim, which can be seen in our testing section later on). Many of these cases started deteriorating quickly (cracking, incomplete closure, etc.) if handled carelessly over time. This forces the consumer to purchase new cases frequently or several initially. Using carbon fiber as a case material gave us flexibility in both designing

and molding, which allowed us to produce a superior sunglasses case that, on average, met our specifications better than the other sample cases.

Additionally, as a high-end carbon fiber case, we can expect people to use it for high-end expensive glasses. We noticed that in existing cases, the standard metal hinge system of closure can bend easily, and while the case still works, the top and bottom halves no longer line up as well as they originally did. With our selected nonconventional design, we did not use a standard hinge rather, we used a Jacob's ladder strap approach, which is described further on.

Listed below, in Table 1, are design requirements and specifications that our team deemed of the utmost importance to a successful sunglasses case. We evaluated the performance of our sunglasses case, compared to other cases, by its ability to meet these requirements.

Table 1. Critical design requirements and specifications

Spec. #	Description	Target/Requirement	Tolerance	Risk	Compliance
1	Fit Size	75% of Glasses	Minimum	High	Inspection
2	Crush Test	250 lbf	Minimum	Medium	Testing
3	Drop Test	10 ft height	Minimum	Medium	Testing
4	Aesthetics	Carbon Weave	-	Low	Inspection
5	Shut Force	2 lbf	±0.5 lbf	Medium	Testing
6	Manufacturability	1 hr Production Time	Maximum	Medium	Trials

4 – CONCEPT DEVELOPMENT

4.1 Top Concepts

The majority of our brainstorming activities and design discussions were based around trying to find a new, unique style of opening and closing the case. We felt that aesthetics heavily dictated the shape of the case, as we wanted to have a very desirable case. When compression molding, draft angles must be considered in the design to be able to successfully remove the part from the negative half of the mold. As for the size of the case, it was specified that it should comfortably fit 75% of all sunglasses on the market in as compact of a design as possible. With these considerations and restrictions, we were not left with much room for case shape innovation. However, we still brainstormed ample designs that we would have liked to look into further, some of these we ruled out based on the difficulty of the machining necessary for the mold production while others based on poor incompatibility with the compression molding process. The following concepts are some of the sunglasses case designs we focused initial efforts on while the rest of our top concept sketches are attached in Appendix A.

4.1.1. Box with a Removable Lid

One of our first concepts was a rather simple design. It consisted of a basic box with a removable lid, presented in Figure 3. For the closing mechanism, either magnets, latches, key ways, or slots could have held the top and bottom parts together. This design would require two unique molds, where one would have a deeper cavity for the larger bottom portion of the case and the other a shallower cavity for the case lid. The lack of draft angles would have made this concept difficult to almost impossible for compression molding. Additionally, the appearance did not look as classy or stylish as we desired seeing that this design is very plain and bulky.

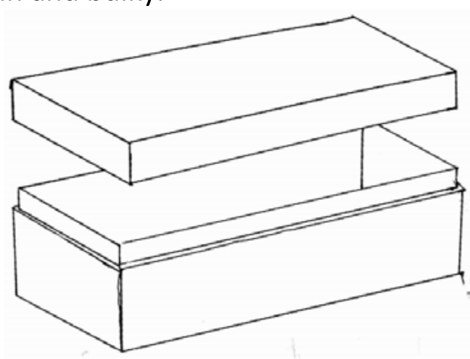

Figure 3. Box with removable lid

4.1.2. Cylinder with a Twisted Cap

Another design we explored was a cylindrical case with a twisted cap, demonstrated in Figure 4. Similar to the box and lid concept, this idea would have required two completely different molds. Having no draft angles and a deep cavity made this concept a poor fit for compression molding. The threaded portion also posed a problem. Even if we were able to successfully machine a mold for each half needed, actually molding this case would present an entirely new challenge, laying up the carbon. Laying up and fully flushing the carbon fiber around the mold would have been very difficult with this design. Aside from that, the heat transfer from the top and bottom plates of the heat press into a mold as tall as this one had potential to be could have presented further challenges.

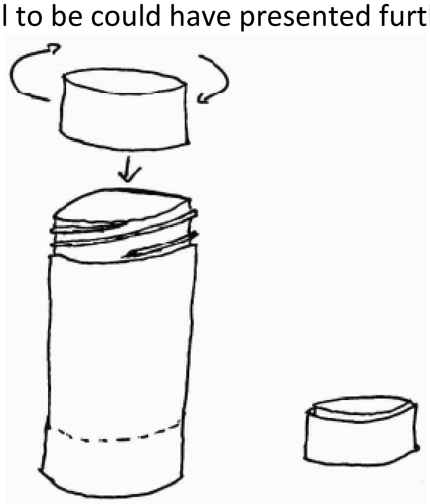

Figure 4. Cylindrical case with a twist on cap

4.1.3. Rounded Corner Box with a Hinge

Another concept we came up with was a diamond shaped case with rounded ends and corners; Figure 5. Keeping the feasibility of easily machining a mold in mind, we included 45° draft angles. This concept would have required only one unique mold since it has a common top and bottom structure. As for the closing mechanism, we envisioned utilizing a metal hinge with magnets to keep the case shut. This case looked slightly bulkier than what we wanted our final design to be and was not therefore used. However, it provided valuable insight into common mold halves and draft angles that we utilized later on.

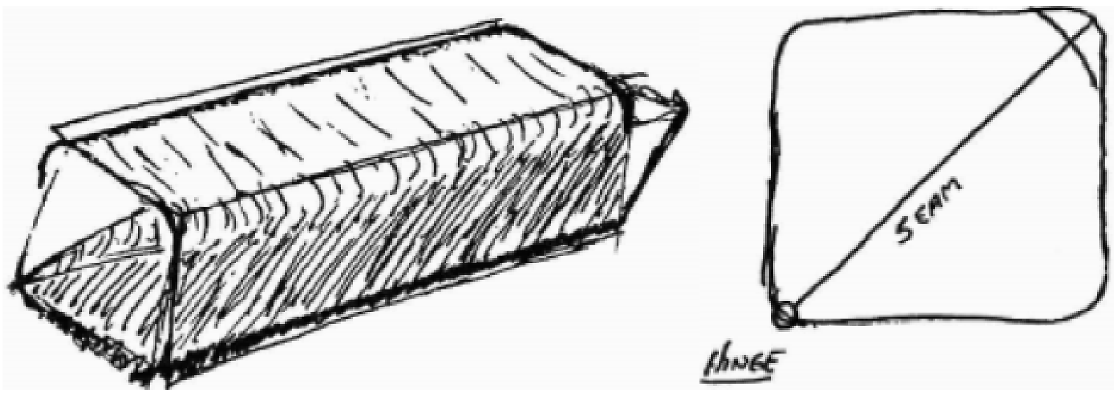

Figure 5. Box design with a hinge and magnet complex

Appendix A includes the rest of our sunglasses case designs. We selected the best qualities from multiple different brainstormed case designs as well as some qualities from cases already on the market to come up with our final design.

4.2. Problems and Solutions in Compression Molding Composites

Research was done into what potential problems may arise when compression molding. A lot of these potential problems come from miscalculations on what parameters to set the heat press systems to. The following are some of the more common problems that might occur during compression molding with solutions presented describing what can be done to prevent these problems if they arise.

4.2.1. Cracks

Cracks within the molded part can happen for various reasons. If there are hold downs and undercuts in the mold, polish or smooth down those features to help avoid this problem. Make sure to allow for sufficient cure times and have the correct mold temperature set, ensure correct/sufficient draft angles are present, and ensure the opening speed of the heat press isn't too rapid; aim for a slower initial opening speed. [2]

4.2.2. Non-fill

Non-fill occurs when the molded part has a severe void, which usually occurs when not enough material is used in the lay-up of the mold. Non-fill can also occur if the heat press is closed to fast or if the mold is too hot. To void non-fill, ensure material lay-up fully covers the mold, be aware of closure speed of the press and monitor the temperature of the mold allowing it ample time to cool between cycle runs. Another factor to be aware of to avoid non-fill is to make sure the release agent used has fully dried before laying up a mold; make sure to fully wipe down the mold and allow plenty of time for it to air out. [2]

4.2.3. Pre-gel

Pre-gel is when a molded part has areas of rough, dull porosity often making it look like it has scales. The most common cause of this problem is having a mold that is too hot. Allow sufficient time for the mold to cool before continuing to use it for production. Make sure that the close speed of the press is not too slow either. For this project it is unlikely pre-gel will be an issue because we will only be using pre-impregnated carbon fiber layers. [2]

4.2.4. Internal Porosity or Delamination

Internal porosity shows up as small voids or delamination's within the molded part. This is caused when air or volatiles get stuck in the component when the press is closed down too quickly. Make sure to slowly compress the mold allowing adequate time for air to escape. Additionally, it is always a good idea to allow time for the mold to cool and air out especially after applying any release agents. [2]

4.2.5. Pinched Fibers

Pinched fibers appear as raised delaminated layers in a component. This happens when fibers become pinched between the mold halves. It may also occur when there are too many plies laid up in a mold. To prevent this problem, replace pre-preg material if it's too dry and ensure that too much material is not being used for a part. [2]

4.2.6. Blisters

Similar to internal porosity, blisters occur when there is air trapped right below the surface of the molded part. Make sure to slowly compress the mold in the press allowing the mold time to vent any excess air trapped. If slowing the compression rate of the mold doesn't fix the problem the temperature of the press may need to be reduced. [2]

Most of the problems listed above can be fixed using the solutions described. If none of these solutions resolve defects encountered while compression molding an outside resource will need to be utilized.

4.3. Concept Selection Process

We went through a series of ideation and conceptualization phases before selecting our final concept design. We considered many different design parameters including the geometry of the case, potential aesthetics of the case, ease of opening and closing the case, as well as the potential for the design to meet and/or exceed our requirements. We also acquired and analyzed a sample population of sunglasses cases on the market to see what we liked and didn't like about potential design ideas. Overall, we based our concept selection on feasibility of manufacturing, aesthetics, and the potential to fulfill our requirements.

4.3.1. Closing Mechanism

Something that we found to be crucial in whatever design we came up with was the closing mechanism. We wanted our case to close securely, open easily, and be more durable than the typical metal hinge approach used in most cases. We wanted to avoid the metal hinge method because it often becomes the weak point of the case design as it can lead to incomplete closure after some use and abuse. We did contemplate whether or not we should incorporate a carbon fiber hinge thereby making the entire exterior of our case composed exclusively of carbon fiber.

We also debated a hinge-less approach. This approach was appealing because the process of attaching a hinge using rivets or fasteners could alter the shape and symmetry of the case after molding. At first, it seemed that the only ways to attach two halves together without a hinge was to use a box and lid method or a twisted cap method. Further exploration of these ideas led us to a "Jacob's ladder" method. This is a method of interlacing at least three different ribbons between the two halves yielding a way of connecting the cases that is fun and unique.

By going for a hinge-less or "Jacob's ladder" approach, we shortened the manufacturing time, eliminate additional tools and materials necessary to add a hinge (hand drill, rivet gun, rivets, etc.), and avoided possible deformations of our sunglasses case. Instead, we used straps and strong adhesives to attach the halves together and magnets to keep the halves closed.

4.3.2. Case Shape

For the shape of our sunglasses case, we took into account different sunglasses sizes making sure 75% of them would fit comfortably in the case as per our requirement; the analysis for what constitutes 75% is detailed further on in section 5.2.5. The feasibility of manufacturing also dictated our shape significantly when we considered the relatively small hydraulic press we had at our disposal. We realized that some design shapes had downfalls including but not limited to: round or cylindrical cases rolling off of flat surfaces, square cases being larger and bulkier than necessary, etc. We also realized the shape and size of our case played an important role in appealing to our consumers.

4.3.3. Webbing and Fabric Lining

The choice of webbing and lining remained just as important as the shape of our design. Since aesthetics heavily dictated whether or not our customers would purchase our case, we had to choose webbing that not only was durable, but also webbing that complimented the carbon fiber texture of our case exterior. We debated between using nylon, polyester, leather, or rubber for the straps. After some market research on different materials, checking out different fabric marts, and reaching out to suggested contacts for suggestions regarding quality of fabric and recommended material we obtained some material from Wolf Pack Gear here in SLO. They ended up providing us with several promising webbing options. Some of the strap options, including nylon and polyester, can be seen in Figure 6.

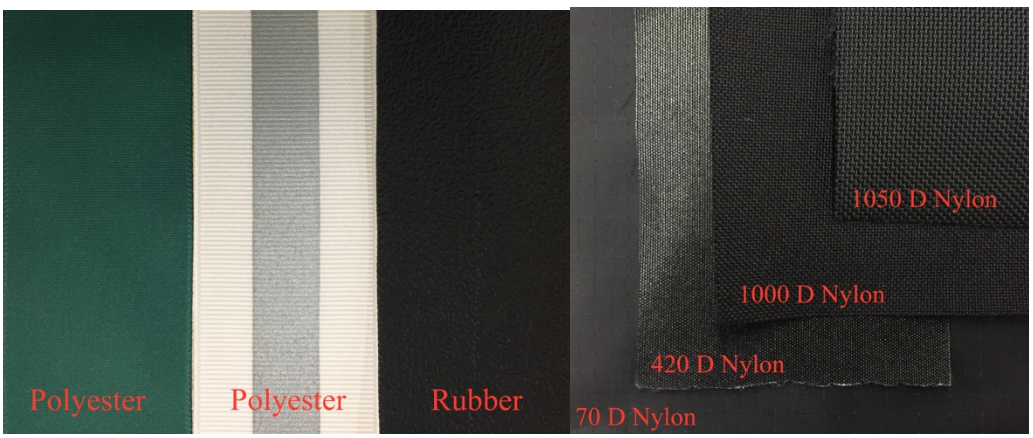

Figure 6. Webbing

We ruled out the following materials initially: polyester because it looked very cheap and tacky, leather because the thickness of the ribbon would not allow us to fully close the case, and rubber because it stuck to other surfaces and caused unwanted shear stress. In the end we decided on the 420 D Nylon material for our case. It had a nice sleek look that complimented the carbon fiber weave look well; additionally, it was found to be durable, and it had a slim profile making it almost mesh into the surface of the case.

For the fabric lining, we wanted a material that would protect the sunglasses and other contents within the case from scratches and damage during case use. We debated between neoprene, foam, and fleece for lining material. A fleece sample, provided by Wolf Pack Gear, led us to choose fleece as our lining material. The softness of the fleece fabric protected glasses perfectly while still remaining easy to form and glue to the inside of our case.

4.3.4. Adhesives

High performance, easy application, and fast cure times were the big factors looked at when selecting the adhesive we wanted to use for gluing our lining, straps, and magnets

in place. We opted out of getting adhesives at home improvement stores as they would struggle to bond any material onto carbon fiber. We found some quality and, relatively cheap, adhesives on Smooth-On. A few different types of adhesive were obtained from them, including epoxy MT-13, Metalset A4, and Sil-Poxy, to test on our initial cases. We considered Loctite products however, this adhesive brand runs on the more expensive side of the market and therefor decided to proceed forward with Smooth-On.

4.4. How Concept Satisfies Specifications

Our final concept meets our engineering specifications and customer requirements specified earlier and presented professionally in our QFD attached in Appendix B. Our Pugh matrix, Appendix C, was used to compare the top design ideas we came up with by employing a rating system. When rating our designs, we deemed aesthetics, cost, manufacturability, ease of use, and sufficient space within the case as crucial factors. This system demonstrated how our ribbon attachment idea was the most ideal design compared to the other designs we came up with. With the "Jacob's ladder" concept, our design will look trendy and sleek without requiring too much post processing on our case. The classic hinge method came in second in our rating system, however, the post processing for this method of attachment is much more difficult than our ribbon method. If this is to become a lab at Cal Poly, our design will be easy and cheap to produce and assemble when compared to designs that have different top and bottom halves, and more complicated hinge attachment methods.

5 – FINAL CONECPT DESCRIPTION

5.1. Detailed Concept Description

For our final design, we decided to go with symmetrical halves. Access to a 3D printer as well as having relatively small parts gave us the advantage of being able to easily print and analyze the shape of our case and our hinge less concept.

5.1.1. Final Design – Rectangular Shape

Our first design iteration had a rectangular shape with symmetrical halves, which can be seen in Figure 7. Detailed dimensions can be seen in Appendix D.

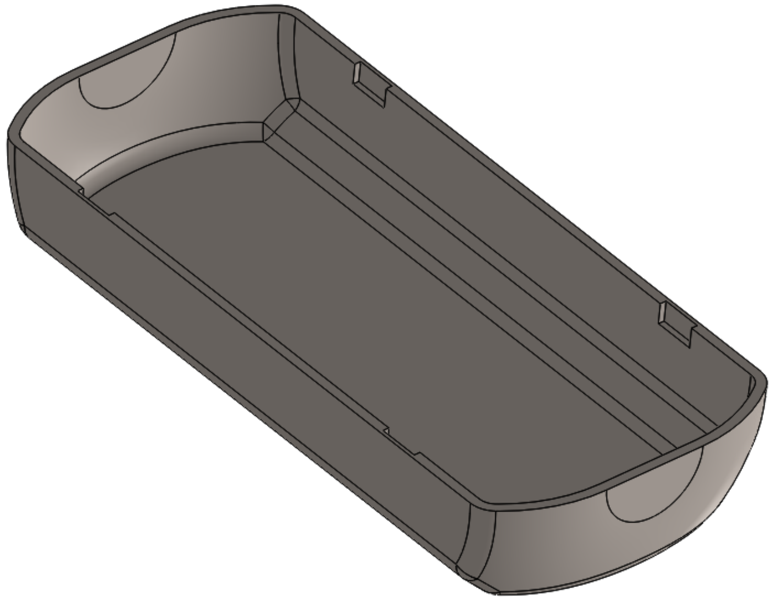

Figure 7. Final Design – Rectangular Shape

Each half had a flat bottom as well as flat edges that mated with the opposite half. The flats ensured that we had a case that would not roll off of surfaces when set down. Magnets located on the interior walls, not visible from the exterior, ensured the case would have stayed closed. The rectangular shape with rounded edges yielded a model that was sleek and appealing to customers. The case exterior would have been a carbon fiber weave with a gloss finish. Figure 8 shows the 3D printed and assembled product of this design iteration.

Figure 8. First 3D-printed design with polyester ribbon

We determined that the dimensions were slightly too big for the look we were going for. The rectangular shape also made the case look very bulky and unpleasant.

5.1.2. Final Design – Hex Shape

We modified our initial design iteration slightly to cut out the excess space and make it look more stylish. Similar to our first design, there were four cylindrical magnets located on the interior corners on each half. This design is presented in Figure 9. Full dimensions for this case design are shown in Appendix E.

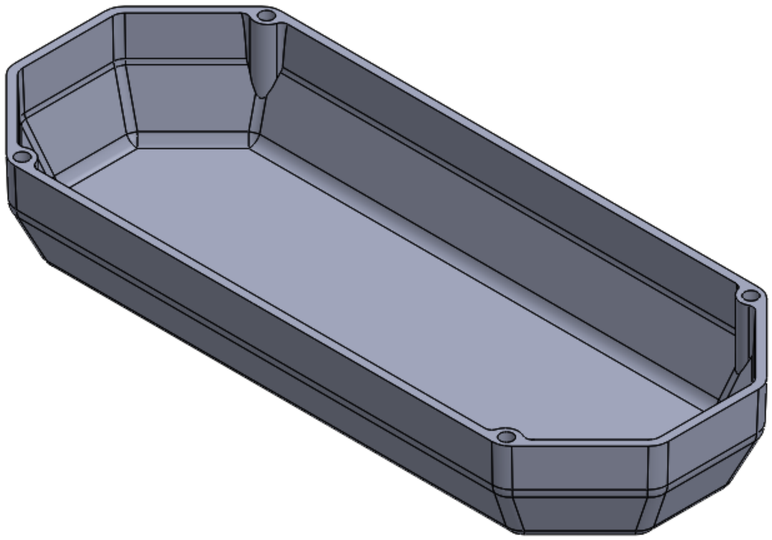

Figure 9. Final Design - Hex Shape

After 3D printing this design, the size of this design turned out to be smaller than expected. The surface of the flat bottom was too small and the draft angles cut out too much space from the case. Thus, lessening the draft angle and changing the vertical height on the edges helped encompass a broader range of sunglasses sizes. A picture of the second 3D printed design iteration with the 420 D Nylon straps used instead of colored ribbon is shown in Figure 10.

Figure 10. Second 3D-printed design with Nylon straps

As seen above, the 'Jacobs ladder' style attachment, allowed for easy assembly as well as an interactive case; no holes for hinge attachment, or a jig for hinge alignment were needed using this method. One simply had lay the halves next to each other and precisely glue the alternating ribbon pattern in place. The interior fleece lining covers the ends of the straps. Eight magnets are glued in the eight locating holes within the corners inside

the case. Epoxy adhesives bond the interior lining, magnets, and straps to the carbon fiber case. Also, when considering this layout and design, it provided a fun interactive case for users on top of satisfying all other specifications previously stated.

5.2. Analysis

The sections following describe the analysis performed regarding our case and the situations we thought it would encounter during its life time that would be critical for one reason or another. Sample calculations for 5.2.1.-5.2.3. can be seen in Appendix F.

5.2.1. Crush Analysis

One situation our case may be exposed to is a crush scenario: someone sitting on their case, stepping on their case, dropping a back pack on their case, etc. It was decided to model this scenario as an equal pressure distribution scenario with a maximum external load of 250 lbf. An external surface area estimate of 49 in^2 per half (obtained from the solid works model of our final design which can be seen in Figure 9) would yield a radial external crush pressure of 5 psi.

5.2.2. Drop Analysis

Another scenario our case might be exposed to is a sudden drop from a given elevation: falling off a table, dropping from hand by mistake, being pushed off of a counter, etc. When modeling this scenario, it was decided to use a maximum fall height of ten feet. Assuming our case is initially at rest before it begins to fall, it will have an estimated impact time lasting 0.1 second before it imparts some of its momentum to the surface of contact and bounces away. The resulting contact force from this fall would be roughly 8 lbf (this is not including the weight of the contents contained inside the case). This force will be a localized pressure on the case with the location depending on the area of contact; it is not a vastly distributed force like with the crush test scenario and therefore has the potential to be more detrimental if it is applied specifically at an area of weakness. When designing for this scenario testing will be our biggest indicator as to whether or not the correct number of layers was used or not; the parameters surrounding testing drops will be discussed further on.

5.2.3. Close Force Analysis

When considering closing/staying closed it was decided our case should have a shut force of 2.5 lbf. Our final design uses four magnets per half with magnets located in the corners of each half. This set up yields a total of eight magnets per case. This would mean to achieve a closing force of 2.5 lbf each magnet would need to be rated to a pull force of at least 0.625 lbf. Our design uses cylindrical magnets that are polarized along their axial direction and are described in more detail further on.

5.2.4. Mold Heat Transfer Analysis

When designing our case, a concern arose surround the mold and press size compatibilities. To further elaborate; the surface area of the press plates are 6 inches by 6 inches. The mold that will be used will have base dimensions of 4 inches by 8 inches (with a 2-inch depth). What is of note here is that the 4 by 8 mold block will over hang the 6 by 6 press plates. This will result in a loss of direct heater contact with our mold for an inch on either side of the press plates. To ensure that the loss of heat from our mold to the environment would not result in significant temperature differences across the mold, and in turn our composite, a thermal finite nodal analysis was performed on our mold block.

Setting up this scenario had several key steps. First, assumptions were made including; 1) the system is at steady state 2) the block is uniform in regards to temperature through the width 3) the loss of heat to the environment was due to free convection with a less than standard room temperature present (50°F) 4) the mold block was symmetric about a vertical center axis and horizontal center axis (which meant ¼ of the mold could be analyzed and then applied to the whole mold. The second step was determining key factors such as the conductivity coefficient of aluminum as well as the convection coefficient for free convection from a solid to a gas. For the first parameter engineering tool box was used; k = 98 BTU/(hr °F ft).[5] For the second parameter a heat transfer analysis book was referred to; h = 4.403 BTU/(hr °F ft^2) [1]. The final step was to create a nodal representation of the mold in excel which can be seen below in Figure 11.

	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	
0.00	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	284.1	283.5	283.2	282.9	0.00
0.25	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	284.9	284.9	284.8	284.7	284.5	284.1	283.7	283.3	283.1	0.25
0.50	285.0	285.0	285.0	285.0	285.0	285.0	284.9	284.9	284.9	284.8	284.7	284.6	284.4	284.0	283.7	283.4	283.2	0.50
0.75	285.0	285.0	285.0	285.0	285.0	284.9	284.9	284.9	284.8	284.8	284.7	284.5	284.3	284.0	283.7	283.5	283.2	0.75
1.00	285.0	285.0	285.0	285.0	285.0	284.9	284.9	284.9	284.8	284.7	284.6	284.5	284.3	284.0	283.7	283.5	283.2	1.00
	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	

Tinf	50	
k	98	
h	4.403	0.881
dx	0.020833	
h*dx/k	0.000936	

Figure 11. Heat transfer analysis

Based on the result of the two dimensional analysis above it was decided that the heat loss from the mold to the environment was not significant enough to warrant any further, more complex analysis. The largest loss being at the corners with a drop of only 2.1 °F.

5.2.5. Market Statistics Analysis

A specification from Table 1 above indicated that it was desired to have 75% of all sunglasses able to fit in our final case. To establish what 75% meant in terms of dimensions some market analysis was required.

Based on a sample data set obtained by measuring an assortment of forty random glasses from various locations two things were able to be concluded. First the data was used to determine whether the population of sunglasses as a whole seems to follow a normal distribution and from there, dimensions were picked which would allow our designed case to fit 75% of all glasses and therefore comply with our specification.

The following figures, Figure 12 and 13, were used to determine whether or not the obtained sample data followed a normal distribution. As can be seen by the scatter plot of all three critical dimensions the spread of each is very reasonable around a plotted average. This is an indicator that 1) our sample population followed a normal distribution and 2) there are not a significant amount of outliers in the sunglasses world.

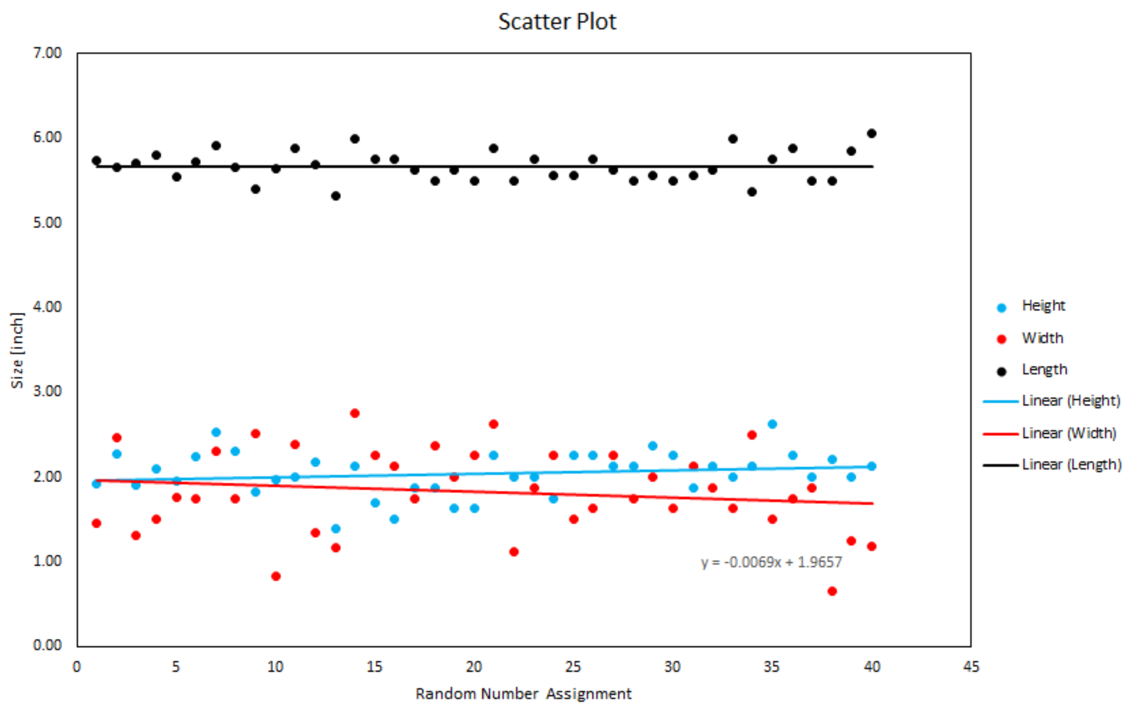

Figure 12. Scatter plots of sample populations key measurements

The following normal distribution, Figure 13, simply helps to further indicate that a normal distribution assumption is valid as can be seen by the linearity of the data sets with no major deviations from a linear trend on either extreme of the sets.

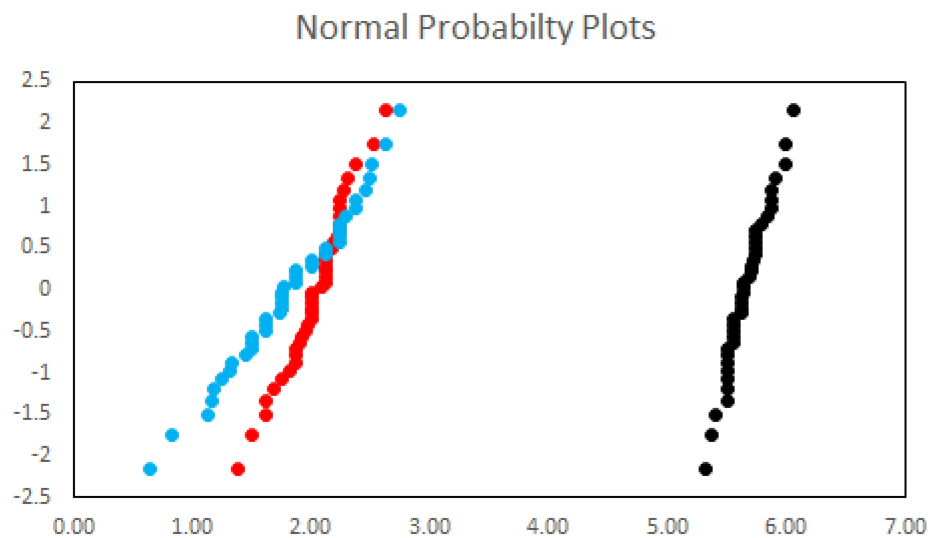

Figure 13. Normal probability plots of sample populations key measurements

After it was determined the population could safety be assumed normal from the sample data set used, it was determined that the volumetric dimensions that would yield a 75% fit of all glasses were as follows; height 2.2", width 2.2", and length 5.8". These base dimensions were used to help pick our final dimensions; keeping in mind that these numbers correspond to internal space and that case thickness, geometry, and shell thickness all needed to be factored in as well for our final dimension picks. The sample population used and all included information can be seen in Appendix G.

6 – MANUFACTURING

6.1. Molding Procedure

Once our design was finalized and our molds were cut, we began molding our cases. By experimenting with different methods and settings, we refined our molding process to create high quality finished parts. A complete lab manual can be found in Appendix L.

In order to create the silicone mold, steps 1 and 2 below are the same. However, rather than laying carbon fiber into the case mold, the smaller mold will be packed tightly with the partially cured silicone. Apply heat and pressure from the press for thirty seconds to allow the silicone to form into the mold shape. More silicone is then packed into the mold, and more heat and pressure re-applied. This is repeated until the mold will not accept any additional material, at which point, pressure is applied and the silicone is allowed to cure for approximately 20 minutes in the hot mold. The silicone is then removed from the mold and the extra flashing can be trimmed off with a knife.

The following instructions describe how to properly prepare the mold cavity, lay up the carbon fiber pre-preg, and what heat press parameters to use in order to cure a finished part.

1 – Turn on the heat press and set temperature to 285°F (yields a 15-minute cure time for carbon fiber). Allow press to warm up sufficiently. Be cautious as the press, even when hot, will not appear so.

2 – Buff mold negatives with F57NC Axel release agent, displayed in Figure 14. Wipe down the press with release agent as well. Wash hands after contact with the release agent to minimize contamination of fiber layers during preparation of the mold.

Figure 14. F57NC Axel release agent with treated Quatro flybox mold negative.

3 – While the press heats up, lay up the composite mold following the diagram displayed in Figure 15, as well as using the subset of instructions following:

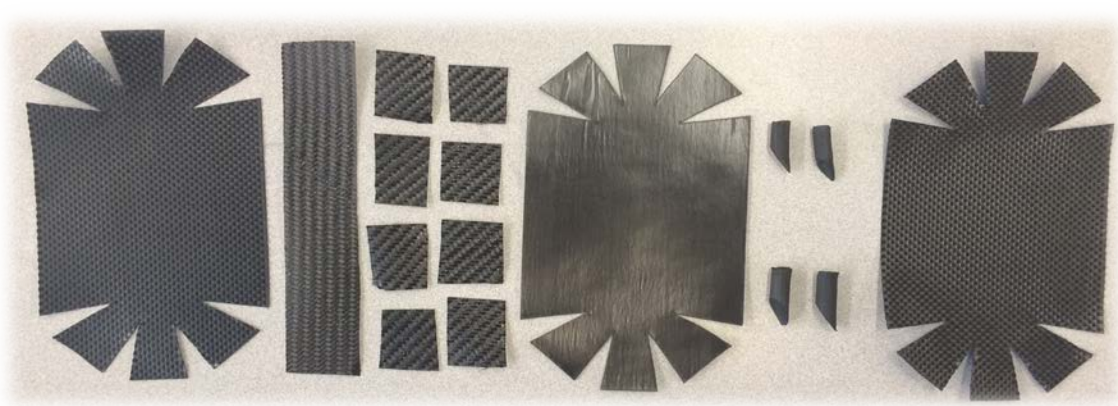

Figure 15. Complete carbon fiber pieces for a case half. The layup process goes from left to right.

4 – Place the first patterned cut out—coined the "money layer" as it will be the outermost layer—in the mold and press form it to the shape of the mold using your fingers. (The best way to insert the layers would be by lightly creasing and folding the edges inwards, as seen in Figure 16, then unfurling it within the aluminum mold.)

Figure 16. Carbon fiber pattern with edges folded inward.

5 – Lay a strip of bi-directional carbon fiber perpendicular to the long axis of the case. This strip should be long enough that it lies partially on the top of the aluminum mold on both sides, which will provide a tab with which to remove the case once it has cured.

6 – With another strip of bi-directional carbon fiber cut it into approximately 1”x1” squares. Place these clips on each seem of the first layer, as presented in Figure 17. This will help to ensure these points of initial weakness cure together to form a strong continuous end sheet.

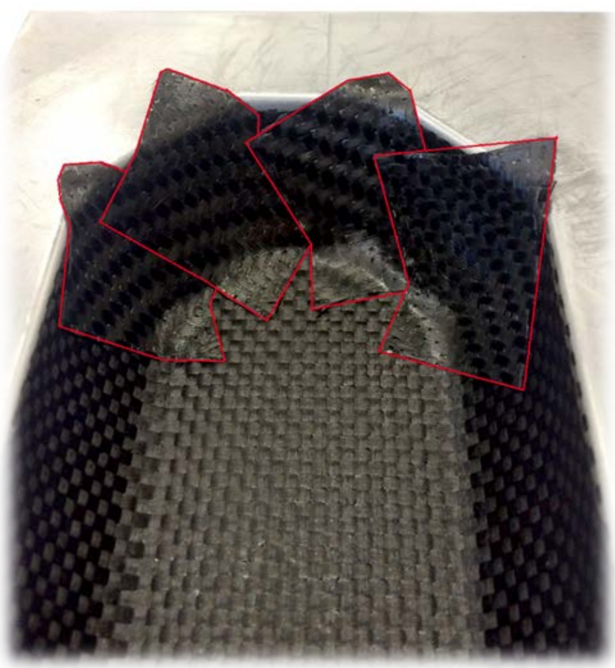

Figure 17. 1” x 1” clips placed on seems

7 – Role up uni-directional carbon fiber into tight rolls approximately 3/8” in diameter. Cut this roll into 1” segments and then cut one end of each segment at a 45° angle; 4 of these segments are needed per case half.

Once these rolls are created, place one in each corner of the case with the slanted end laying down into the case allowing the roll to sit vertically.

8 – Insert the second patterned uni-directional cut out into the aluminum mold. Ensure that all edges are thoroughly pressed. Figure 18 shows how to easily lay up the pattern in the mold.

Figure 18. Lay up of second patterned uni-directional cut out in mold

9 – Place the third patterned carbon fiber layer into the aluminum mold. At this point, ensure that the carbon fiber pieces are well press formed into the shape of the mold.

10 – Take the plastic film (approximately 8"x8") and wrap the silicone insert. Carefully place the silicone, cover in plastic, into the aluminum mold. Ensure that the silicone is fully pressed into the mold; it might be a little snug. Figure 19 demonstrates a cross section of how all the layers should fit nicely into the aluminum mold.

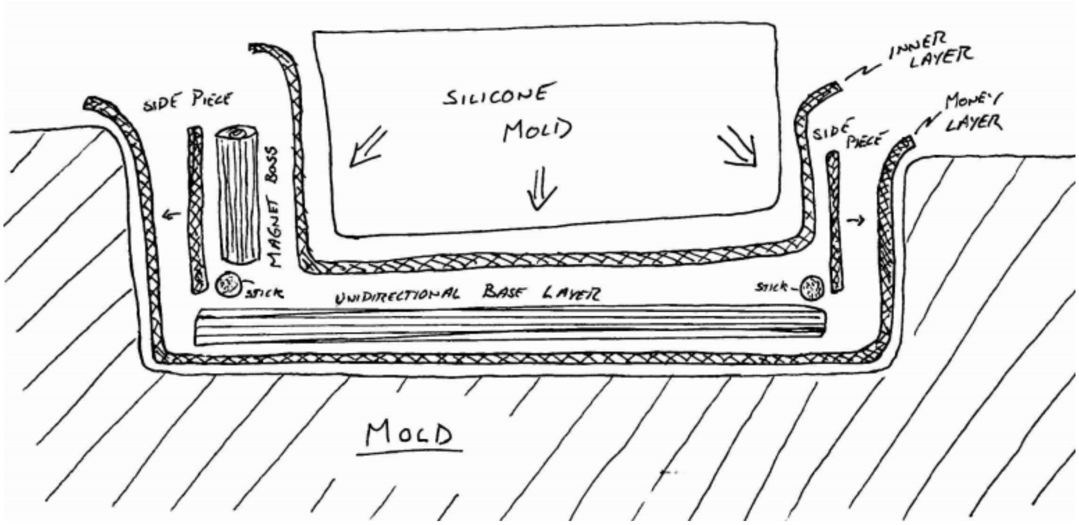

Figure 19. Cut-away of mold lay-up

11 – Spray the heat press with release agent to prevent the excess resin that flows out of the carbon fiber from sticking to the two plates. Use gloves to carefully place the prepared aluminum mold into the heat press; making certain that the silicone is fully covered under the heated plates.

Compress to roughly 100 psi material pressure, which equates to roughly 1700 pounds on the press read out. Leave in the heat press for about 15 minutes at 285°F. Another way to determine if the carbon fiber has fully cured is to see if the flashed resin has a jell like feel and consistency (General rule of thumb for cure times: at 250°F, allow 1 hour of cure time. Every 15°F increment increase in temperature cuts the cure time in half.).

12 – Once sufficient time has elapsed carefully remove the aluminum mold from the heat press. The silicone should easily pop out. Run water over the silicone to cool it quickly. Wait a few minutes before taking out the composite component. Use a joint/taping knife to assist with extraction of the cured composite. Grab the pull tab with pliers and lift straight up if the part is stuck or difficult to remove.

13 – Repeat steps 1 through 10 for the second case half.

6.2. Post Process Finishing

Once two molded halves have successfully been created, post processing can begin. To start, the flashing on the halves needs to be trimmed away using the provided jig and Dremel to trim each mold half to the pre-set height. Place the flat side of the case on the table with the opening up, and rotate it slowly allowing the tool to cut off all the excess flashing. It is recommended to wear a dust mask and wear gloves, as lots of dust will result from trimming the carbon fiber. Be careful to keep your fingers clear of the cut-off disk!

After trimming the flashing off, move on to the drill press to drill the magnet holes. Use the provided jig to drill 1/8" holes in each of the corner nubs to the pre-set depth, which is about ¼" down. Be careful to drill the holes as accurately as possible so the magnets will align the case halves properly later on.

Lastly, lightly sand (roughly 1mm depth) the long edges of the halves, as seen in Figure 20. This creates space for the ribbons and allows the two halves to shut fully.

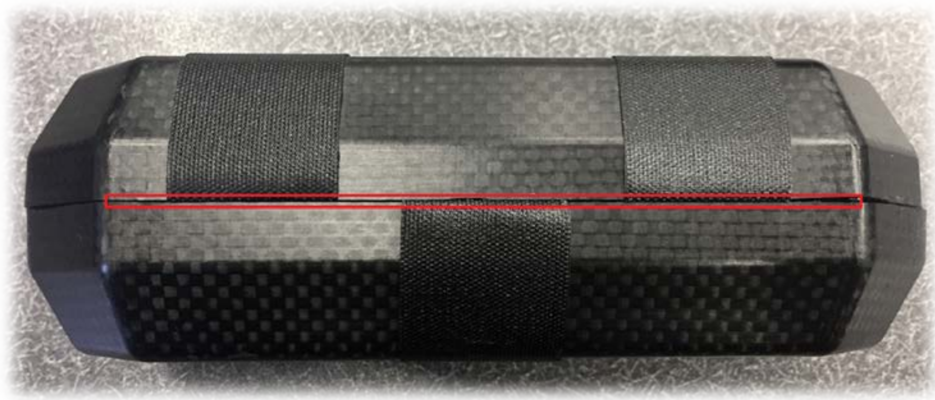

Figure 20. Sand off the carbon fiber enclosed in the red box

6.3. Assembly Method

The assembly method for our prototype cases was done one case at a time from start to finish, as opposed to an assembly line type method which would be more effective in a large run of manufacturing of these cases.

We prepared several "kits" containing what was needed to assemble two finished case halves and create a final product. These kits include:

- 3 x 6" long x 1" wide ballistic Nylon straps used for the hinge
- 2 x Fleece liners (2) pre-cut to fit the case
- 8 x cylindrical 1/8" diameter magnets used to hold the case shut
- Two part Super Instant Epoxy
- 3M Spray Adhesive
- Optional: binder clips

Mix the two-part epoxy using a disposable stir stick. The glue used to attach these components to our case is a two-part epoxy with a very fast cure time. Because of this the epoxy was only mixed in small amounts as it was needed and is not part of each assembly kit. Apply glue to the carbon fiber case in the locations indicated in Figure 21. Allow the glue to have a tacky consistency before inserting the ribbons. Use the binder clips to hold the ribbon in place. Ensure that the ribbons are tightly wrapped around the case halves, as this determines how accurately the two cases will line up with each other. The further the ribbons are apart from each other, the tighter the case halves will be. Wait about 5-10 minutes before removing the binder clips.

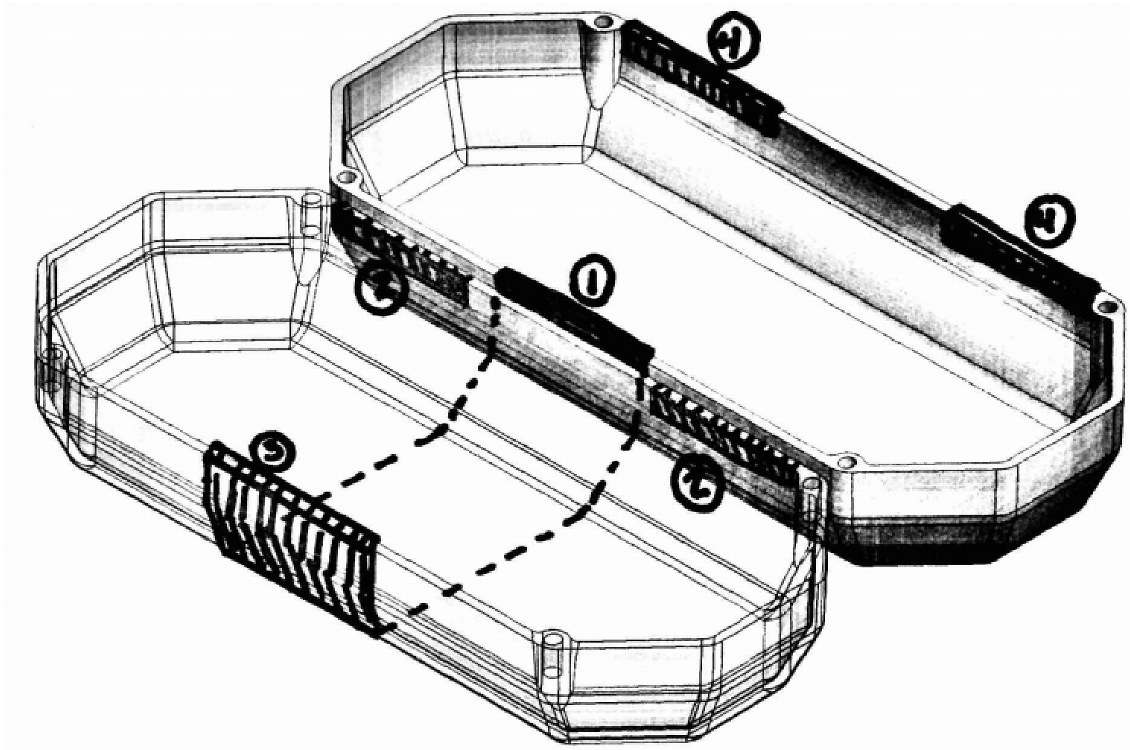

Figure 21. Assembly reference points for manufacturing purposes

Before the glue hardens fully, use the remaining to glue the ends of the 8 magnets into the drilled holes. Press the magnets in by hand until they are flush with the surface, taking special consideration to be certain each will match up with its mate and maintain the attractive force between them.

Using the 3M spray adhesive, spray glue into the case (only one half of the case at a time) in a well-ventilated area. Quickly, but carefully, attach the pre-cut fleece liner into the case starting from one end and working down and across with the same method that the layers of carbon fiber were applied to inside the mold. The cure time is about 30 seconds. Trim the extra lining as desired.

6.4. Detailed Cost Analysis

In order to estimate the manufacturing cost of this case accurately the process needed to be broken down into separate parts. The material used at each step in the process, the labor rates for each step, the tooling, and all scrap and waste along the way. Since we have not reached a point where we are producing these cases at a steady rate much of this is an approximation based on our experiences molding and prototyping cases one or two at a time.

The molds used to create our cases and the tooling used in the post processing are constant indirect costs. They are factored into the cost of each case, however the more cases made the less these will contribute to the cost of each case, as they will be paid for all at once and not per case created. For the sake of this analysis I used a sample run of

50 cases (or 100 parts made) which seemed like a reasonable number for a first run. All of the material costs used are based on readily available materials and advertised prices. If we were to produce a large quantity of this product many of these prices would come down due to buying in bulk, and seeking out better prices with suppliers. Some of the quantities used in this analysis are known such as the number of magnets per case, or layers of carbon fiber, and others are estimations such as the amount of glue used per case. These estimations would become more accurate if this process were to go to production leading to an easily calculated average based on our materials used and the number of cases completed. The total direct material cost for these cases comes out to $27.40 per case for a run of 50 cases. Most of this cost (60%) comes from the cost of the pre-preg carbon fiber. In order to lower the cost of this product I believe we would need to get a better deal on this material than what is openly advertised to the everyday consumer.

The labor was broken down into three separate parts with separate cycle times and pay rates. The molding can be done in 15 minutes per part at an estimated rate of $18 per hour. The post process machining will pay a little more due to the use of a CNC machine at $22 per hour, but this process will be able to clean up the edge on the parts and drill the magnet holes at a rate of 12 per hour or 5 minutes per part. Finally, the assembly is estimated at 3 cases per hour (or 6 individual halves connected) and a pay rate of $15 per hour. These steps bring the total direct labor costs to $18.23 per case, which is not something we will have to pay at this point as we are currently performing all of the labor ourselves. However, it is a useful approximation and valuable piece of knowledge to have if we were to consider taking these cases to production.

The total cost for producing one of these cases with an approximation of a 50 case run comes out to $45.63, of which 40% is labor costs which are not necessarily a concern for us at this point in time. A spreadsheet that has more information on this cost analysis can be seen in Appendix H following this report.

6.5. Plans for Fabrication

With our selected concept, we used SolidWorks to create a 3-dimensional model of our mold. Due to the fact that our case uses a common top and bottom half, only 2 total molds were needed. One used to create the silicone positive mold and one used to create the actual carbon case. These molds are the same shape and only vary slightly in size. The process of creating these molds was difficult and time consuming, and by using a common top and bottom half for our case we were able to save both time and resources. As well as simplify the manufacturing and assembly portions of this process.

Once we reviewed the geometry and dimensions of our case, we created a CNC code using HSMworks CAM software to machine our molds. The molds were then cut on a Haas VF-2 CNC mill using tools and material supplied by Quatro Composites. Once we had finished molds, we were finally able to begin molding our carbon fiber halves. It

anticipated that it would take several trials to perfect our compression mold and produce a part that we were happy with. However, the first trials were more successful than we had thought they would be, and we were making useable parts by our third attempt. None of our cases had any cracks, non-fill, or pinched fibers, and the surface finish was better than expected. We were very pleased with the way this worked out, although we had allotted enough time to create new molds, we were happy that we did not have any reason to.

Assembly was also much easier with a common top and bottom piece since they match up perfectly and there is no chance of mixing up or confusing parts. As mentioned earlier, we are using Smooth-On Super Instant two-part epoxy to attach our straps and magnets (for secure closure), and 3M Super 77 spray adhesive for the soft liner on the inside of the carbon shells. We decided to use these products after some testing and comparison with other adhesives. We decided on 420 D Nylon webbing since it is easily accessible and relatively inexpensive. To fully close our case, four pairs of cylindrical magnets with a theoretical closing force of 0.85lbf between each pair will be used, resulting in a theoretical force of 1.7lbf to open one side of the case. During the post processing of our case halves we drill 4, 1/8" holes in the corners of each part into which the magnets are pressed and glued.

6.6. Maintenance and Repair Considerations

When this case is properly assembled, there is no necessary maintenance to perform. The durable carbon fiber material on our prototypes has thus-far withstood many drops and crushes without any visible damage beyond scratches. If and permanent damage or failure were to occur repairing individual parts of the case seems unpractical since everything is either cured or glued in. Replacing the case would be the best option at this point, and if these cases were to be available to the public there would be some sort of warranty or replacement program in affect.

7 – TESTING

Once a number of cases had been successfully molded and assembled, testing for strength, durability, and resilience took place. Field testing along are described in detail further on. The use of test cases in day to day life also helped us determine if our specifications were met. The tests, described below, were performed to simulate a person's day to day interaction with their sunglasses case and situations that may result in damaged sunglasses, both of which helped us determine successful test parameters.

7.1. Crush Test

For crush testing we used the Instron electromechanical tester available to us in the Cal Poly composites lab. The purpose of this test was to determine how much crushing force the case would withstand while protecting the glasses inside.

A successful crush test involves having the case still intact with no critical damage to the sunglasses when exposed to a load of 250lbs. There should be no delamination or structural defects to the case from the applied load. A closed case was placed on a flat rigid surface with a standard pair of sunglasses placed inside. The load was slowly increased and it soon became apparent that the case would be able to withstand much more than our specification of 250lbs. As can be seen in Figure 22 below, the case withstood approximately 1700lbs before any failure occurred. At this load the case developed a crack and the two halves no longer lined up correctly, however the glasses inside were not damaged. Although the case now had a crack in it, when the load was removed the case still functioned correctly and had very little visible damage.

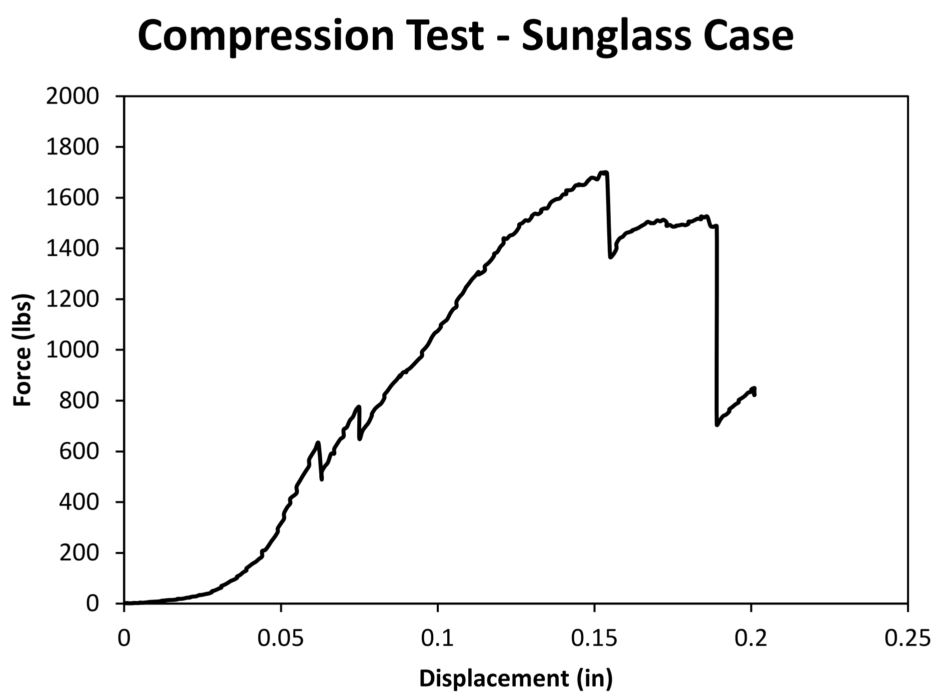

Figure 22. Force vs. Displacement for crush test

7.2. Drop Test

Drop testing was as simple as it sounds. We dropped a case from our defined height of 10 feet onto a hard flat surface with a pair of sunglasses inside, and allowed the system to equilibrate after impact and then inspected the case and glasses. We selected 10 feet as our height as it accounts for different heights that one may accidently drop their cases such as from their pockets, backpack, or off a table. We performed this same test with

some of the cases we had purchased so we would be able to compare our case to other sunglasses cases on the market. All of the cases tested were dropped a total of five times from each of the following orientations 1) the main axis towards the ground 2) the weak axis towards the ground 3) and finally, the tall axis towards the ground, these axes can be seen in Figure 23. Tests will once again be performed in the order of described axis to ensure consistency and limit uncontrollable variables from disrupting our data.

Passing measures for a durable sunglasses case include having the case close properly, no obvious lateral displacement of the ribbons, and no pronounced dents on the outside of the case. The glasses may spill out of the case upon impact as long as there is no critical damage done to them.

Although, on a few of the drops our case did open, there was never any damage to the glasses inside as the case took the impact before opening. After all of the drops our case showed no visible damage except for some scratches on the corners, and continued to function as intended. However, the other cases that we had purchased sustained damage and had various issues with the hinges and dents in the case. Although, in all of the tests the glasses were not damaged.

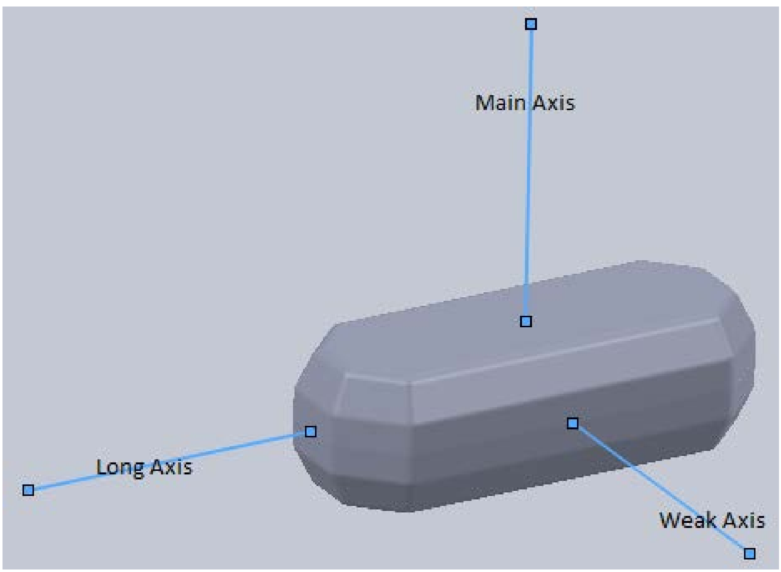

Figure 23. Orientations of the case for testing reference

7.3. Close/Staying Shut Test

In order to measure the case's ability to withstand opening, we pulled the two halves apart using a spring scale and read the value that the case was able to withstand before opening. The bottom half was help stationary and the scale was attached to the top half and lifted directly upwards.

Our design specifications called for the case to withstand 2lbs of force before opening as a success parameter. Theoretically, our magnets have a force of 1.7lbs, and although we were not able to get an accurate reading of just how much force they were actually withstanding it did seem to be less than 2lbs. Our case did not meet this specification and we have to say that it failed this test. However, we think that the feel of opening the case is about what we were looking for and may want to re-consider our design specification.

7.4. Durability Test

We felt that the best way to test the durability of these cases was to expose them to daily use and wear for as long as possible. We began test once we had finished cases by using them and acting as field testers waiting to see what, if any, problems arose. We attempted to expose our cases to harsh conditions as often as possible and simulate situations that they would likely be put through by a consumer.

A successful test was defined as the case continuing to function as intended and not show any signs of failure after this heavy use. We stuffed them in backpacks and toolboxes, dropped them, took them camping and even stepped on them. Although we would like to see this test run for a longer period of time, as of now, all of our cases still function as intended, and only show a few scratches as a sign of wear, which is to be expected.

7.5. Aesthetics Test

We performed preliminary analysis on the aesthetics of our case. After thoroughly inspecting and modifying our design, we conducted a survey asking the general public for their input on what they think about the shape, size, and appearance of the carbon fiber sunglasses case.

We defined a success for this test as 75% of people liking, or approving of, our case. We definitely met this number, and passed this test.

Overall, people were very impressed by the case and many of the people who have seen the case have asked if they will be available to purchase. The hinge design is also well liked and gives the case a certain, unique, quality that people seemed to like.

8 – PROJECT MANAGEMENT PLAN

It was decided early on that team members should be primarily fluid in their responsibilities. This meant that regardless of initial managerial assignments, it was each team member's responsibility to see that all areas of the project met deadlines and succeeded. With that being said, the following roles for each team member were decided upon through general consensus.

Kyle Hammell was our secretary. He planned meeting agendas, and kept meeting minutes, and made sure every team member had access to the most current information and team plans.

Greg Hermansen was our communications coordinator as well as our lead machinist. He ensured that all team members are up to date with current sponsor information and acted as a liaison between our team, our sponsor, and our technical advisors. He also provided primary input on mold construction and fabrication, indicating what operations or features were and were not realistic.

Larsson Johnson was our treasurer as well as our lead analyst. He handled all of the budget and acquisition of materials ensuring that the project has the funds and resources to reach a conclusion by set deadlines. He also ensured that test parameters were realistic based on preliminary analysis and helped determine what needed to be changed if tests were failed.

Joanne Medrano was head of research on composites and materials assistant where needed. She ensured that everyone was aware of the limitations of composites, and played a vital role in the progress of the manufacturing aspects of the project helping extensively with whatever part of the project was critical at that moment in time.

9 – CONCLUSION AND RECOMMENDATIONS MOVING FORWARD

Upon conclusion of our project, we successfully fabricated five identical, fully functioning cases. Of those five, one case was cracked during the crush test. Although the case we designed didn't pass all of the tests for our design requirements, we are still pleased with the final product that we produced. We are confident that the assembly time can be reduced to achieve our goal, and although the force required to open the case didn't meet our 2lbs specification we believe that it feels like an appropriate force and gives our case a high quality feel. Our final cost of $45.63 per case is very appropriate considering the design and current market products. We were able to maintain a 5% waste due to our optimized mold design and fabrication method. This is a major improvement over the 30-50% average waste from using the autoclave molding method.

As for future developments, we investigated ways to customize these cases by adding initials or designs to the outer most layer that is visible on the case. We would like to reduce the cycle time required to fully manufacture one complete case. An area with the most room for improvement is the assembly, specifically the attaching of the straps and liner. Perhaps, future senior project groups could explore ways to build a fixture or jig that holds the case halves together for this operation. It would be ideal to have a more accurate way to drill the magnet holes in the four corners, a more efficient way to hold the two halves in place while attaching the ribbons, and a more consistent way to cut the fleece liners for the case.

Beyond the case design, this project was a very informative investigation that proves compression molding is a highly versatile out-of-autoclave molding method, capable of producing very strong parts with a high quality finish. We are very confident in the lab activity accompanying this project, and hope students who complete this activity will reach the same appreciation and understanding of composite compression molding that we have.

10 – BIBLIOGRAPHY

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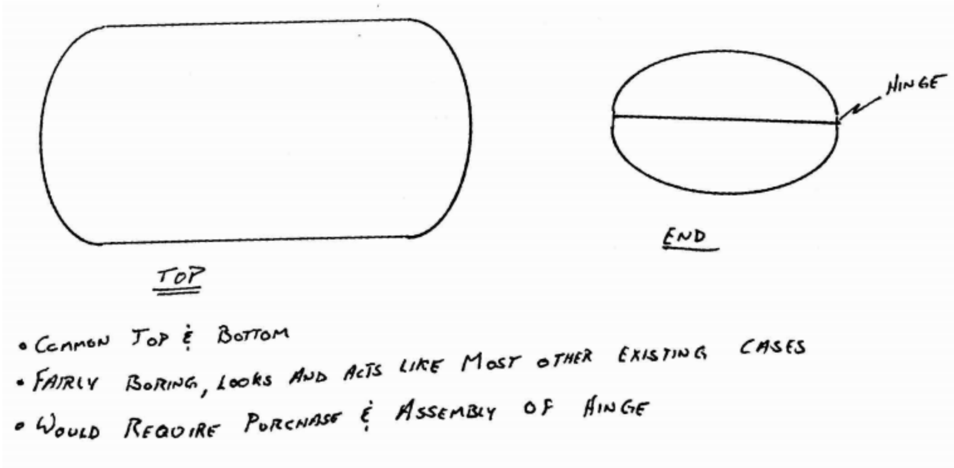
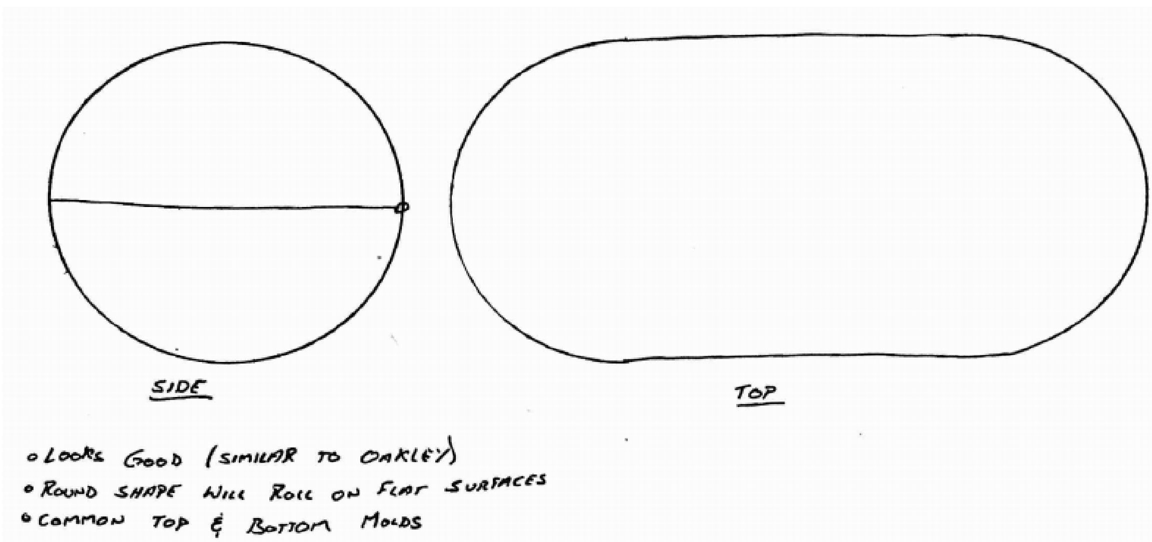
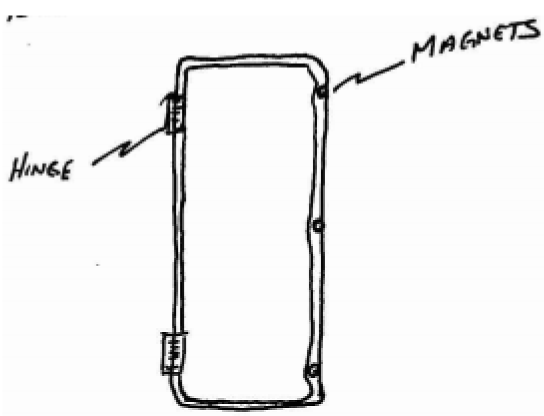
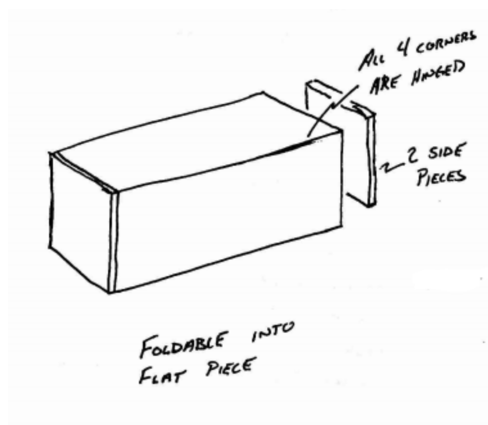
11 – APPENDIX

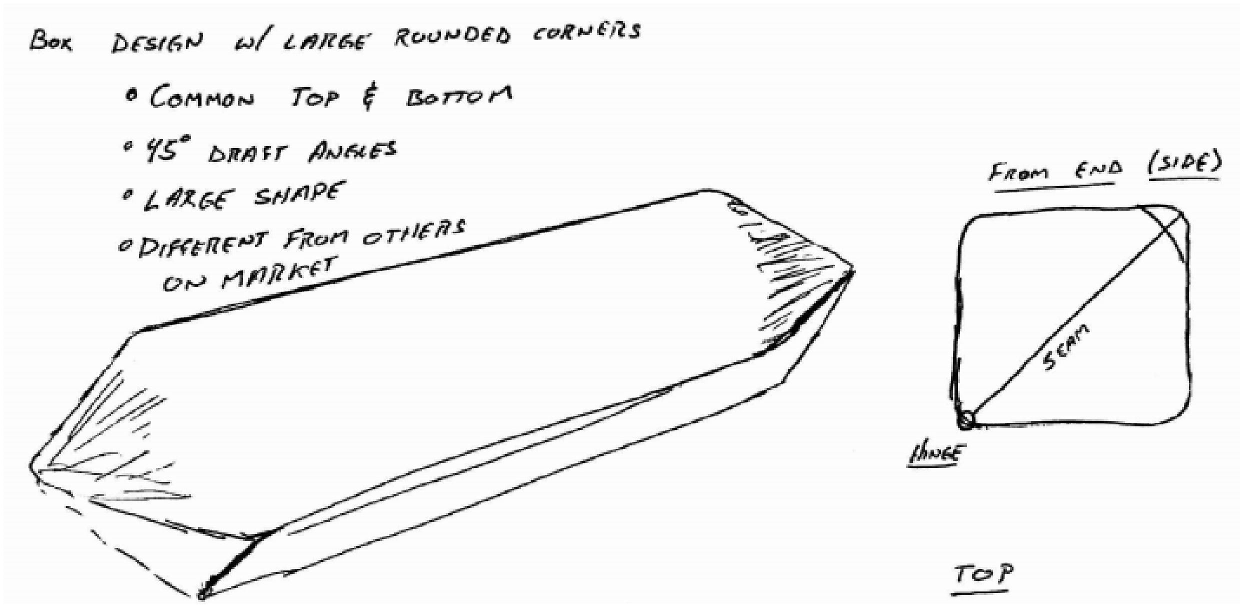
[A] Sunglasses Case Sketches
[B] QFD Diagram
[C] Pugh Matrices
[D] Detailed Dimensions of Rectangular Case
[E] Detailed Dimensions of Hex Case
[F] Crush, Drop, and Closing Force Analysis.
[G] Statistics on Sunglasses Size Analysis
[H] Cost Analysis
[I] Gantt Chart
[J] PERT Chart
[K] Critical Design Hazard Identification Checklist
[L] Sample Lab Manual

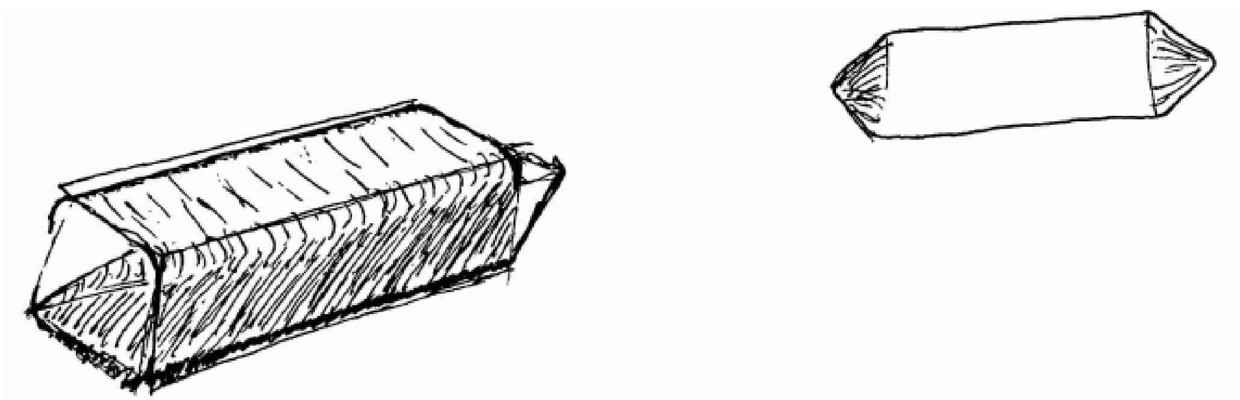

HINGE
END
TOP
• COMMON TOP & BOTTOM
• FAIRLY BORING, LOOKS AND ACTS LIKE MOST OTHER EXISTING CASES
• WOULD REQUIRE PURCHASE & ASSEMBLY OF HINGE

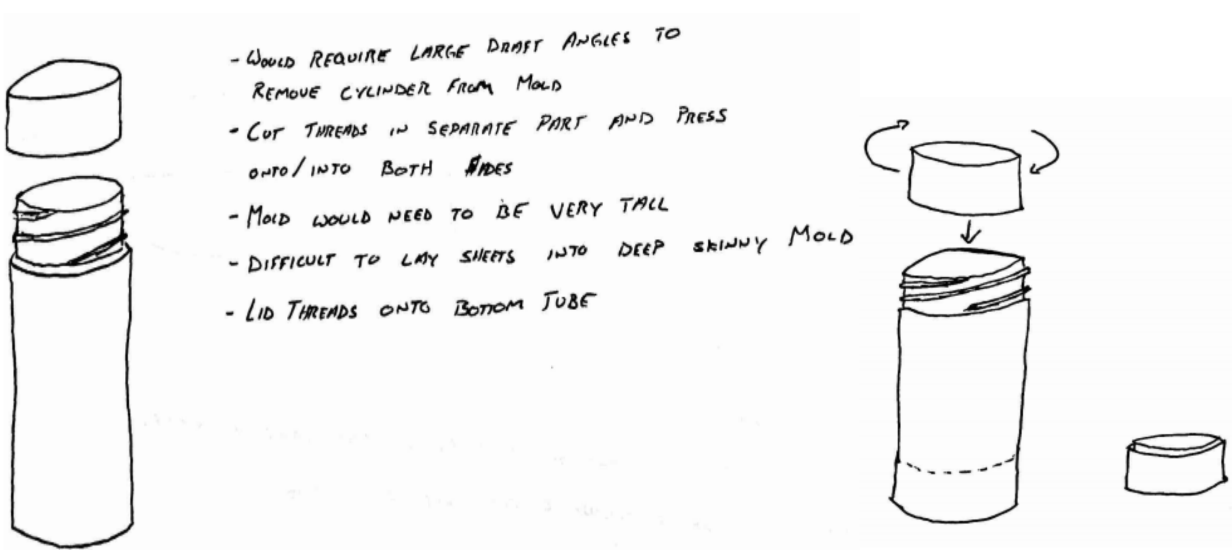

SIDE
TOP
• LOOKS GOOD (SIMILAR TO OAKLEY)
• ROUND SHAPE WILL ROLL ON FLAT SURFACES
• COMMON TOP & BOTTOM MOLDS

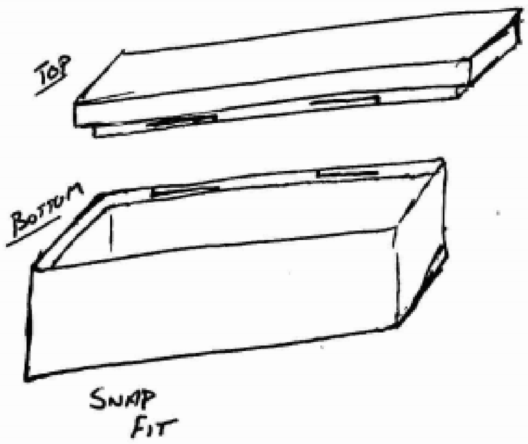

MAGNETS
HINGE


ALL 4 CORNERS ARE HINGED
2 SIDE PIECES
FOLDABLE INTO FLAT PIECE


Box design w/ large rounded corners
• Common top & bottom
• 45° draft angles
• Large shape
• Different from others on market
From end (side)
Seam
Hinge
Top




- Would require large draft angles to remove cylinder from mold
- Cut threads in separate part and press onto / into both sides
- Mold would need to be very tall
- Difficult to lay sheets into deep skinny mold
- Lid threads onto bottom tube



CLOSURE IDEAS

HINGE & LATCH

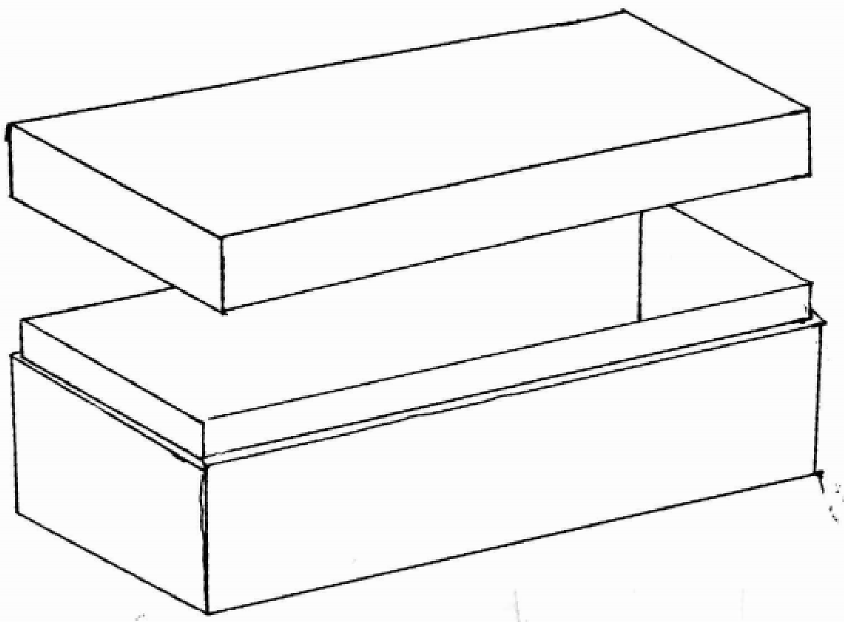
ZIPPER

HINGE & MAGNETS

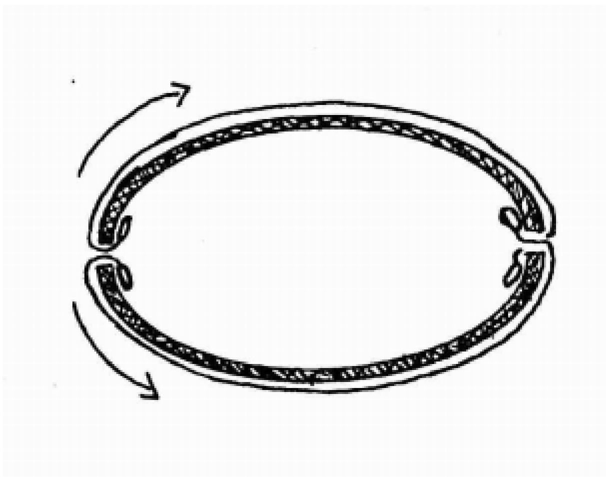
2 SEPARABLE PIECES W/ MAGNETS

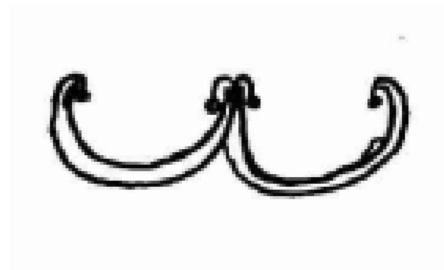
THREAD TOGETHER

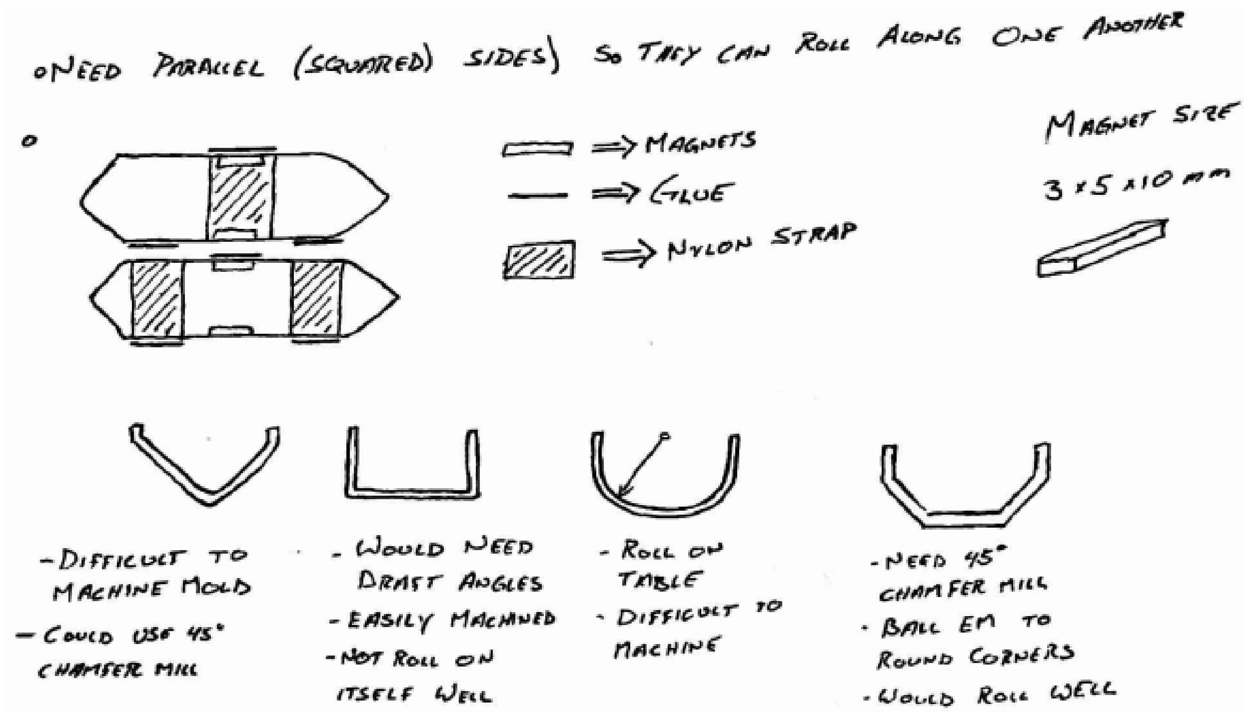
SNAP TOGETHER

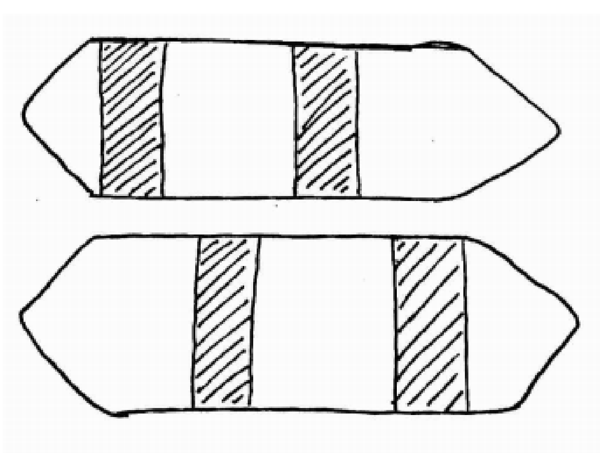


- BOX W/ REMOVABLE LID
- COULD BE HELD IN PLACE W/ MAGNETS, LATCHES, KEY WAY, SLOTS, ETC
- WOULD REQUIRE 2 MOLDS
  - ONE DEEP W/ LARGE DRAFT
- DIFFICULT TO MACHINE INSIDE CORNERS
  - (COULD BE ROUNDED






NEED PARALLEL (SQUARED) SIDES) SO THEY CAN ROLL ALONG ONE ANOTHER
MAGNETS
GLUE
NYLON STRAP
MAGNET SIZE
3 x 5 x 10 mm
- DIFFICULT TO MACHINE MOLD
- COULD USE 45° CHAMFER MILL
- WOULD NEED DRAFT ANGLES
- EASILY MACHINED
- NOT ROLL ON ITSELF WELL
- ROLL ON TABLE
- DIFFICULT TO MACHINE
- NEED 45° CHAMFER MILL
- BALL EM TO ROUND CORNERS
- WOULD ROLL WELL



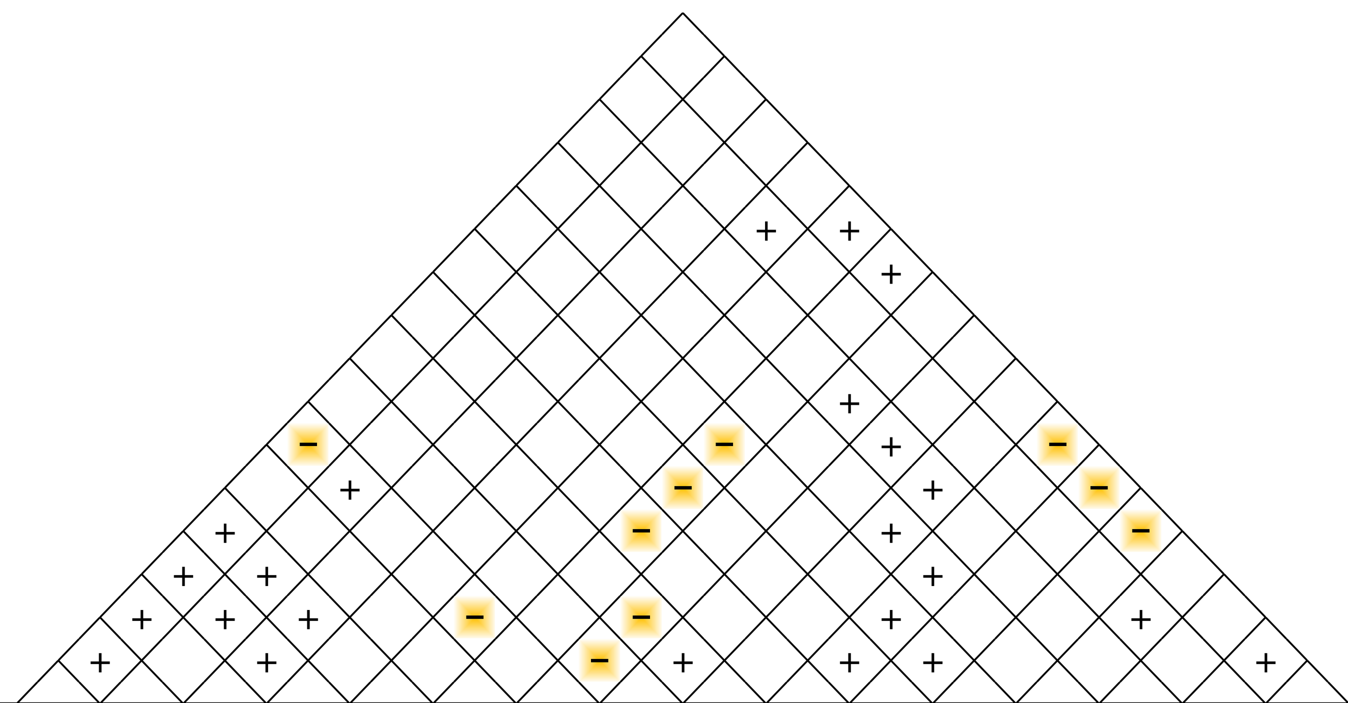
QFD: House of Quality

Project:	COMP3 SUNGLASS CASE
Revision:	1
Date:	1/26/2016

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

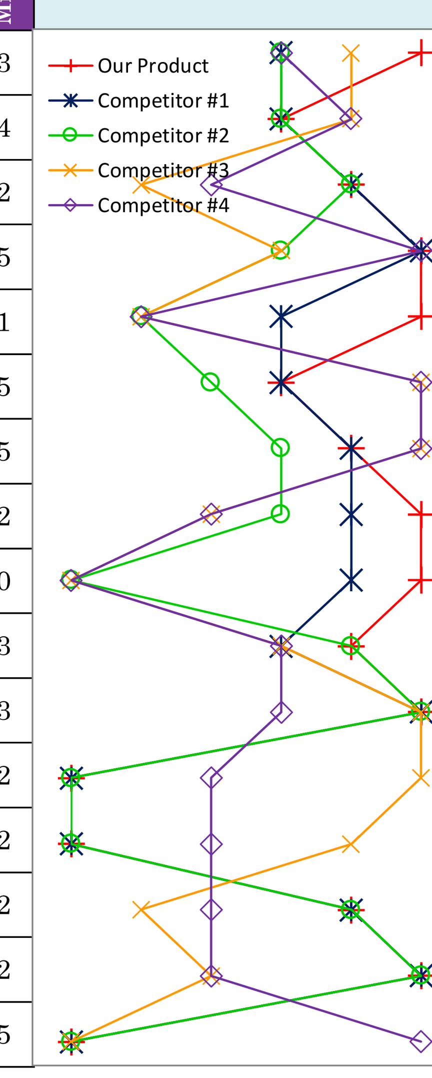
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



WHO: Customers

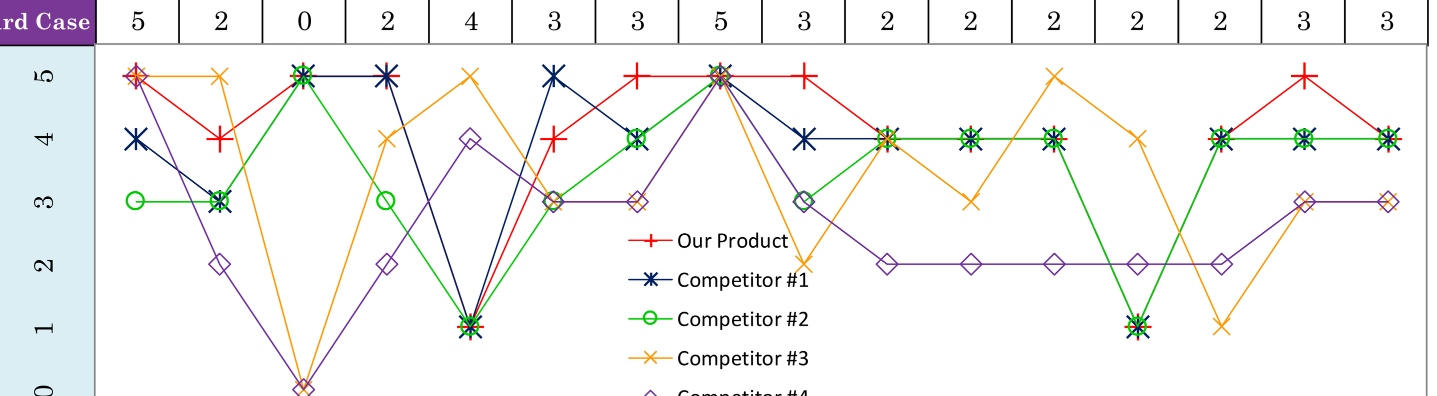
NOW: Current Product Assesment - Customer Requirements

Row #	Weight Chart	Relative Weight	Manufacturing Dept.	Sales/Marketing	End User	Maximum Relationship	WHAT: Customer Requirements (explicit & implicit) / HOW: Engineering Specifications	Drop Test (No Critical Damage, No open)	Crush Test	Force to Open (lbf)	Hinge Life/Durability	Water Resistance	% Production Yield Pass	Weight	Length	% Like the Appearance	# of Parts	# of Steps to MFG	# Steps to Assemble	Colors Available	% Glasses that fit	Cost of Materials	Total Cost to Produce	COMP3 CF Case	Oakley Large CF Hard Cases	Clamshell Diva XL Hard Case	Witz LensLocker Waterproof	Mil-Pod Hazard 4 Hard Case	Row #
							Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
							Direction of Improvement	▼	▲	◇	▲	◇	▲	▼	◇	▲	▼	▼	▼	◇	▲	▼	▼						
1		5%	2	8	8	9	Lightweight	●	●	▽	○	▽	▽	●	○	▽	○	▽	▽	▽	▽	○	○	5	3	3	4	3	1
2		5%	2	8	8	9	Compact	▽	▽	▽	○	▽	▽	●	○	○	▽	▽	▽	▽	●	▽	▽	3	3	3	4	4	2
3		7%	2	10	10	9	Universal	▽	▽	▽	▽	▽	▽	●	○	○	▽	▽	▽	▽	●	▽	▽	4	4	4	1	2	3
4		6%	8	6	6	9	Durable	○	○	○	●	○	▽	○	▽	▽	▽	▽	▽	▽	▽	○	○	5	5	3	3	5	4
5		8%	8	8	8	9	Cool Logo	▽	▽	▽	▽	▽	▽	▽	▽	●	▽	▽	▽	▽	▽	▽	▽	5	3	1	1	1	5
6		7%	8	6	8	9	Soft/Padded Liner	○	▽	▽	▽	▽	▽	○	▽	▽	●	○	●	▽	○	○	○	3	3	2	5	5	6
7		5%	4	4	8	9	Stays Shut In Storage/During Use	●	○	●	●	○	▽	▽	▽	▽	▽	▽	▽	▽	▽	▽	▽	4	4	3	5	5	7
8		7%	4	10	10	9	Aesthetically Pleasing	▽	▽	▽	▽	▽	▽	○	○	●	▽	▽	▽	▽	▽	▽	▽	5	4	3	2	2	8
9		6%	6	6	8	9	Carbon Fiber Texture/Appearance	▽	▽	▽	▽	▽	▽	○	▽	●	▽	▽	▽	●	▽	▽	▽	5	4	0	0	0	9
10		5%	2	6	10	9	Low Cost	▽	▽	▽	▽	●	○	▽	▽	○	○	○	○	○	○	●	●	4	3	4	3	3	10
11		6%	8	6	6	9	Hard Case	●	●	▽	○	▽	▽	○	▽	▽	▽	▽	▽	▽	○	▽	▽	5	5	5	5	3	11
12		6%	8	4	8	9	Waterproof	▽	▽	●	○	●	○	○	▽	▽	●	○	○	▽	▽	○	●	0	0	0	5	2	12
13		7%	8	6	8	9	Floating	▽	▽	▽	▽	●	○	●	▽	▽	▽	▽	▽	▽	▽	▽	▽	0	0	0	4	2	13
14		6%	8	6	6	3	Extra Space For Cleaning Cloth	▽	▽	▽	▽	▽	▽	○	▽	○	▽	▽	▽	▽	○	▽	▽	4	4	4	1	2	14
15		5%	4	4	8	9	Easy To Open By User	●	▽	●	●	▽	○	▽	▽	▽	▽	▽	▽	▽	▽	▽	▽	5	5	5	2	2	15
16		6%	8	6	6	9	Clip/Belt Attachment	▽	▽	▽	▽	▽	○	○	▽	●	●	●	●	▽	▽	○	●	0	0	0	0	5	16
							HOW MUCH: Target	10ft	250 lbf	3-5lbf	10^4 Cycles Lifetime	IP54 Rating	95%	<6oz	<7"	75%	5	8	8	2	75%	<$15	<$50						
							Max Relationship	9	9	9	9	9	3	9	3	9	9	9	9	9	9	9	9						
							Technical Importance Rating	300.19	217.86	241.92	277.22	272.09	160.05	401.19	149.53	369.28	280.16	189.13	231.15	160.71	246.62	205.94	282.95						
							Relative Weight	8%	5%	6%	7%	7%	4%	10%	4%	9%	7%	5%	6%	4%	6%	5%	7%						
							Weight Chart																						



Current Product Assesment - Engineering Specifications

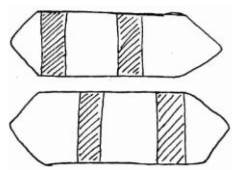
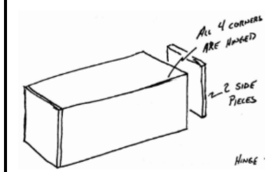
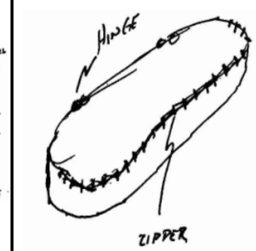
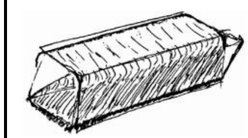
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
COMP3 Carbon Fiber Case	5	4	5	5	1	4	5	5	5	4	4	4	1	4	5	4
Oakley Large CF Hard Cases	4	3	5	5	1	5	4	5	4	4	4	4	1	4	4	4
Clamshell Diva XL Hardcase	3	3	5	3	1	3	4	5	3	4	4	4	1	4	4	4
Witz LensLocker Waterproof	5	5	0	4	5	3	3	5	2	4	3	5	4	1	3	3
Mil-Pod Hazard 4 Hard Case	5	2	0	2	4	3	3	5	3	2	2	2	2	2	3	3



Column # 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

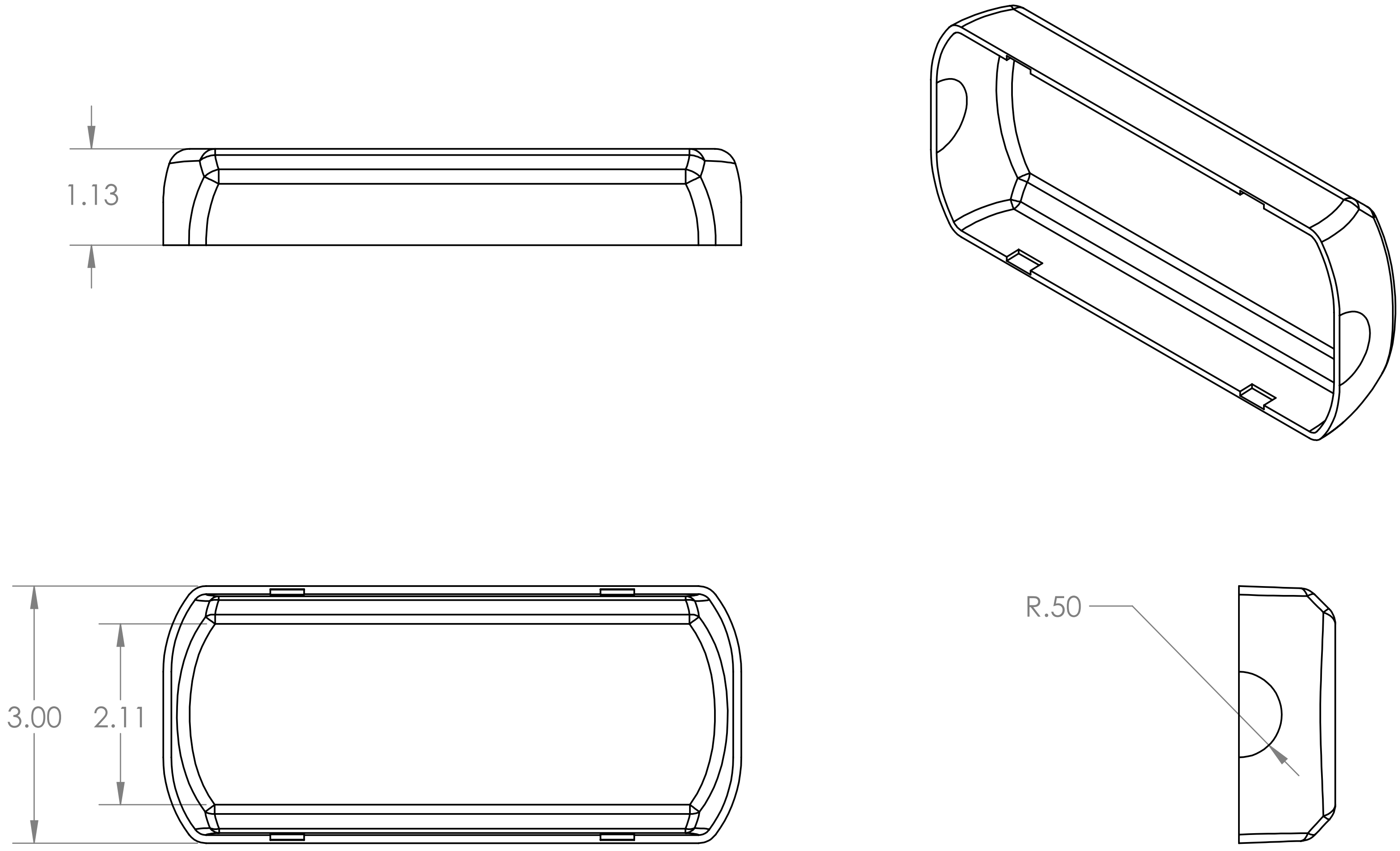
Different Designs

Design Considerations	Importance 1 - low 2 - high	Oakley carbon fiber case	Strap connections in "Jacob's ladder" design	Twisted or threaded cap	Hinged on all four edges	Zipper and hinge	Classic hinge on one edge
							
Aesthetics	2	D	++	+	+	-	0
Cost	2		+	--	--	--	0
Manufacturability	2	A	+	--	--	--	-
Ease of use	2		0	-	-	-	0
Spacious	2	T	0	+	+	+	0
Collapsible	1		0	-	++	0	0
Waterproof	1	U	-	+	-	-	0
Universal	1		0	0	0	0	0
		M					
	+	0	8	5	6	2	0
	0	13	6	1	1	2	11
	-	0	1	11	11	13	2
	Total	0	7	-6	-5	-11	-2

Appendix C: Pugh Matrices

Hinge styles

Design Considerations	Importance 1 - low 2 - high	Spring hinge	Common fibers hinge	Fabric hinge	No hinge	Piano hinge	Jacobs ladder
Cost	2	D	+	+	+	0	+
Patent restrictions	1		-	+	+	+	+
Ease of integration	2	A	-	+	+	0	+
Durability	1		-	-	0	0	0
Assembly steps	2	T	0	0	+	0	0
Aesthetics	1		+	0	-	0	+
Coolness factor	2	U	++	-	-	0	++
Obtainability	1		+	+	++	0	+
Hold closed	1	M	-	-	-	-	-
	+	0	8	6	8	1	11
	0	13	2	3	1	11	3
	-	0	5	4	4	1	1
	Total	0	3	2	4	0	10



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ANSI Y14.5 2009

CAL POLY
SAN LUIS OBISPO

MATERIAL:

TITLE:

DRAWN BY:
COMP3

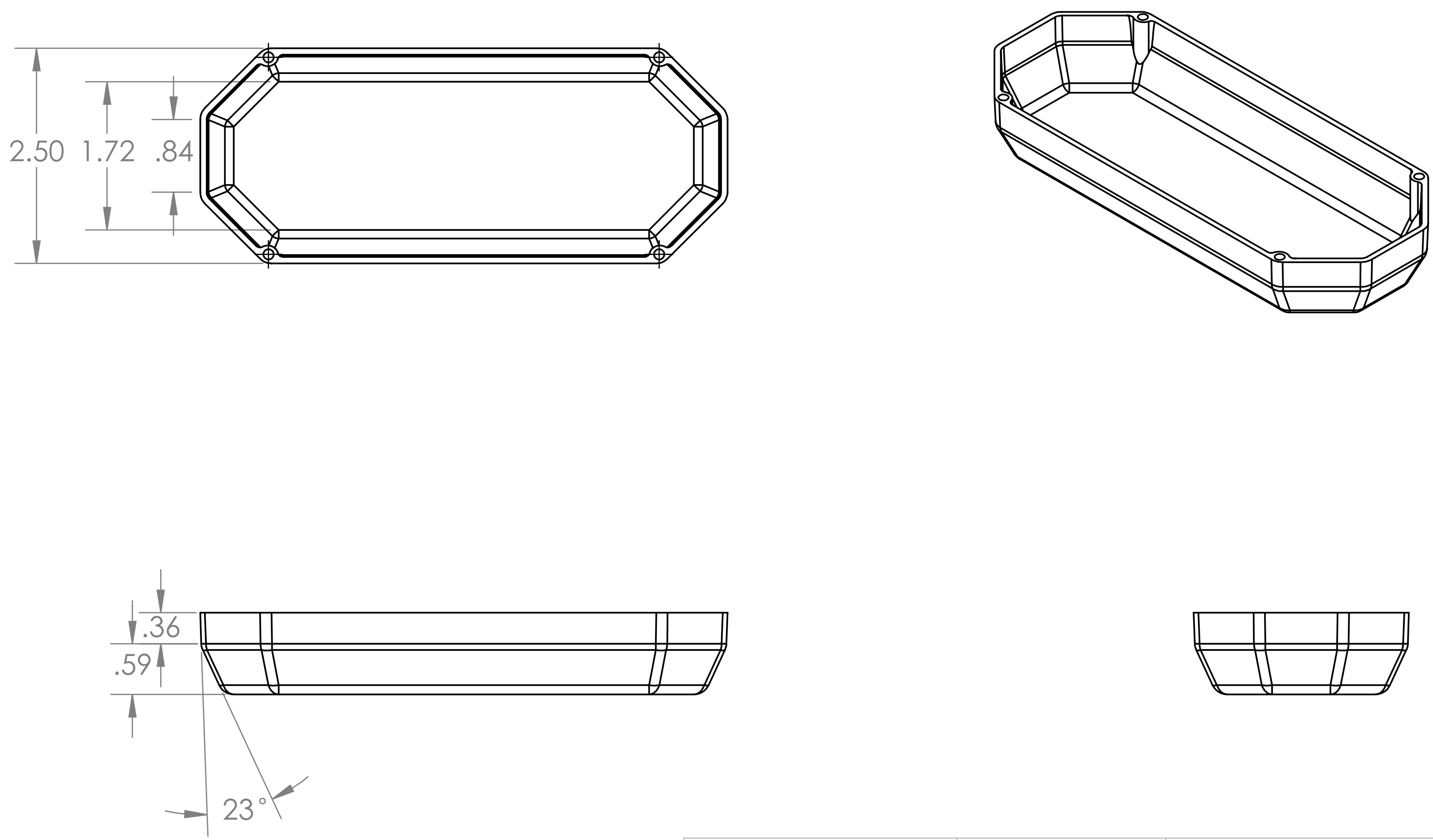
DATE:

SHEET 1 OF 1

SCALE: 1:2

REV

SIZE
A



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .5°
TWO PLACE DECIMAL ± .01
THREE PLACE DECIMAL ± .005

INTERPRET DRAWING PER ANSI Y14.5 2009

CAL POLY
SAN LUIS OBISPO

MATERIAL: Carbon Fiber

TITLE: Hex Case

DRAWN BY: Greg Hermansen

DATE: 5/02/2016

SHEET 1 OF 1

SCALE: 1:2

REV

SIZE A

ANALYSIS

CRUSH TEST - 250 lb_F

DROP TEST - 10 FT

SHUT FORCE - 2.5 lb_F

ESTIMATE OF SURFACE AREA

$$SA = 2\pi r l = 2\pi(2)(8)\ in^2 = 32\pi\ in^2$$

- FOR CRUSH TEST CASE MUST SURVIVE MIN OF 2.5 PSI EXTERNAL PRESSURE

- DROP TEST

* NEGLECT VISCOSITY / DRAG

$$v^2 = \cancel{v_0^2} + 2a(x - \cancel{x_0})$$

$$v^2 = 2ax \quad \text{WHERE} \quad x = 10\ FT \quad a = ~~9.81~~\ 32.2\ \frac{FT}{s^2}$$

V AT IMPACT ~~14.007~~ 25.4 $\frac{FT}{s}$

IMPACT FORCE OF FALLING OBJECT

$$F = \frac{mgh}{s}$$

s ← IMPACT DISTANCE

$$F(t) = m(V_1 - V_2)$$

* ASSUME .1 SECOND IMPACT TIME, INELASTIC

$$V_2 = 0 \quad V_1 = 25.4\ \frac{FT}{s} \quad m = 1\ lb_m \quad t = .1\ s$$

$$F = \frac{1}{32.2}(25.4)\left(\frac{1}{.1s}\right)\frac{FT}{s}\ SLUG$$

$$= 7.9\ lb_F$$

LJ FEB 23, 2016 17

Sunglasses Case Dimensions

Model	Height ["]	Width ["]	Length ["]	C.S. Shape ["]
S1	1.00	2.25	6.00	Rectangular
AS302	1.00	2.25	6.00	Rectangular
AS196	0.75	2.19	5.75	Rectangular
Oakley Square O Hard Case	2.00	3.00	6.20	Rectangular
Oakley Pill Case	2.25	2.25	6.63	Cicular
Rugged Optics Case	2.68	3.42	7.10	Oval
Avenue Lou	2.50	3.00	6.50	Clam
Avenue Lou Large	3.00	3.50	6.50	Clam
Average	1.90	2.73	6.33	

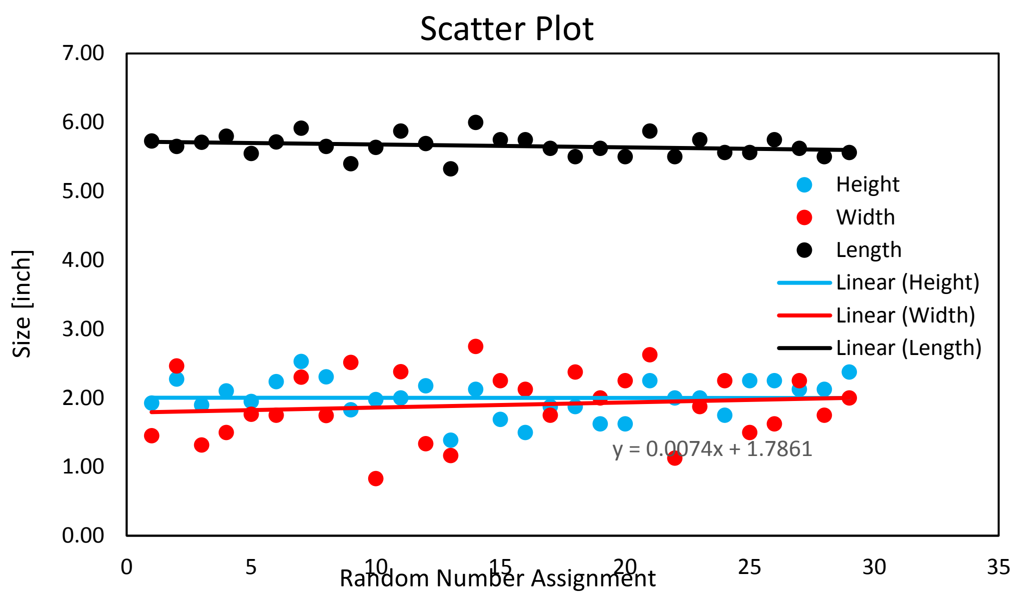
Sunglasses Dimensiosn

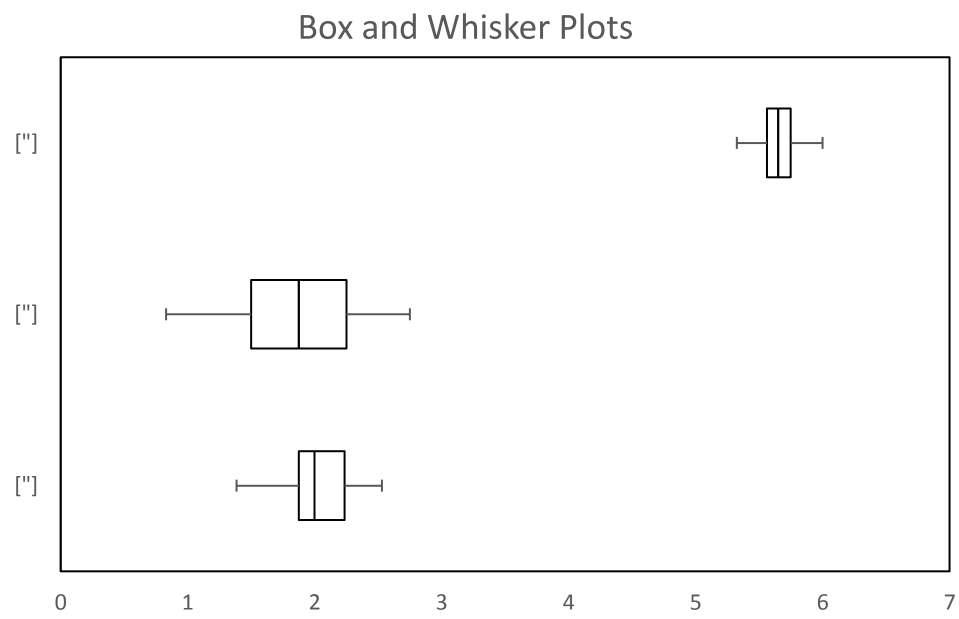
Model	Height ["]	Width ["]	Length ["]	#
townies	1.93	1.45	5.73	1
VZ Mindglo	2.28	2.47	5.65	2
Google Townies	1.90	1.32	5.71	3
Stun Shades	2.10	1.50	5.80	4
.Dash Cannonball	1.95	1.77	5.55	5
.Dash Young Turks	2.24	1.75	5.72	6
Transformers	2.53	2.30	5.92	7
Kreed Mac&Cheese	2.31	1.75	5.65	8
U.O. ZQ5050	1.83	2.52	5.40	9
Ray Ban KO Aviators	1.98	0.83	5.64	10
Safety Glasses	2.00	2.38	5.88	11
.Dash Staghorn	2.18	1.34	5.70	12
Spy Dane (vision)	1.39	1.17	5.33	13
Oakley Saw Breaker	2.13	2.75	6.00	14
Oakley Flak 2.0	1.69	2.25	5.75	15
Maui Jim MJ Sports	1.50	2.13	5.75	16
Oakley Mainlink	1.88	1.75	5.63	17
Oakley Batwolf	1.88	2.38	5.50	18
Oakley Gascan	1.63	2.00	5.63	19
Arnette AN4147	1.63	2.25	5.50	20
Oakley Jaw Breaker	2.25	2.63	5.88	21
RayBan OG Aviators	2.00	1.13	5.50	22
RayBan RB3393	2.00	1.88	5.75	23
RayBan Cats 5000	1.75	2.25	5.56	24
Tory Burch TY9034	2.25	1.50	5.56	25
Michael Kors MK6017	2.25	1.63	5.75	26
Michael Kors MK5050	2.13	2.25	5.63	27
Michael Kors MK5004	2.13	1.75	5.50	28
Vogue VO2669S	2.38	2.00	5.56	29

Sunglasses Dimensiosn

Model	Height ["]	Width ["]	Length ["]	#
Vogue VO5033S	2.25	1.63	5.50	30
Coach Noelle	1.88	2.13	5.56	31
Coach 5344T356	2.13	1.88	5.63	32
RalphP RA5202	2.00	1.63	6.00	33
RalphP RA4106	2.13	2.50	5.38	34
Prada PR27NS	2.63	1.50	5.75	35
Versace VE4284	2.25	1.75	5.88	36
Persol PO9649S	2.00	1.88	5.50	37
Generic Aviators	2.20	0.65	5.50	38
Wannabe raybands	2.00	1.25	5.85	39
Some girl sunglasses	2.13	1.19	6.06	40
Mean	2.00	1.90	5.66	
Q1-Min	0.49	0.67	0.24	
Minimum	1.385	0.830	5.325	
Q1	1.875	1.5	5.5625	
Median-Q1	0.13	0.38	0.09	
Median	2.00	1.88	5.65	
Q3-Median	0.24	0.38	0.10	
Q3	2.235	2.25	5.75	
Maximum	2.53	2.75	6.00	
Max-Q3	0.30	0.50	0.25	
Stand. Dev.	0.272	0.492	0.154	
Dimensions(75%, z=.68)	2.2	2.2	5.8	

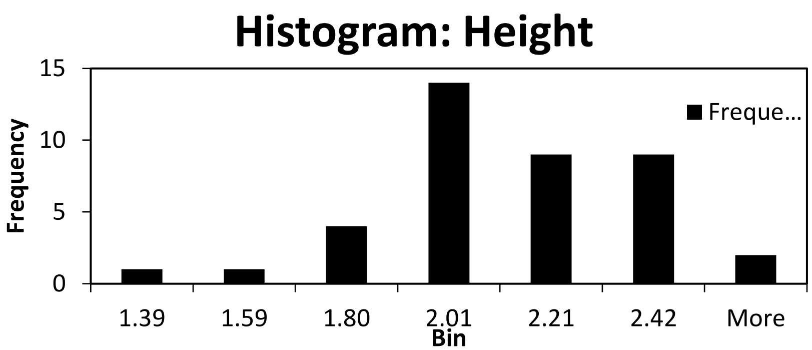
Money Numbers

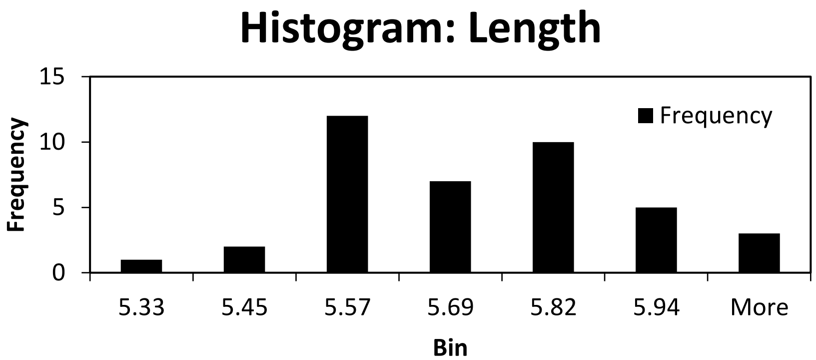

Scatter Plot
Size [inch]
Random Number Assignment
Height
Width
Length
Linear (Height)
Linear (Width)
Linear (Length)
y = 0.0074x + 1.7861

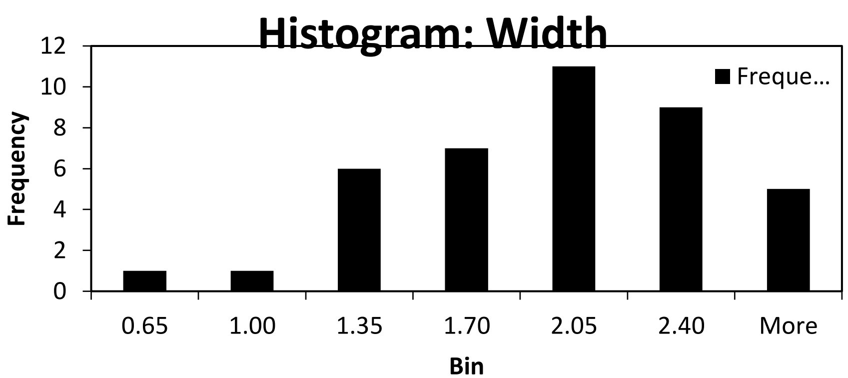

Box and Whisker Plots
["]
["]
["]

	75%
z	0.68

Height		Width		Length	
Bin	*Frequency*	*Bin*	*Frequency*	*Bin*	*Frequency*
1.39	1	0.65	1	5.33	1
1.59	1	1.00	1	5.45	2
1.80	4	1.35	6	5.57	12
2.01	14	1.70	7	5.69	7
2.21	9	2.05	11	5.82	10
2.42	9	2.40	9	5.94	5
More	2	More	5	More	3





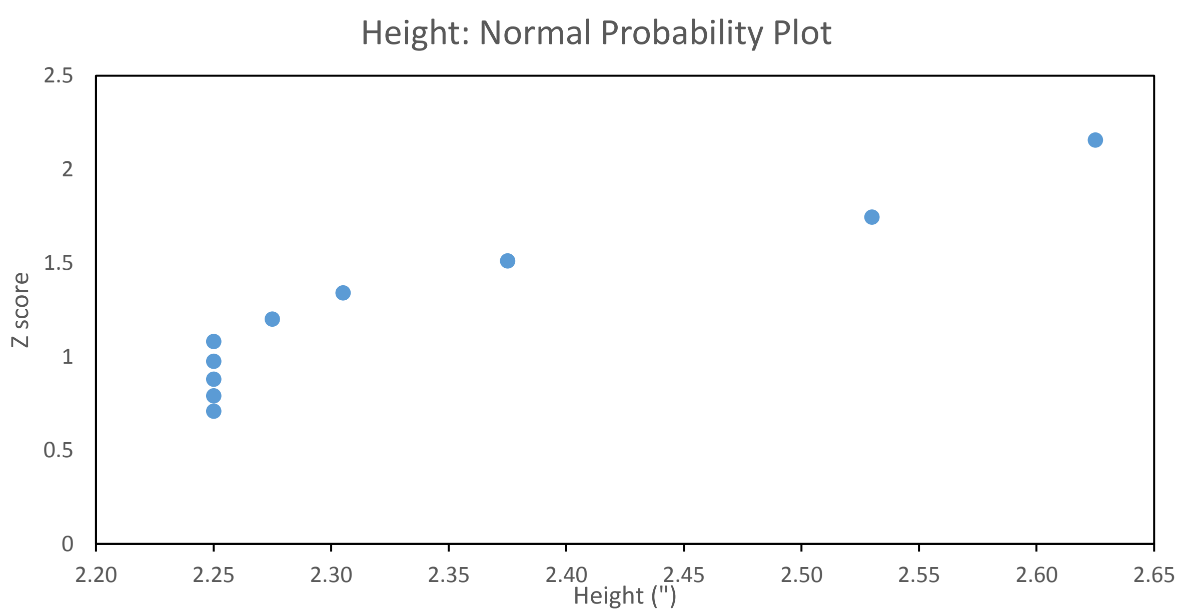


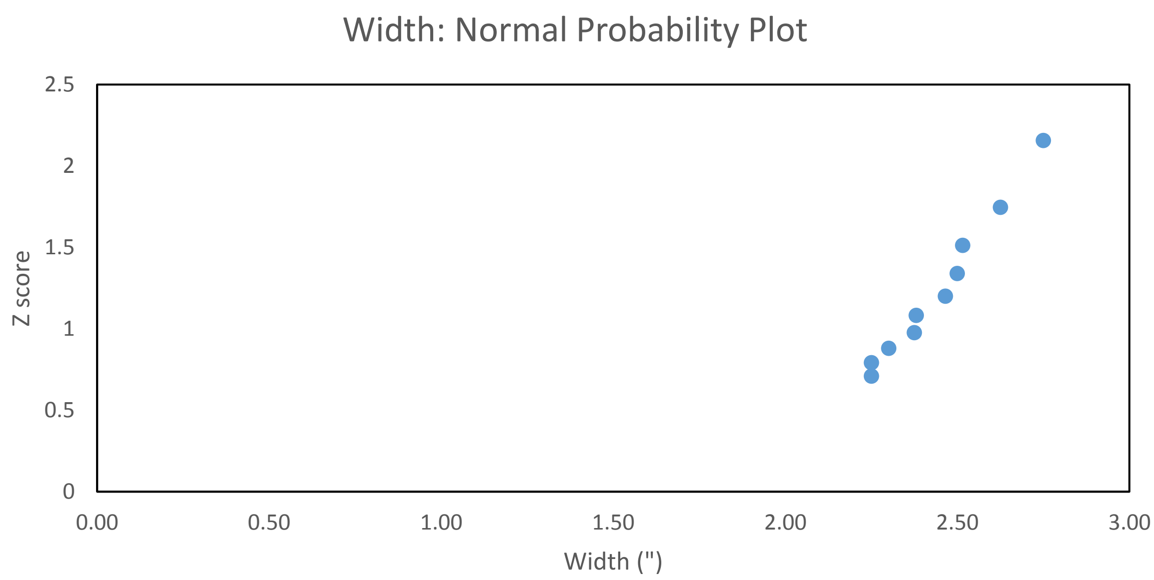
Normal Probability Plot

X	Height	f_i =	z-value	Width	fi =	z-value	Length	fi =	z-value
1	1.39	0.01553	-2.15636	0.65	0.01553	-2.15636	5.33	0.01553	-2.15636
2	1.50	0.04037	-1.74638	0.83	0.04037	-1.74638	5.38	0.04037	-1.74638
3	1.63	0.06522	-1.51239	1.13	0.06522	-1.51239	5.40	0.06522	-1.51239
4	1.63	0.09006	-1.34037	1.17	0.09006	-1.34037	5.50	0.09006	-1.34037
5	1.69	0.11491	-1.20084	1.19	0.11491	-1.20084	5.50	0.11491	-1.20084
6	1.75	0.13975	-1.08144	1.25	0.13975	-1.08144	5.50	0.13975	-1.08144
7	1.83	0.1646	-0.97574	1.32	0.1646	-0.97574	5.50	0.1646	-0.97574
8	1.88	0.18944	-0.87996	1.34	0.18944	-0.87996	5.50	0.18944	-0.87996
9	1.88	0.21429	-0.79164	1.45	0.21429	-0.79164	5.50	0.21429	-0.79164
10	1.88	0.23913	-0.7091	1.50	0.23913	-0.7091	5.50	0.23913	-0.7091
11	1.90	0.26398	-0.63114	1.50	0.26398	-0.63114	5.55	0.26398	-0.63114
12	1.93	0.28882	-0.55684	1.50	0.28882	-0.55684	5.56	0.28882	-0.55684
13	1.95	0.31366	-0.48549	1.63	0.31366	-0.48549	5.56	0.31366	-0.48549
14	1.98	0.33851	-0.41653	1.63	0.33851	-0.41653	5.56	0.33851	-0.41653
15	2.00	0.36335	-0.34951	1.63	0.36335	-0.34951	5.56	0.36335	-0.34951
16	2.00	0.3882	-0.28402	1.75	0.3882	-0.28402	5.63	0.3882	-0.28402
17	2.00	0.41304	-0.21972	1.75	0.41304	-0.21972	5.63	0.41304	-0.21972
18	2.00	0.43789	-0.15633	1.75	0.43789	-0.15633	5.63	0.43789	-0.15633
19	2.00	0.46273	-0.09355	1.75	0.46273	-0.09355	5.63	0.46273	-0.09355
20	2.00	0.48758	-0.03114	1.75	0.48758	-0.03114	5.64	0.48758	-0.03114
21	2.10	0.51242	0.03114	1.77	0.51242	0.03114	5.65	0.51242	0.03114
22	2.13	0.53727	0.09355	1.88	0.53727	0.09355	5.65	0.53727	0.09355
23	2.13	0.56211	0.15633	1.88	0.56211	0.15633	5.70	0.56211	0.15633
24	2.13	0.58696	0.21972	1.88	0.58696	0.21972	5.71	0.58696	0.21972
25	2.13	0.6118	0.28402	2.00	0.6118	0.28402	5.72	0.6118	0.28402
26	2.13	0.63665	0.34951	2.00	0.63665	0.34951	5.73	0.63665	0.34951
27	2.13	0.66149	0.41653	2.13	0.66149	0.41653	5.75	0.66149	0.41653
28	2.18	0.68634	0.48549	2.13	0.68634	0.48549	5.75	0.68634	0.48549
29	2.20	0.71118	0.55684	2.25	0.71118	0.55684	5.75	0.71118	0.55684
30	2.24	0.73602	0.63114	2.25	0.73602	0.63114	5.75	0.73602	0.63114

31	2.25	0.76087	0.7091	2.25	0.76087	0.7091	5.75	0.76087	0.7091
32	2.25	0.78571	0.79164	2.25	0.78571	0.79164	5.80	0.78571	0.79164
33	2.25	0.81056	0.87996	2.30	0.81056	0.87996	5.85	0.81056	0.87996
34	2.25	0.8354	0.97574	2.38	0.8354	0.97574	5.88	0.8354	0.97574
35	2.25	0.86025	1.08144	2.38	0.86025	1.08144	5.88	0.86025	1.08144
36	2.28	0.88509	1.20084	2.47	0.88509	1.20084	5.88	0.88509	1.20084
37	2.31	0.90994	1.34037	2.50	0.90994	1.34037	5.92	0.90994	1.34037
38	2.38	0.93478	1.51239	2.52	0.93478	1.51239	6.00	0.93478	1.51239
39	2.53	0.95963	1.74638	2.63	0.95963	1.74638	6.00	0.95963	1.74638
40	2.63	0.98447	2.15636	2.75	0.98447	2.15636	6.06	0.98447	2.15636

f_i =	(i-.375)/(n+.25)
n	40

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Z score
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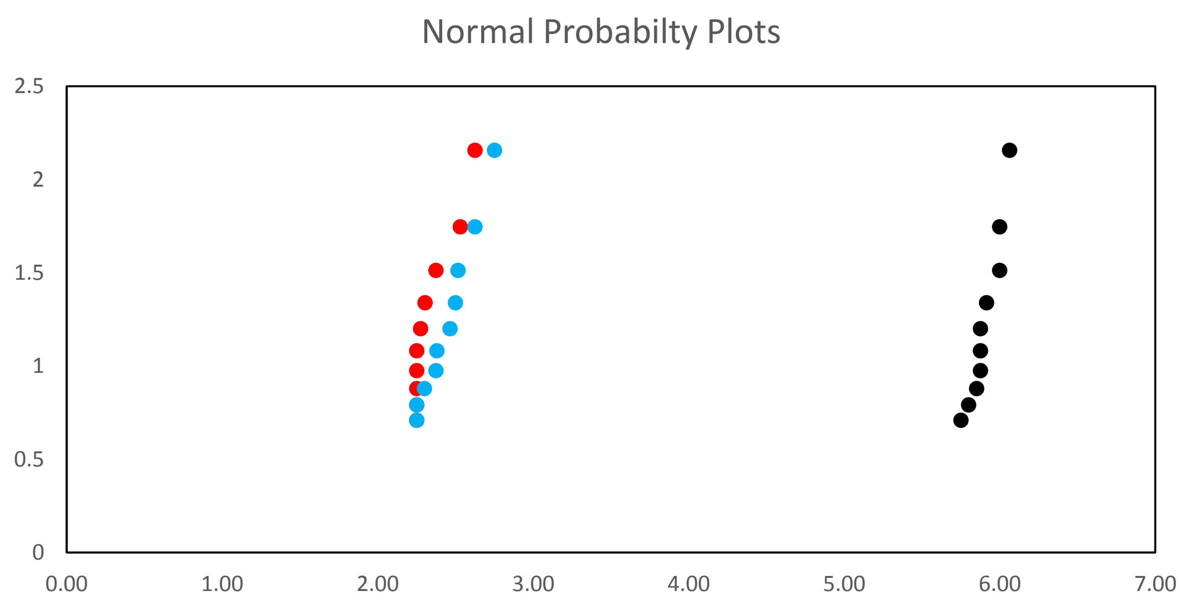
2
1.5
1
0.5
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Width (")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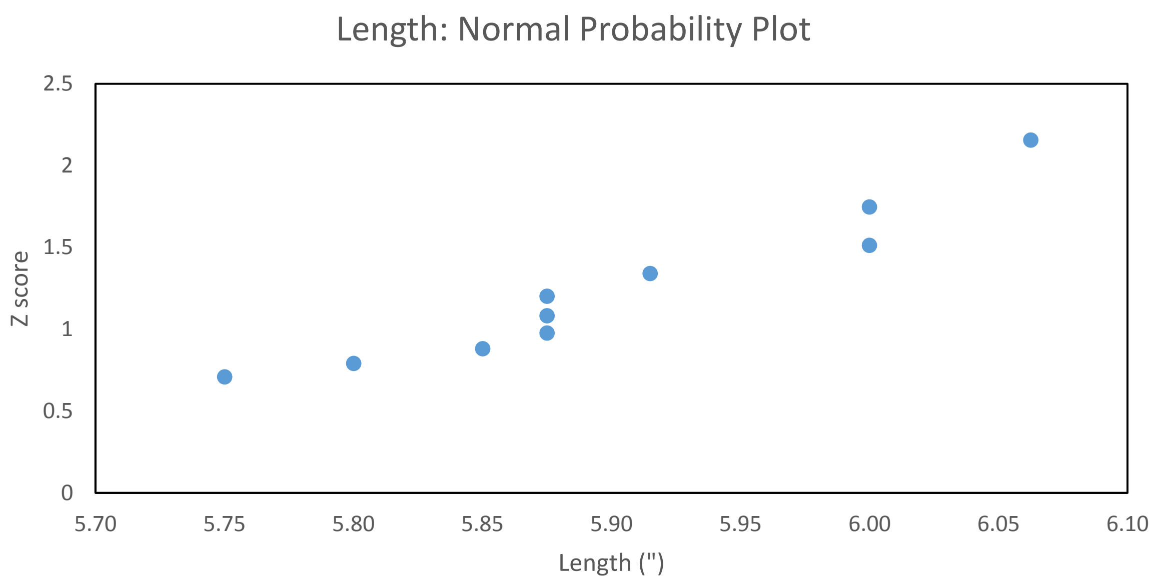
7.00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1
0.5
0
5.70
5.75
5.80
5.85
5.90
5.95
6.00
6.05
6.10
Length (")

Cost Analysis

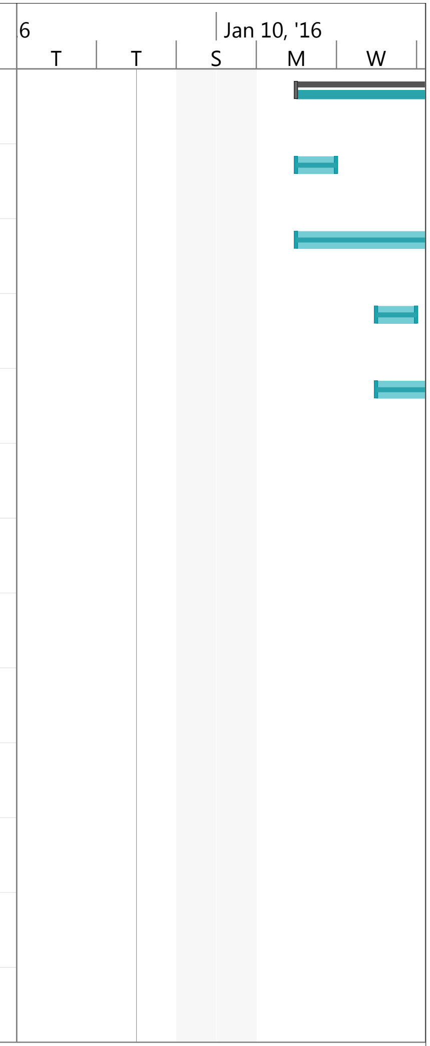
Material	Quantity/Part	Price/Quantity	Waste (%)	Direct Material Cost
Carbon Fiber (in^2)	147	0.05275	5	8.162368421
Nylon Straps (in^2)	12	0.014	10	0.186666667
Fleece (in^2)	45	0.0029	15	0.153529412
Magnets (ea)	4	0.046	0	0.184
Glue (oz)	0.1	0.125	10	0.013888889
Molds/Tooling	500			5
Order Qty (cases)	50			
			Total	13.70045339

Labor	Rate ($/Hr)	Qty/Hr	Scrap (%)	Direct Labor Cost
Molding	18	4	5	4.7368
Finishing	22	12	1	1.8519
Assembly	15	6	1	2.5253
			Total	9.1139

Total Cost Per Finished Case	45.6288

Appendix I: Gantt Chart

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1	✓		**Project Introduction**	**8 days**	**Tue 1/12/16**	**Thu 1/21/16**	
2	✓		Intro Letter	1 day	Tue 1/12/16	Tue 1/12/16	
3	✓		Team Contract	6 days	Tue 1/12/16	Tue 1/19/16	
4	✓		Sponsor Conference	1 day	Thu 1/14/16	Thu 1/14/16	
5	✓		Problem Statement	6 days	Thu 1/14/16	Thu 1/21/16	
6	✓		Conference Call w/ Tech Advisors	1 day	Thu 1/21/16	Thu 1/21/16	
7	✓		**Define Problem**	**9 days**	**Thu 1/21/16**	**Tue 2/2/16**	
8	✓		Project Scope	1 day	Thu 1/21/16	Thu 1/21/16	
9	✓		Define Customer Needs	4 days	Thu 1/21/16	Tue 1/26/16	
10	✓		Market Research	9 days	Thu 1/21/16	Tue 2/2/16	
11	✓		Prelim. QFD Diagram	3 days	Tue 1/26/16	Thu 1/28/16	
12	✓		Project Proposal	4 days	Thu 1/28/16	Tue 2/2/16	
13	✓		PROJECT PROPOSAL DUE	0 days	Tue 2/2/16	Tue 2/2/16	



Project: Simple Project Plan
Date: Thu 4/28/16

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
14			**Conceptualize**	**14 days**	**Tue 2/2/16**	**Fri 2/19/16**	
15	✓		List Ideas	7 days	Tue 2/2/16	Wed 2/10/16	9
16	✓		Build Foam Prototypes	1 day	Thu 2/11/16	Thu 2/11/16	15
17			Obtain Current Products	11 days	Sat 2/6/16	Fri 2/19/16	10
18	✓		Research Existing DIY Projects	7 days	Sat 2/6/16	Mon 2/15/16	
19	✓		Final Ideation	4 days	Tue 2/16/16	Fri 2/19/16	16,18
20	✓		**Evaluate Concepts**	**16 days**	**Sat 2/20/16**	**Fri 3/11/16**	
21	✓		Compare Ideas	3 days	Sat 2/20/16	Tue 2/23/16	19
22	✓		Update QFD	1 day	Tue 2/23/16	Tue 2/23/16	17,19
23	✓		Preliminary Drawings	4 days	Wed 2/24/16	Sun 2/28/16	21
24	✓		Outline DVT procedures	2 days	Fri 2/26/16	Sun 2/28/16	
25	✓		PD REPORT DUE	0 days	Mon 2/29/16	Mon 2/29/16	22,23,24
26	✓		SPONSOR PD REVIEW DEADLINE	0 days	Fri 3/11/16	Fri 3/11/16	

6 | Jan 10, '16

T | T | S | M | W

Project: Simple Project Plan
Date: Thu 4/28/16

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID	ℹ	Task Mode	Task Name	Duration	Start	Finish	Predecessors
27			**Detail Design/Molding Practice**	**48 days**	**Tue 3/1/16**	**Thu 5/5/16**	
28	✓		Final Rough Prototypes	8 days	Mon 2/29/16	Wed 3/9/16	23
29			Obtain Current Materials	16 days	Fri 3/11/16	Fri 4/1/16	
30	✓		Heat Transfer Analysis	21 days	Tue 3/29/16	Tue 4/26/16	37
31			Order Release Agents, Acquired	20 days	Mon 4/4/16	Fri 4/29/16	29
32	✓		Quatro Advisors Visit	1 day	Fri 4/8/16	Fri 4/8/16	
33	✓		Fly Box Practice	14 days	Mon 4/11/16	Thu 4/28/16	31
34			FINAL DESIGN REPORT	0 days	Tue 5/3/16	Tue 5/3/16	
35			SPONSOR CRITICAL DESIGN REVIEW DEADLINE	0 days	Thu 5/5/16	Thu 5/5/16	34
36			**Prototyping (3D Modeling)**	**47 days**	**Thu 3/10/16**	**Fri 5/13/16**	
37	✓		Initial CAD Drawing	19 days	Thu 3/10/16	Tue 4/5/16	28
38	✓		3D Print First Design	2 days	Fri 4/8/16	Mon 4/11/16	37
39	✓		Analyze Design	9 days	Tue 4/12/16	Fri 4/22/16	38

6 | Jan 10, '16

T T S M W

Project: Simple Project Plan
Date: Thu 4/28/16

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
40	✓		Recreate CAD Model	2 days	Mon 4/25/16	Tue 4/26/16	39
41			3D Print Second Design	3 days	Thu 4/28/16	Mon 5/2/16	40
42			Analyze and Finalize Design	5 days	Tue 5/3/16	Mon 5/9/16	41
43			Update QFD	0 days	Tue 5/10/16	Tue 5/10/16	42
44			**First Manufacture**	**20 days**	**Mon 5/9/16**	**Fri 6/3/16**	
45			Fabrication Process Outline	4 days	Tue 5/10/16	Fri 5/13/16	42
46			Finalize Design	4 days	Tue 5/10/16	Fri 5/13/16	42
47			Parts Ordered, Acquired	15 days	Mon 4/11/16	Fri 4/29/16	45
48			Program Mold Fabrication	2 days	Mon 5/16/16	Tue 5/17/16	45,46
49			Fabricate Mold	6 days	Wed 5/18/16	Wed 5/25/16	48,47
50			First Product Completed	5 days	Wed 5/25/16	Tue 5/31/16	49
51			Senior Project Expo	1 day	Fri 6/3/16	Fri 6/3/16	50
52			**Validate & Test**	**25 days**	**Mon 5/9/16**	**Fri 6/10/16**	

6 | Jan 10, '16
T T S M W

Project: Simple Project Plan
Date: Thu 4/28/16

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

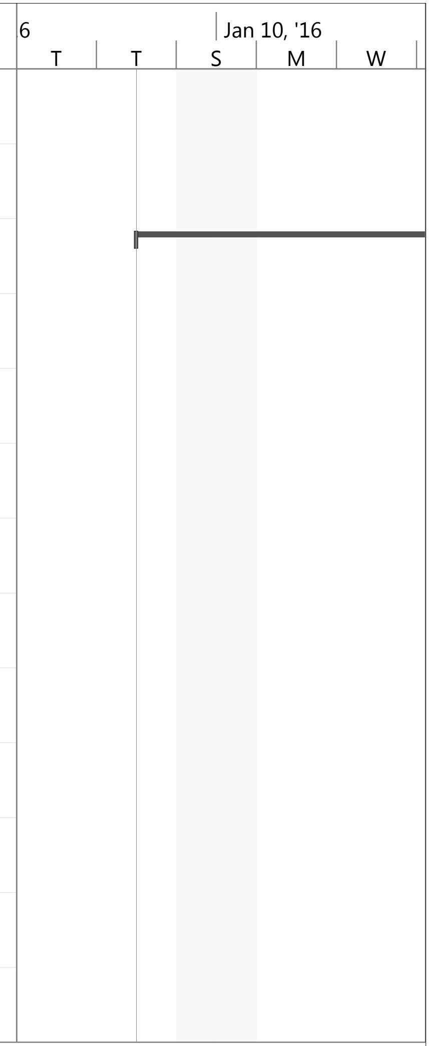
ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
53			Test Current Products	5 days	Mon 5/9/16	Fri 5/13/16	
54			DVT First Production	8 days	Wed 6/1/16	Fri 6/10/16	50
55			Peer Review on Product	3 days	Wed 6/1/16	Fri 6/3/16	50
56			Update QFD	6 days	Fri 6/3/16	Fri 6/10/16	53,54,55
57			**Second Manufacture (if needed)**	**20 days**	**Mon 9/19/16**	**Fri 10/14/16**	
58			Fabrication Review	4 days	Mon 9/19/16	Thu 9/22/16	
59			Final Product	6 days	Fri 9/23/16	Fri 9/30/16	58
60			DVT Final Product	6 days	Fri 9/30/16	Fri 10/7/16	59
61			**Report**	**51 days**	**Thu 9/22/16**	**Thu 12/1/16**	
62			Final BOM	3 days	Mon 9/19/16	Wed 9/21/16	
63			Final Product Review	4 days	Fri 9/30/16	Wed 10/5/16	
64			Extra Production	18 days	Wed 10/5/16	Fri 10/28/16	63
65			MFG and Test Review	8 days	Fri 10/28/16	Tue 11/8/16	64

6 | Jan 10, '16
T T S M W

Project: Simple Project Plan
Date: Thu 4/28/16

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	Predecessors
66			PROJECT UPDATE MEMO	0 days	Fri 9/30/16	Fri 9/30/16	62,63
67			FINAL PROJECT REPORT	0 days	Fri 10/28/16	Fri 10/28/16	65,66
68			**Individual Assignments**	**238 days**	**Fri 1/8/16**	**Tue 12/6/16**	
69	✓		1st Team Evaluation	0 days	Thu 2/4/16	Thu 2/4/16	
70	✓		1st Reflection	0 days	Thu 2/11/16	Thu 2/11/16	
71	✓		Gold Card	22 days	Thu 1/21/16	Fri 2/19/16	
72	✓		Yellow Card	0 days	Thu 3/3/16	Thu 3/3/16	
73			2nd team Evaluation	0 days	Tue 3/8/16	Tue 3/8/16	
74			2nd Reflection	0 days	Tue 3/8/16	Tue 3/8/16	
75			3rd Team Evaluation, Reflection	0 days	Tue 5/3/16	Tue 5/3/16	
76			Ethics Memo	0 days	Thu 5/12/16	Thu 5/12/16	
77			4th Team Evaluation, Reflection	0 days	Thu 6/2/16	Thu 6/2/16	
78			5th Team Evaluation, Reflection	0 days	Thu 10/27/16	Thu 10/27/16	



Project: Simple Project Plan
Date: Thu 4/28/16

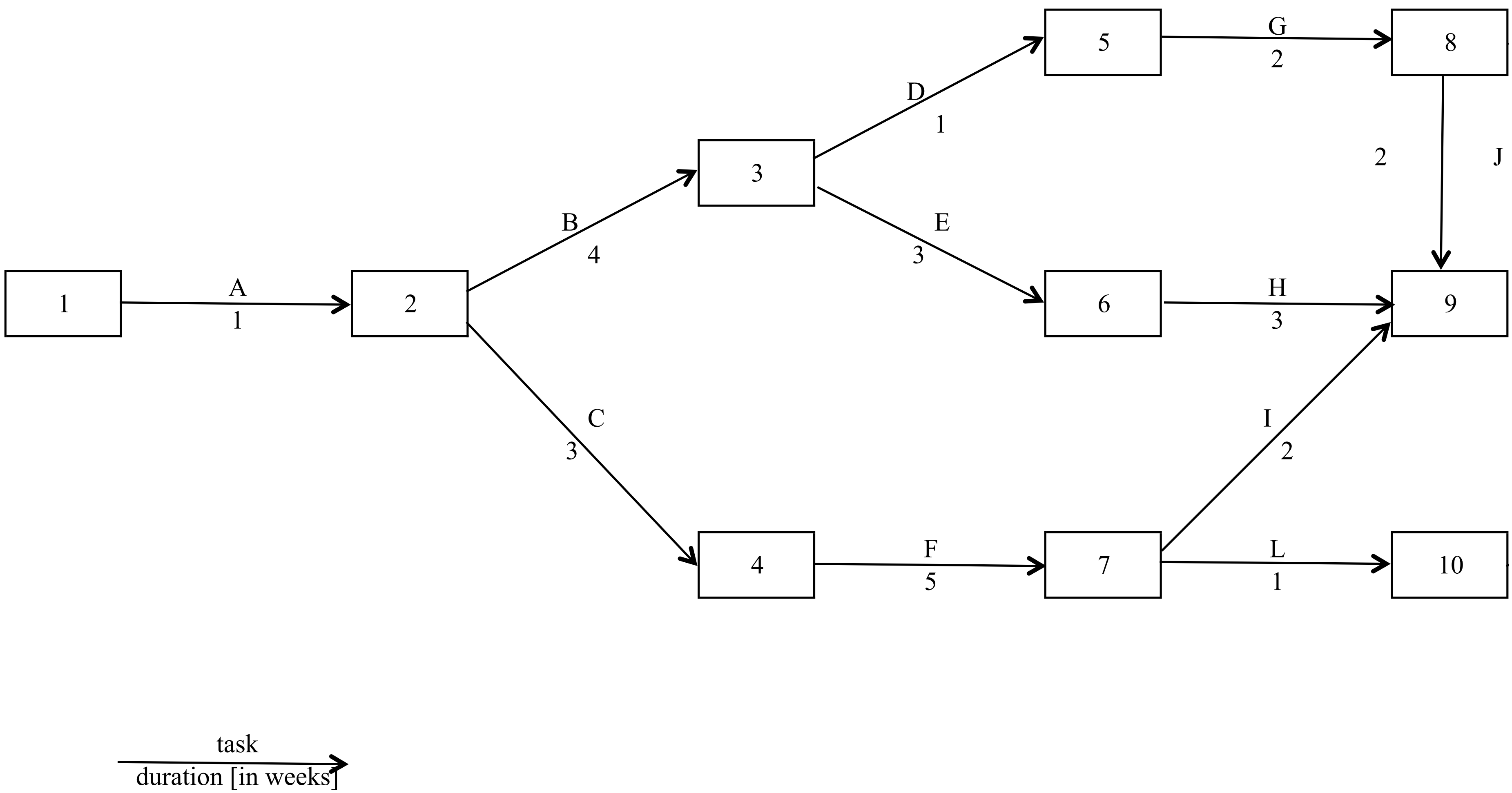
Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	6 / Jan 10, '16 (T T S M W)
79			6th Team Evaluation, Reflection	0 days	Tue 12/6/16	Tue 12/6/16		

Project: Simple Project Plan
Date: Thu 4/28/16

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

	Task	Duration [weeks]	Predecessors
A	Project intro	1	-
B	Market research	4	A
C	Contact sponsors/tech advisors	3	A
D	Obtain current products	1	B
E	Conceptualize	3	B
F	Gold card and yellow tag	5	C
G	Test current products	2	D
H	Refine ideas	3	E
I	Training to use heat press	2	F
J	Project proposal	2	G
K	Select final design	2	H,I,J
L	Visit Quatro & get molds	1	F
M	Prototype several designs	2	G
N	Preliminary design report	2	K
O	Practice compression molding	3	L
P	CAD modeling	3	M,N,O
Q	Order parts	2	M,N,O
R	Consult tech advisors	6	P
S	Manufacture	6	Q
T	Validate & test	6	R,S
U	Final report & product	4	T
V	Project expo	1	U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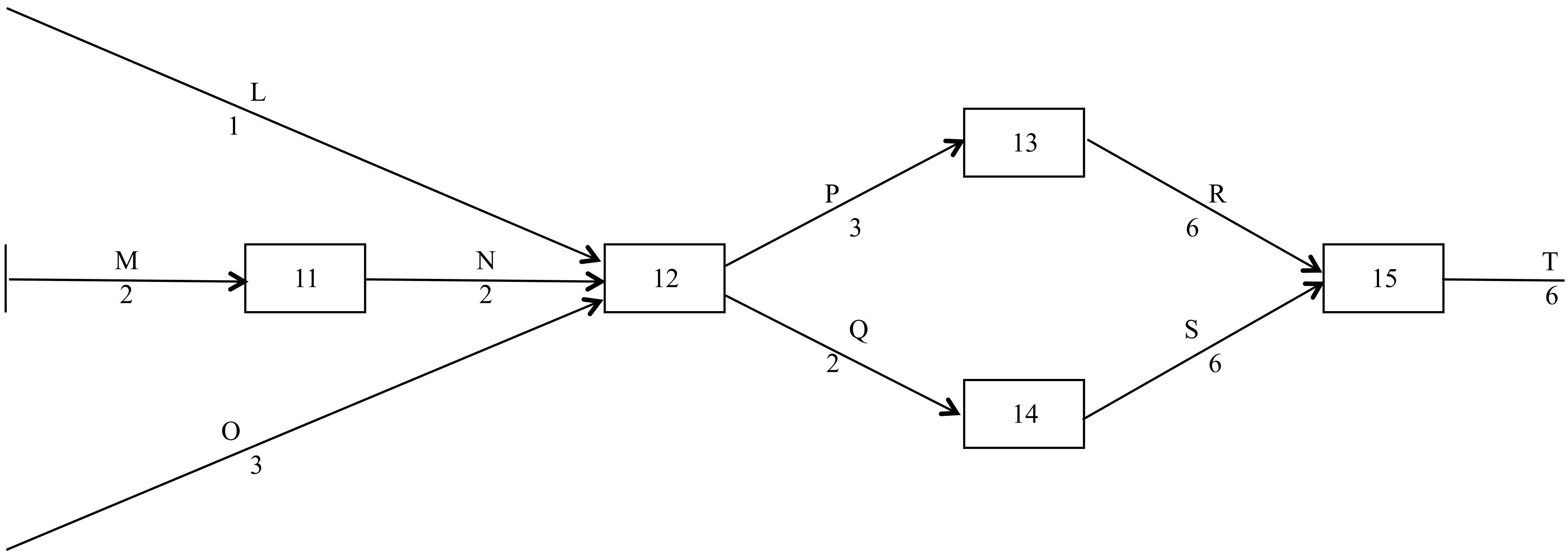
10
task
duration [in weeks]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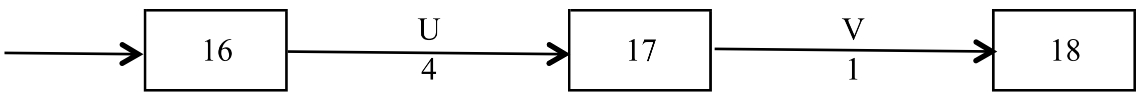
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ME428/429/430 Senior Design Project 2015-2016

SENIOR PROJECT CRITICAL DESIGN HAZARD IDENTIFICATION CHECKLIST

Team: Comp³ Advisor: Prof Davol

Y	N	
☐	☒	Do any parts of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points adequately guarded?
☐	☒	Does any part of the design undergo high accelerations/decelerations that are exposed to the user?
☐	☒	Does the system have any large moving masses or large forces that can contact the user?
☐	☒	Does the system produce a projectile?
☐	☒	Can the system to fall under gravity creating injury?
☐	☒	Is the user exposed to overhanging weights as part of the design?
☐	☒	Does the system have any sharp edges exposed?
☐	☒	Are there any ungrounded electrical systems in the design?
☐	☒	Are there any large capacity batteries or is there electrical voltage in the system above 40 V either AC or DC?
☐	☒	Is there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids when the system is either on or off?
☐	☒	Are there any explosive or flammable liquids, gases, dust, or fuel in the system?
☐	☒	Is the user of the design required to exert any abnormal effort and/or assume a an abnormal physical posture during the use of the design?
☒	☐	Are there any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☒	Will the system generate high levels of noise?
☐	☒	Will the product be subjected to extreme environmental conditions such as fog, humidity, cold, high temperatures ,etc. that could create an unsafe condition?
☐	☒	Is it easy to use the system unsafely?
☐	☒	Are there any other potential hazards not listed above? If yes, please explain on the back of this checklist.

For any "Y" responses, add a complete description on the reverse side. DO NOT fill in the corrective actions or dates until you meet with the mechanical and electrical technicians.

Description of Hazard	Corrective Actions to Be Taken	Planned Completion Date	Actual Completion Date
HAZARDOUS FUMES FROM RELEASE AGENT	USE IN WELL VENTILATED AREA	N.A.	N.A.

LAB

Composite Compression Molding

Joanne Medrano – Greg Hermansen – Larsson Johnson – Kyle Hammell

Objectives

The following lab is designed to allow students to explore the capabilities and process of compression molding. It is another form of manufacturing used for composite components.

Students will create a sunglasses case through a manufacturing process that will help them explore the capabilities and limitations of compression molding.

Once finished with the lab, students will have created a product from start to finish that is heavily manufacturing based and demonstrates process flow and product development.

Introduction

Autoclave molding is still a common method of molding, especially in the aerospace industry where parts require a high strength-to-weight ratio. An autoclave, pictured in Figure 1, is a heated pressure vessel containing pressure and vacuum systems.

Figure 1. An industrial size autoclave used for creating composite parts [1]

To autoclave mold a part, the lay-up on the mold is vacuum-bagged then put into an autoclave, which is then pressurized and heated. The part is held at the desired temperature and pressure for a specific amount of time, after which the autoclave is cooled and depressurized in order to safely remove the cured part. This entire process can take hours and, as stated above, produces a lot of waste. The compression molding method is similar to the autoclave method in that sheets of high strength fibers pre-impregnated with resin, also known as pre-preg, are shaped and cured. However, using an autoclave is different than compression molding which is described in more detail following.

The biggest notable characteristic of compression molding is that it uses a heat press, such as the one shown in Figure 2, which has systems for controlling applied temperature and pressure.

Figure 2. Cal Poly heat press

These heat presses must be large enough to contain the entire mold for the part just like an autoclave, but they are much less costly to operate and have a lower cycle time with faster loading and process execution times. Prior to inserting a mold in a press though a compression molded component must have pre-impregnated sheets of fibers laid up in the negative half of a mold, have the positive half mated with the negative half, and then compress the entire mold set in the preheated press for a specific amount of time. The mold set can be removed from the heat press once the desired time has been met and then the cured part released from the mold halves. The entire compression molding process usually takes less than an hour (in our case less than 20 minutes) and yields a near net shape part with little waste. These characteristics make it an ideal process for a Cal Poly engineering lab session.

Equipment and Material

All equipment needed for this lab is detailed in the list below. Note that some of this material will only be handled by the professor.

- Aluminum silicone mold
- Partially cured silicone
- Aluminum composite mold
- Case lay-up material
    - Bi-directional carbon fiber case patterns
    - Uni-directional carbon fiber sheets
    - Bi-directional carbon fiber strips
    - Mold release agent
- Heat Press
- Plastic film
- Dremel
- Flash removal jig
- Drill press
- Magnet hole jig
- Cylindrical magnets
- Hot Knife
- Epoxy

Laboratory Procedures

Molding

Turn the heat press on making sure the temperature is set to 285°F, which yields a 15-minute cure time for carbon fiber. Allow to heat up for several minutes. Be cautious as the press, even when hot, will not appear so.

While the press is heating up, lay up the composite mold following the diagram displayed in Figure 3 as well as the subset of instructions following:

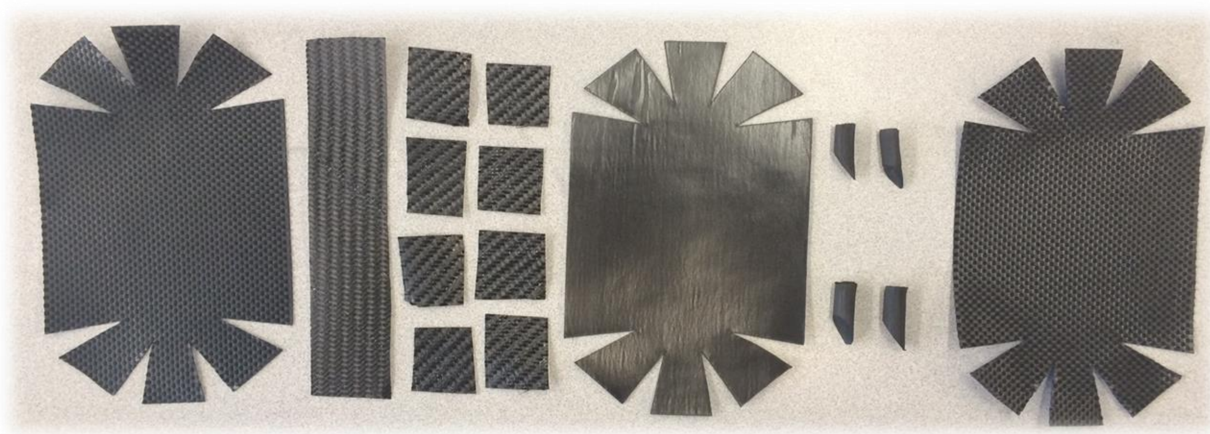

Figure 3. Complete carbon fiber pieces for a case half

1. Coat the aluminum mold in release agent and buff thoroughly.

2. Place the first patterned cut out—coined the "money layer" as it will be the outermost layer—in the mold and press form it to the shape of the mold using your fingers. (The best way to insert the layers would be by lightly creasing and folding the edges inwards, as seen in Figure 4, then unfurling it within the aluminum mold.)

Figure 4. Carbon fiber pattern with edges folded inward

3. Lay a strip of bi-directional carbon fiber perpendicular to the long axis of the case. This strip should be long enough that it lies partially on the top of the aluminum mold on both sides, which will provide a tab with which to remove the case once it has cured.

4. With another strip of bi-directional carbon fiber cut it into approximately 1”x1” squares. Place these clips on each seem of the first layer, as presented in Figure 5. This will help to ensure these points of initial weakness cure together to form a strong continuous end sheet.

Figure 5. 1” x 1” clips placed on seems

5. Roll up uni-directional carbon fiber into tight rolls approximately 3/8” in diameter. Cut this roll into 1” segments and then cut one end of each segment at a 45° angle; 4 of these segments are needed per case half.

   Once these rolls are created, place one in each corner of the case with the slanted end laying down into the case allowing the roll to sit vertically.

6. Insert the second patterned uni-directional cut out into the aluminum mold. Ensure that all edges are thoroughly pressed. Figure 6 shows how to easily lay up the pattern in the mold.

Figure 6. Lay up of second patterned uni-directional cut out in mold

7. Place the third patterned carbon fiber layer into the aluminum mold. At this point, ensure that the carbon fiber pieces are well press formed into the shape of the mold.

8. Take the plastic film (approximately 8"x8") and wrap the silicone insert. Carefully place the silicone, cover in plastic, into the aluminum mold. Ensure that the silicone is fully pressed into the mold; it might be a little snug.

9. Spray the heat press with release agent to prevent the excess resin that flows out of the carbon fiber from sticking to the two plates. Use gloves to carefully place the prepared aluminum mold into the heat press; making certain that the silicone is fully covered under the heated plates.

   Compress to roughly 100 psi material pressure, which equates to roughly 1700 pounds on the press read out. Leave in the heat press for about 15 minutes at 285°F. Another way to determine if the carbon fiber has fully cured is to see if the flashed resin has a jell like feel and consistency (General rule of thumb for cure times: at 250°F, allow 1 hour of cure time. Every 15°F increment increase in temperature cuts the cure time in half.).

10. Once sufficient time has elapsed carefully remove the aluminum mold from the heat press. The silicone should easily pop out. Run water over the silicone to cool it quickly.

Wait a few minutes before taking out the composite component. Use a joint/taping knife to assist with extraction of the cured composite. Grab the pull tab with pliers and lift straight up if the part is stuck or difficult to remove.

11. Repeat steps 1 through 10 for the second case half.

Post Process Finishing

Once two molded halves have successfully been created post processing can begin. To start, the flashing on the halves will need to be trimmed away. Use the provided jig and Dremel to trim each mold half to height. Place the flat side of the case on the table with the opening up and rotate it slowly allowing the tool to cut off all the excess flashing. Be careful to keep your fingers clear of the cut-off disk!

Next, move on to the drill press and use the provided jig to drill $^1/_8$" holes in each of the corner nubs to the pre-set depth, which is about ¼" down. Be careful to drill the holes as accurately as possible so the magnets will align the case halves properly later on.

Lightly sand (roughly 1mm depth) the long edges of the halves, as seen in Figure 7. This creates space for the ribbons and allows the two halves to shut fully.

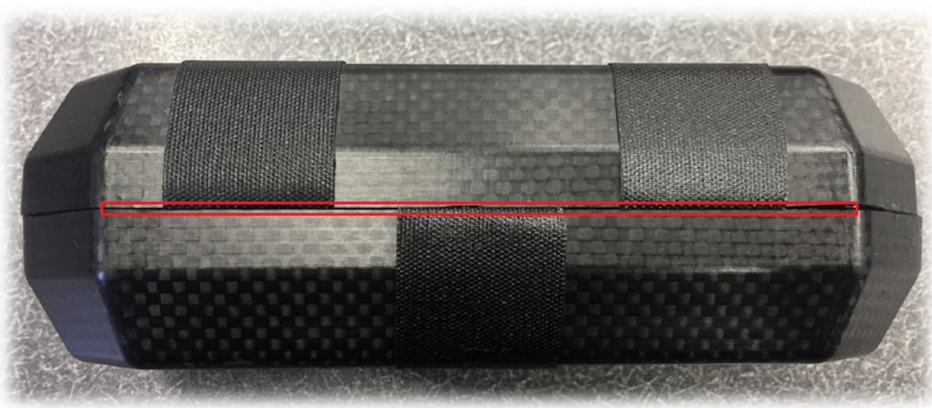

Figure 7. Sand off the carbon fiber enclosed in the red box

Assembly

After post processing, the sunglass case can now be assembled. The necessary materials for this are:

- Two post process finished case halves
- 8 x $\frac{1}{8}$" diameter, ¼" long axially magnetized magnets
- Two fleece pre-cut patterns
- Two part Super Instant Epoxy
- 3M spray adhesive
- 3 x 6" long, 1" wide ballistic nylon fabric strips
- Optional: binder clips

1. Mix the two-part epoxy using a disposable stir stick (Note: the epoxy cures quickly; about 5-10 minutes). Apply glue to the carbon fiber case in the locations indicated in Figure 7. Allow the glue to have a tacky consistency before inserting the ribbons. Use the binder clips to hold the ribbon in place. Ensure that the ribbons are tightly wrapped around the case halves, as this determines how accurately the two cases will line up with each other. The further the ribbons are apart from each other, the tighter the case halves will be. Wait about 5-10 minutes before removing the binder clips. Figure 7 demonstrates the placement of the ribbons.

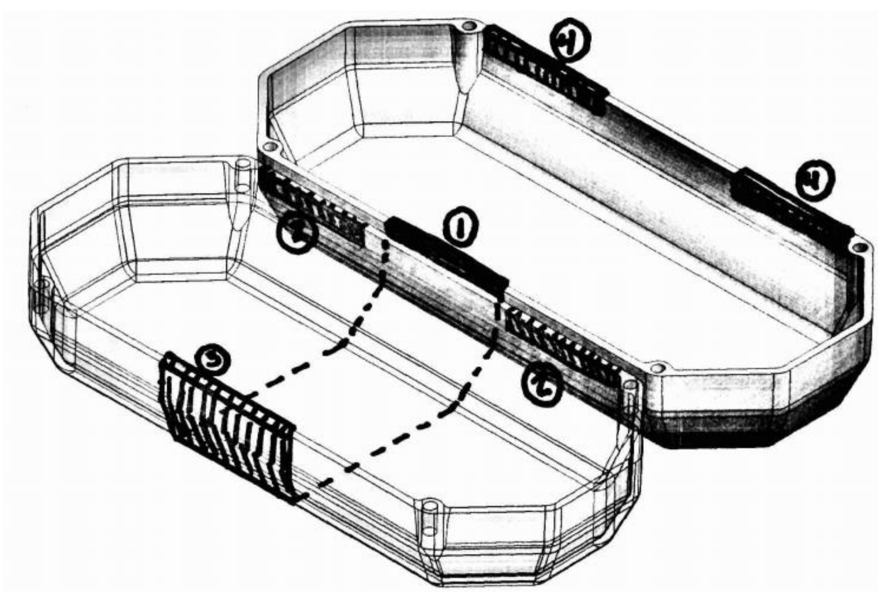

Figure 7. Diagram of ribbon placement

2. Apply glue to the ends of the 8 magnets and insert them into the drilled holes. Be sure to match north and south poles of magnets with the holes that will be aligning so the magnets hold the case shut and don't repel one another!

3. Using the 3M spray adhesive, spray glue into the case in a well-ventilated area. Quickly attach the fleece into the case, as the cure time is about 30 seconds. Trim the extra lining.

Voila, you have just created your very own carbon fiber sunglasses case.

References

[1] "Home of the Econoclave." *Autoclave Systems*. Web. 02 May 2016. <http://www.aschome.com/index.php/en/products/autoclaves>.