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Ideal Lacrosse Stick

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Ideal Lacrosse Stick Design

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University of Akron Senior Design Project
Mechanical Engineering - Spring 2020

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Executive Summary

This project is focused on the design of a new and innovative lacrosse stick. Our main points of focus will be the strength and durability of the head. As well as solving some of the problems that exist in existing equipment. These problems were identified by interviewing experienced players at the college level. Benefits would include a stronger head that is easier to use for a player on the field to do things like pass, catch, shoot, and field ground balls in an optimal manner. Normally players will have to purchase new heads every season as a result of warping or possible breaking. We aim to increase the durability and lifetime of stick head use. This goal is because many players are willing to pay for high end sticks that last longer than the current models on the market. Another main focus will be shaft design on the lacrosse stick. This is to improve the durability and flex of the stick when passing and shooting in-game. We will choose the shape and material composition of the stick.

To determine the specific needs of a lacrosse stick we will interview players in the game currently who have 6+ years of experience. We will then take the information gained and attempt to solve the problems that were mentioned. We are going to use CES, a material selection software to determine the best materials to use. Following that we will use engineering design tools such as SolidWorks, AutoCAD, PTC Creo, and 3D printing to design iterations of our solutions. Finally, when we are happy with our designs we will run FEA on the designs to ensure the parts are durable.

Table of Contents

Introduction

This project was performed for the purpose of creating the ideal lacrosse stick in today's sport. As engineers and sports fans, we are passionate in creating the best possible lacrosse stick. This means creating, designing, analyzing, and confirming the design for a lacrosse stick shaft and head. Design of strings and shooting strings will be omitted from the design process but will select the best ones on the current market that we see fit for our head design. We will design this stick to follow current league guidelines later shown in this report. We will also design the full stick based on engineering software such as Solidworks, AutoCAD, Creo, Matlab, Ansys Workbench, CES, and our schooling from each of our University of Akron Mechanical Engineering Degrees and co-op experience. This stick's main purpose is to last longer than current ones on the market that have a lifetime of around 1 to 1.5 years and to be of a reasonable price. Creating a stick that will last longer than this will be of great use in the current market.

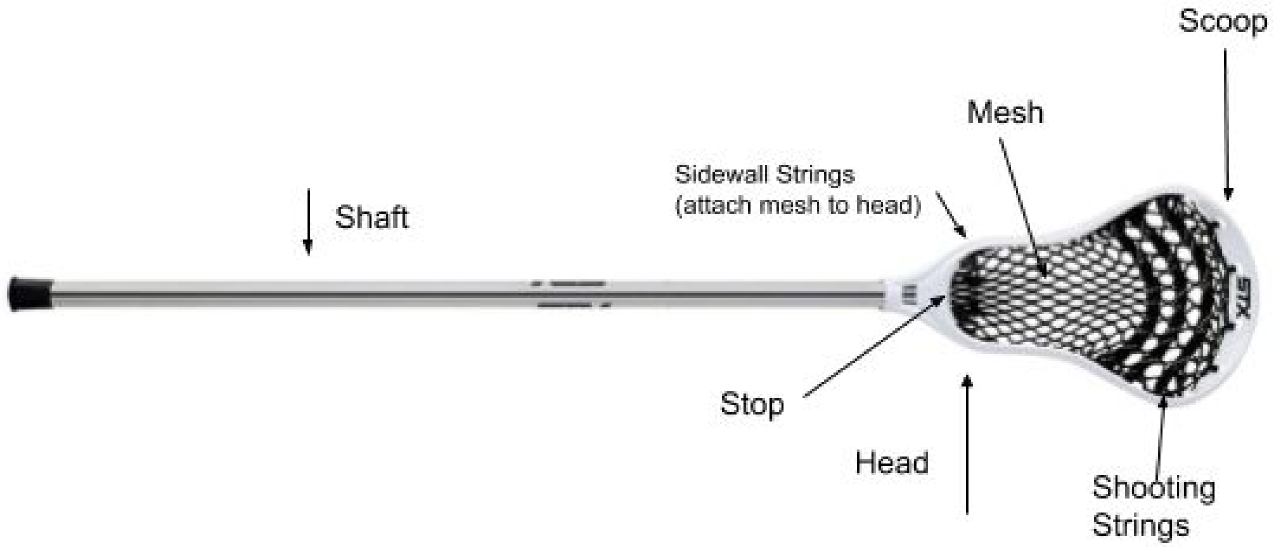
NOTE TO THE READER: Due to the Covid-19 national pandemic and states along with the University of Akron closing down or going remote we had many restrictions put on our original goals. Due to university wide closure we lost access to 3D printers, CNC machines, computers with FEA software, testing, and other university related materials. Due to these restrictions we were not able manufacture the carbon fiber shaft.

Problem/Project Definition

Definitions:

In the figure below is an image of a generic lacrosse stick with the parts of the stick called out. The stick is made of two main components, the shaft and the head. The shaft is a 30 inch long solid piece that can be made of a variety of materials. The head is typically made of plastic and has several components. The most important of which is the mesh of strings where the ball sits. This mesh is attached to the plastic using sidewall strings. Towards the flared end of the head are shooting strings. The purpose of these strings is for the ball to exit the pocket of the mest smoothly. At the top of the head is a rounded smooth part called the scoop. Its purpose is to literally scoop when the ball is on the ground. Finally, the base of the head is referred to as the stop. See Figure 1 on the next page for a visual representation of these parts.

Figure 1: Lacrosse Stick Parts



Project objectives:

To design and create an ideal and improved lacrosse stick for the game today. This includes realistic and ideal material design, shape for the shaft, proper head shape design for the most durability, and overall usability. In the design of the head, the objective is to engineer solutions to existing problems in heads today. Some of these problems include unprotected strings that hold the mesh onto the stick.

Parameters and Constraints:

This Lacrosse stick design must follow and adhere to the Lacrosse NFHS and NCAA guidelines for lacrosse sticks. This includes a 6 inch width at the widest part of the scoop and 3 inch width bottom portion of lacrosse head, no protruding edges and smooth surfaces, stick length between 30” and 43.25”, and various other constraints listed in *Appendix F -NFHS and NCAA Lacrosse Stick Regulations* and *Reference A.* We also plan to stay close to a $600 budget due to the funding received from Smithers Rapra.

Ways to improve upon current design:

The ways we improved upon the existing, standard design is by creating multiple new shaft cross section geometries. Then, current lacrosse players were surveyed for their preference while also researching hand geometries and ergonomics to find the most preferred shape that has the best feel and overall functionality. We also would like to create a feature that helps the player identify the orientation of the stick without taking their eyes off play. For the lacrosse stick head, we are able to modify things such as head shape according to what type of stick we want it to be, head taper for holding the ball, catching and shooting, string holes for the sidewall stings and shooting strings, sidewall head bridges, and a ball feeder feature for scooping the ball off the ground that doesn't interfere with shooting.

Short Design Brief:

The lacrosse stick will be designed to be legal in high school, collegiate, and professional play. The most realistic and durable material found will be used as the shaft material. The grip shape will be 3D printed and surveyed with several lacrosse players to decide upon the most comfortable grip shape. The head shape will be modified to protect the sidewall strings and be designed for most advantageous overall play. Designs will all be analyzed using FEA.

Expanded Design Brief:

The lacrosse stick will be designed to adhere to the NFHS and NCAA lacrosse stick specifications. This lacrosse stick head will be modeled similar to the shape of either a midfielder head, as it provides the most versatile use on the field. The lacrosse stick itself will have its material selected from the material selection software CES and the shape will be chosen upon by 3D printing shapes, surveying lacrosse players, hand gripping research, and analyzing shapes currently on the market. Features that may or may not be modified on the head include the sidewall string holes, shooting string holes, ball feeder on head tip, head sidewall bridges, taper of lower head to upper head, some form of sidewall string protection, and the connection from head to shaft. The sidewall and shooting strings will not be considered for this design project.

Evaluation of Alternatives

The 2 sticks we reviewed and analyzed are heads of a Midfielder stick from Nike and StringKing. These heads were used very early on to get an idea of what the market design of the heads were like outside of just online research. We used these to do some hands-on research and familiarize group members on some of the features that these heads have for play

.

Figure 2: Reference Lacrosse Sticks

We also analyzed and researched brands online such as Epoch, STX, ECD, and Under Armour to see what designs are on the current market and where they fit in the market vs the current reviews and life of them.

Design Approach

Customer Needs/Potential Markets:

Per our interviews and general research in *Appendix - A: Interviews with Customers and User Examples,* we found that many lacrosse stick users spend a lot of money on sticks year after year. Players have to buy these sticks every year and would be willing to pay more to have the stick last longer than the 1-1.5 year lifespan that is on the current market. All of the interviewed lacrosse players said that money is not much of a barrier within reason, as long as the stick can last them longer than current sticks on the market. Our designed stick would fit in the market aspects shown below:

- Higher End Stick Market (Priced higher - Longer life)
- Durable and longer lasting
- Practical/Easy to use
- High School/College/Professional Level
- Midfielder Stick Head

Additionally, players noted several design flaws on current market options. One of the largest problems with head design that was found was the heads do not protect the sidewall strings. The sidewall strings, which hold the mesh onto the head, are open to being hit by the ball when catching and throwing. Many players experience their sidewall strings breaking in games requiring them to switch to a different stick. Experienced players were also able to note that when coaching or training new players the inexperienced players will oftentimes not be able to remember which way their stick is facing. As a result the player will catch the ball in the back side of their stick and then drop it. Players noticed that their sidewall strings would often come loose over time resulting in inconsistency in throwing over time. Finally, players complain that their heads wobble on their shaft over time due to the fit between the shaft and the head loosening. This causes there to be a wobble when throwing and catching.

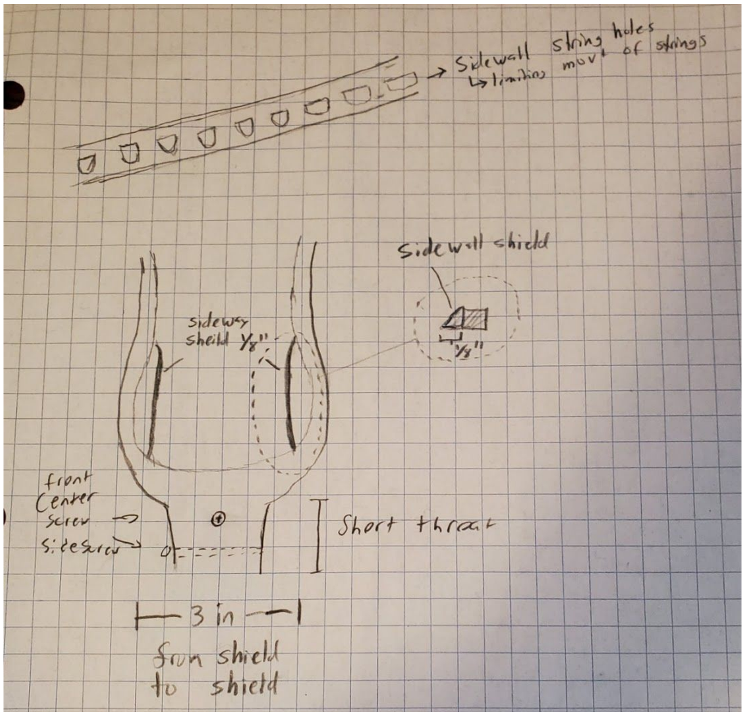
Initial Design Sketches:

From player feedback, a solution to the problem started to take shape. The design process started with initial features we wanted to include in our final design that satisfy all the criteria from the players as well as encapsulate the engineering requirements, such as durability. The first solution was to address the issue of sidewall strings breaking. A lip will be created just above the sidewall holes extending towards the center of the head approximately 1/8th inch to protect the strings from the incoming ball.

A sketch was also created outlining the shape of the sidewall holes. The shape of a round bottom with a square top was created. The motivation behind this feature is to maximize the surface area of plastic contacting the string. As opposed to a square cutout, as is standard on most current products, a rounded design will hug the string, thus increasing the contact surface area. This will create more friction in the knot and allow it to hold tighter for longer.

Finally the throat area was outlined. The throat is the connection of the head to the shaft. The decision was made to go with a shorter throat section for the head that is significantly shorter than most midfield heads on the market. The reason for this is to reduce the amount of plastic on the head and reduce weight. Additionally, such a long throat would not be necessary due to the method of connection. Traditionally in lacrosse, the heads are secured by a single screw that attaches at the back of the head. The decision was made to innovate on this design and improve it to eliminate head wobble. A second screw was added. Now, there will be one screw going through the front and connecting at the back and one from the side going through the assembly. Figure 3 on the next page will show the preliminary sketches.

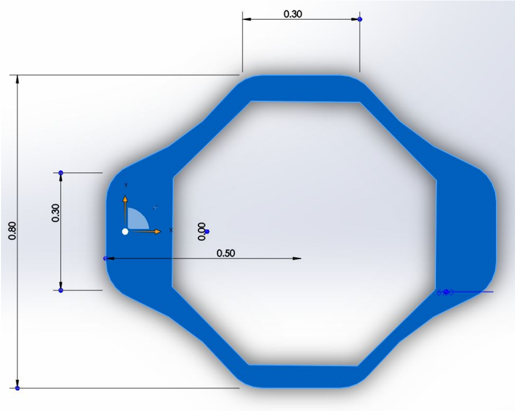
Figure 3: Preliminary Feature Sketches



Following the design features of the head, the initial shaft design was developed. For shaft design the variable parameters are the choice of material, wall thickness, and cross sectional shape. The length and circumference are restricted by the NCAA Rules. Four different cross section variations were developed with each design specifying a different feature. These features will then be surveyed by experienced players and the best design will be chosen and iterated on to make it optimal.

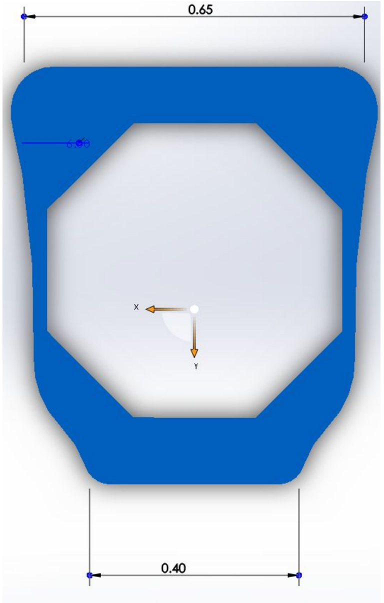
Design #1 features a rounded shape that is reminiscent of current lacrosse shafts on the market. This was developed as a baseline to find out if players prefer a more rounded feature or a shaft with sharper edges such as design #3. It has long concaves which would be spots for the tips of the fingers to grip while a player is delivering a strong shot. This would make it such that the shaft will not rotate or slip at all during the shot improving accuracy.

Figure 4: : Design #1 - Long Concave Shaft Design



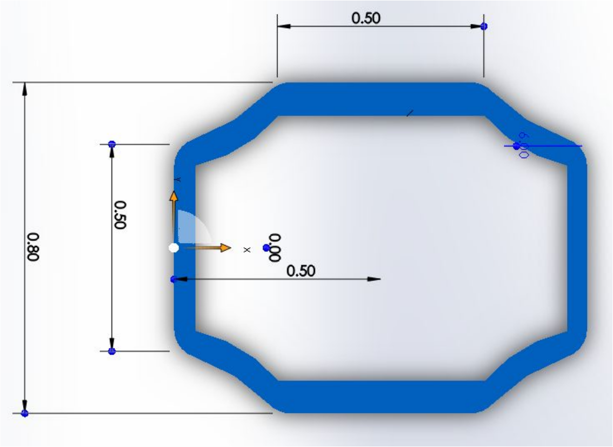
Design #2 is a very unique shape and cannot be found in any current market shaft. Current market shafts are symmetric all the way around. As the players noticed there are instances that newer players will forget which direction their shaft is facing resulting them to catch the ball in the wrong side of the head. This shape is designed to fix that problem. The flat end, wide end of the shaft is designed to sit in the palm while the figers wrap up and around the top part. This will allow for a strong grip because the shaft tapers to contour with the fingers. This will make it so the player will know without a doubt and without looking that their stick is facing the right direction. For the experienced player it will make it a very stable shaft. This design allows for a very strong and consistent grip which will increase power and accuracy.

Figure 5: Design #2 - Big Knob Shaft Design



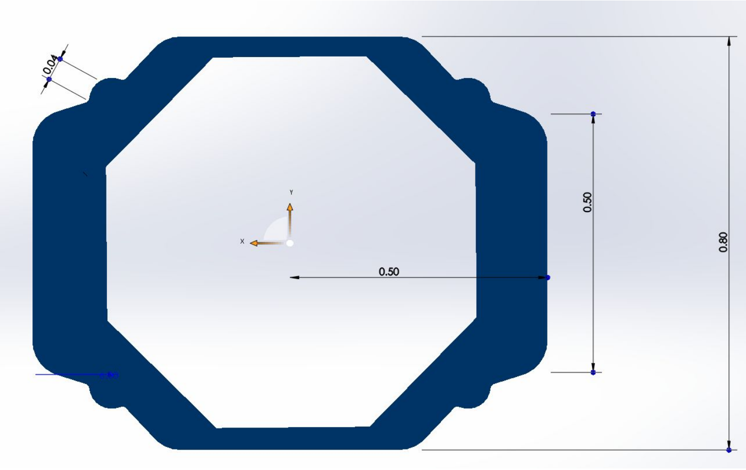
Design #3 is similar to Design #1 in the way that it is fairly reminiscent of shafts that are currently on the market. However, it has sharper edges and shorter concave portions. This design, in conjunction with Design #1 was to get a feel for players preference on a shaft with rounded edges versus sharp edges.

Figure 6: Design #3 - Standard with Round Edges



Finally Design #4 is another unique design. The design is geometrically similar to design #3 however on the concave portions of the shaft it has nubs built in. The Idea behind the nubs is to decrease the amount of surface area in contact with the glove to increase the speed a player can switch hands with the stick. It would also provide more texture to the shaft.

Figure 7: Design #4 - Round Edge with Nubs Design



Analyzing Proposed Solutions:

The proposed shaft designs were 3D printed and brought to players to get their feedback. The players were instructed to examine the sections with and without lacrosse gloves on to feel them best. The results of the feedback were as follows:

- Players liked the sharper feel of Design #3.
- Players liked the idea behind Design #2, but it was uncomfortable to hold.
- Players did not like the feel of Design #4.
- Players liked the way Design #1 felt compact and less bulky in their hand.

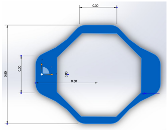
This feedback will be taken into consideration and integrated into the final design of the cross section of the shaft.

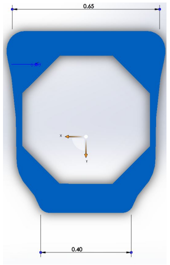
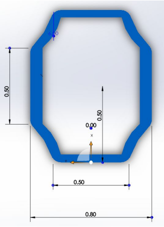
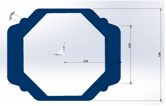
For the material of the shaft, we took a more analytical approach along with interviews. Below is a table that analyzes material options for the shaft of the lacrosse stick. Each option has pros and cons of each material, and what we believed we could use in the final design. The table below shows another big feature of the project that includes the cross section shaft shape. This includes pros and cons and opinions gathered from interviews of lacrosse players shown in *Appendix A - Interviews with Customers and User Examples.* This also shows which designs were considered in our final project considerations. The 3D printed shaft samples are also shown in *Appendix D - 3D Printed Shafts Designs.*

Table 1: Analysis of Solution of Lacrosse Shaft Material Table

Design of Shaft	**Analysis of Solution**	**Select Design (Y/N)**
Carbon Fiber	Lightweight, Flexible for shooting, customizable weaving, good strength and grip but can be too light for some players and some can break on cross check.	Y
Titanium alloy	Strength, lightweight and good grip but bends overtime and can be slippery - More expensive to manufacture	Y
Scandium alloy	Strength, lightweight and good grip but bends overtime and can be slippery - More expensive to manufacture	Y
Wood/Bamboo	Stronger checks, long lasting, but warp and gripping is not the best along with it being heavy	N

Table 2: Analysis of Solution of Lacrosse Shaft Material Table

Design of Shaft	**Analysis of Solution**	**Select Design (Y/N)**
#1 	Fits well into hand geometry. Is medium size for all hand types. Has thick walls on 2 sides to protect from impact and breaking. Has curved diagonal sides to fit hand even better.	Y

#2 	Would give a clear distinction on how the shaft is oriented in hand during play but won't fit into hand as naturally.	N
#3 	Bigger shape to fit well into hands during play but has thin walls and could run into problems with smaller hands. Players enjoyed the sharper feel.	Y
#4 	Fits well into hand geometry. Is medium size for all hand types. Nubs may increase manufacturing difficulty and players did not enjoy the feel.	N

Segmentation Techniques (Smaller Parts):

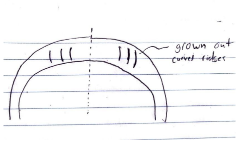
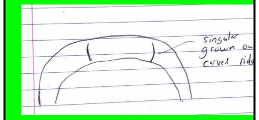
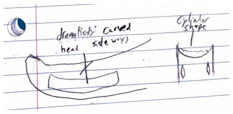
- Shaft Shape
- Shaft orientation indicator
- Head Sidewall string holes
- Head Shooting string holes
- Head Support bridges

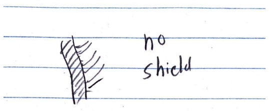
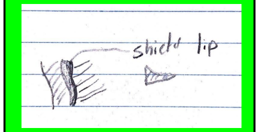
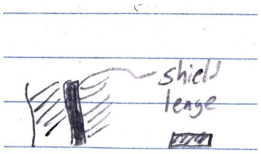
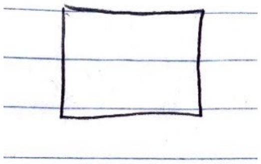
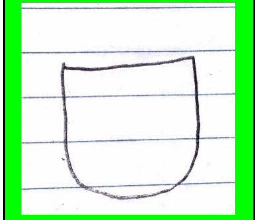
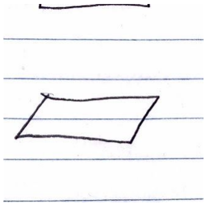
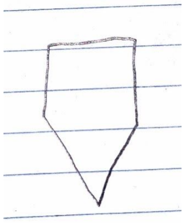
- Head scoop/scoop angle
- Head flare/flare angle
- Shaft-Head Connection Method

This shows how we separated the different features and how we went through many design processes. This made it easier to design the stick as a whole and focus on certain features of the shaft. There are many features and with this we were able to focus on the biggest things to improve on. These features were then iterated on and many designs were considered. Below shows the selection process.

Morphological Chart:
(Green = Feature Selected)

Table 3: Morphological Chart of Lacrosse Stick Features

Morphological Chart of Lacrosse Stick Features				
Lacrosse Stick Head Ball feed	3 Extruded ball feeder lines  	1 Extruded ball feeder line  .	Half cylinder top of head ball feeder  	
Sidewall String Shield (protects	No Sidewall string hole shield	Sidewall string shield lip	Sidewall Sting shield ledge	

string from breaking)				
Sidewall string holes (all holes extend longer when get to top of head)	Square hole shape 	Shield hole Shape 	Quadrilateral Shape 	Pointed shield shape 
General Head Shape	Midfielder Head 	Draw Head 	Defensive Head 	Goalie Head 

Many of these features in the Morphological chart had 3 to 4 options that we determined could be useful in our final design. The ones highlighted in green are the features we deemed best for various reasons shown throughout the report.

Objective Tree:

Figure 8: Objective Tree for Ideal Lacrosse Stick

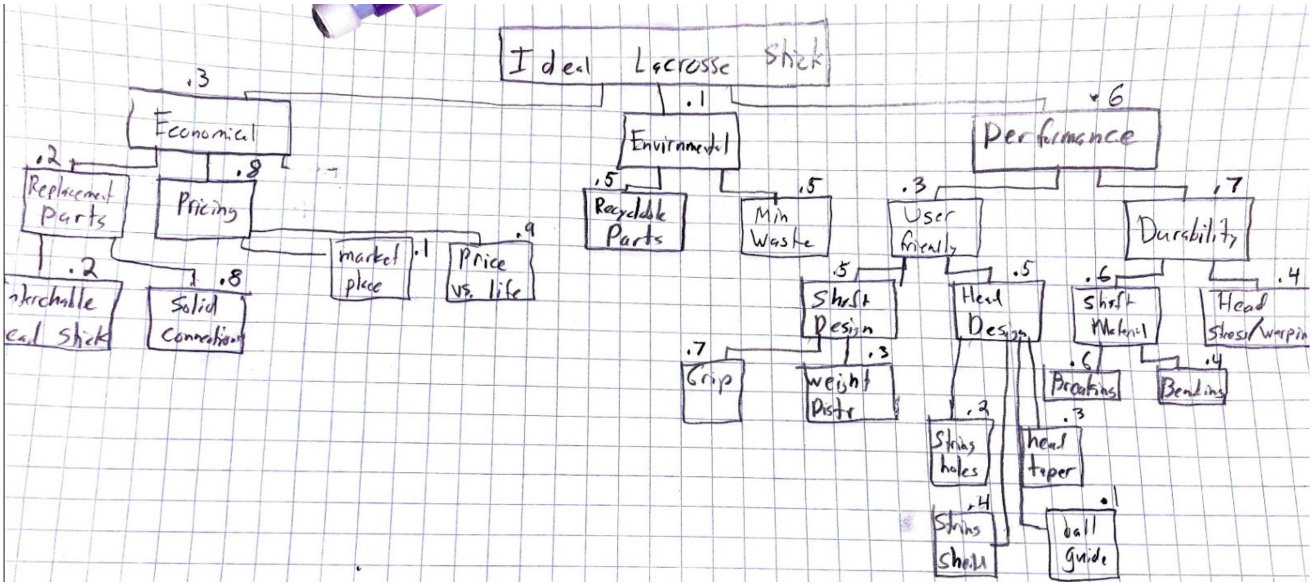


Figure 8 is our objective tree for the project. It shows where our main focuses were on the project and how we weighed certain aspects of the overall goals. It can be seen that most of the emphasis was on the performance with some emphasis on the economical aspects of the design. This is because we wanted to make the ideal lacrosse stick and only keep some economical factors into consideration since this was designed to be a high end stick. We also took some environmental aspects into consideration to do our due diligence on the design. All of these factors were then further split out and weighted to give a better look into the goals of the design.

Final Design & Material Selection

Head Design:

To create a working CAD model of a complex shape such as a lacrosse head it is useful to start out with detailed hand drawings. These detailed drawings incorporate all of the features layed out from the player interviews as well as encapsulate the rules and regulations laid out by the NCAA. The design also calls out wall thicknesses, dimensions, lengths, etc…

As previously mentioned, the players wanted a more durable head. Over time lacrosse heads tend to warp. The middle of the head tends to warp inward. This pinches the head inward making it illegal according to the NCAA regulations. To improve the durability of the head two things were done. The first thing is to increase the wall thickness. Heads typically are around ¼ inches in thickness around the middle of the head where warping is most typical. For this design, a wall thickness of 5/16in was chosen for the wall thickness of the head. Additionally, in an effort to create a durable head that will resist warping, the main sidewall strut is directly in the middle of the head where warping will occur. This strut will oppose the plastic wanting to warp. There is an illustration of a warped head in Figure 9. The new strut placement can be seen in Figures 10 and 11.

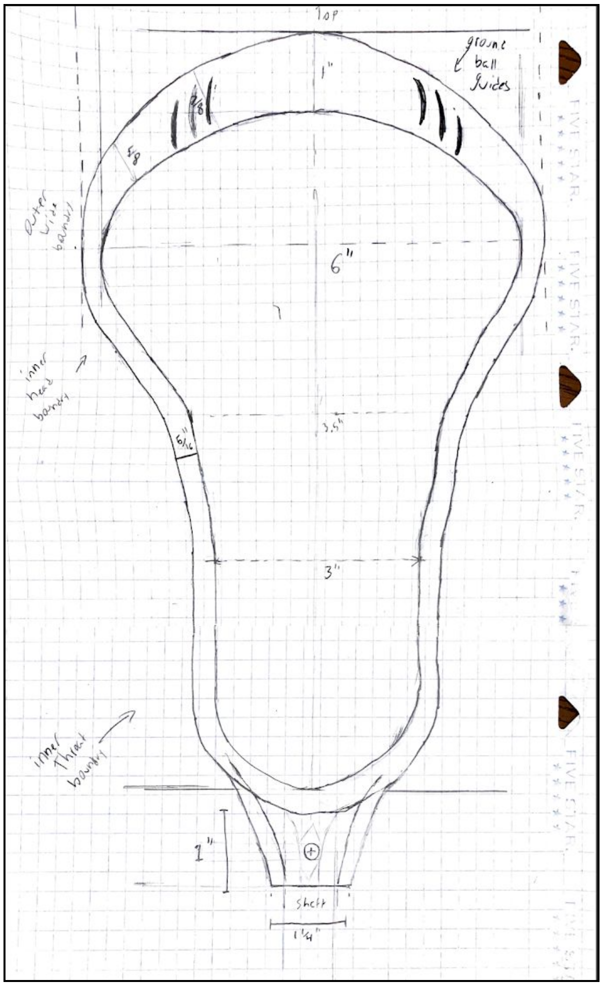
Figure 9: Lacrosse Stick with warping

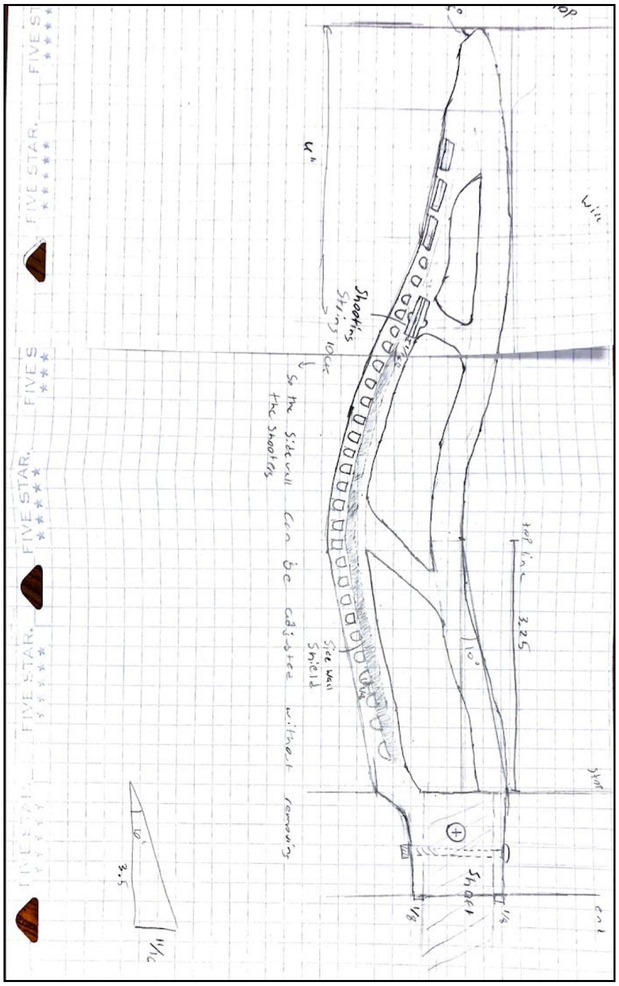
The front and side view also call out the length and depth of the throat connection and the location of the screws. The sidewall holes are also pictured along the whole length of the head. The holes expand at the top of the head to accommodate multiple strings going through them for the top string and shooting strings. There was also a feature cut into the plastic above the sidewall holes around the top sidewall strut. This long wide hole is for the shooting strings. This sort of feature allows for a player to be able to adjust his sidewall strings without having to remove the shooting strings like you would have to do on a head on the current lacrosse market.

On the side profile, the drawings call out a very aggressive offset as well. Offset on a lacrosse head is the sidewall extending lower than the throat. Offset results in a lower pocket and a lower position of the ball in the head. This will give a player more feel of the ball in the stick and allow him to control the ball better. The offset allows for better ball retention as well. Since the ball will be sitting lower in the head, a smoother, less aggressive pocket will be able to be put on the head. This will allow for a faster release. Typically with a less aggressive pocket, you have to sacrifice ball retention. However, this design features a very aggressive offset of 10 degrees. Such an aggressive offset will counteract the ball retention problem. Therefore, a smooth and fast release will be possible while keeping superior ball retention.

Other features of this head that will be molded into the plastic of the head are the 1/8th in sidewall shield to protect the sidewall strings from the ball. As previously mentioned, this feature will stop the ball from rubbing on the strings when catching to extend the life of the strings. Additionally, there will be plastic ribs in the scoop that are intended to direct the ball into the head while picking up a ball that is on the ground.

Figure 10 & 11: Final Lacrosse Stick Head Design Hand Drawings





With all the design features in place, it is now acceptable to create the computer generated model of the head. This was done using PTC Creo Parametric. A variety of techniques such as cuts, extrudes and swept blends were used. Below the final CAD of the head can be seen in Figures 12 and 13.

Figure 12: **Final Lacrosse Stick Head Creo Drawings**

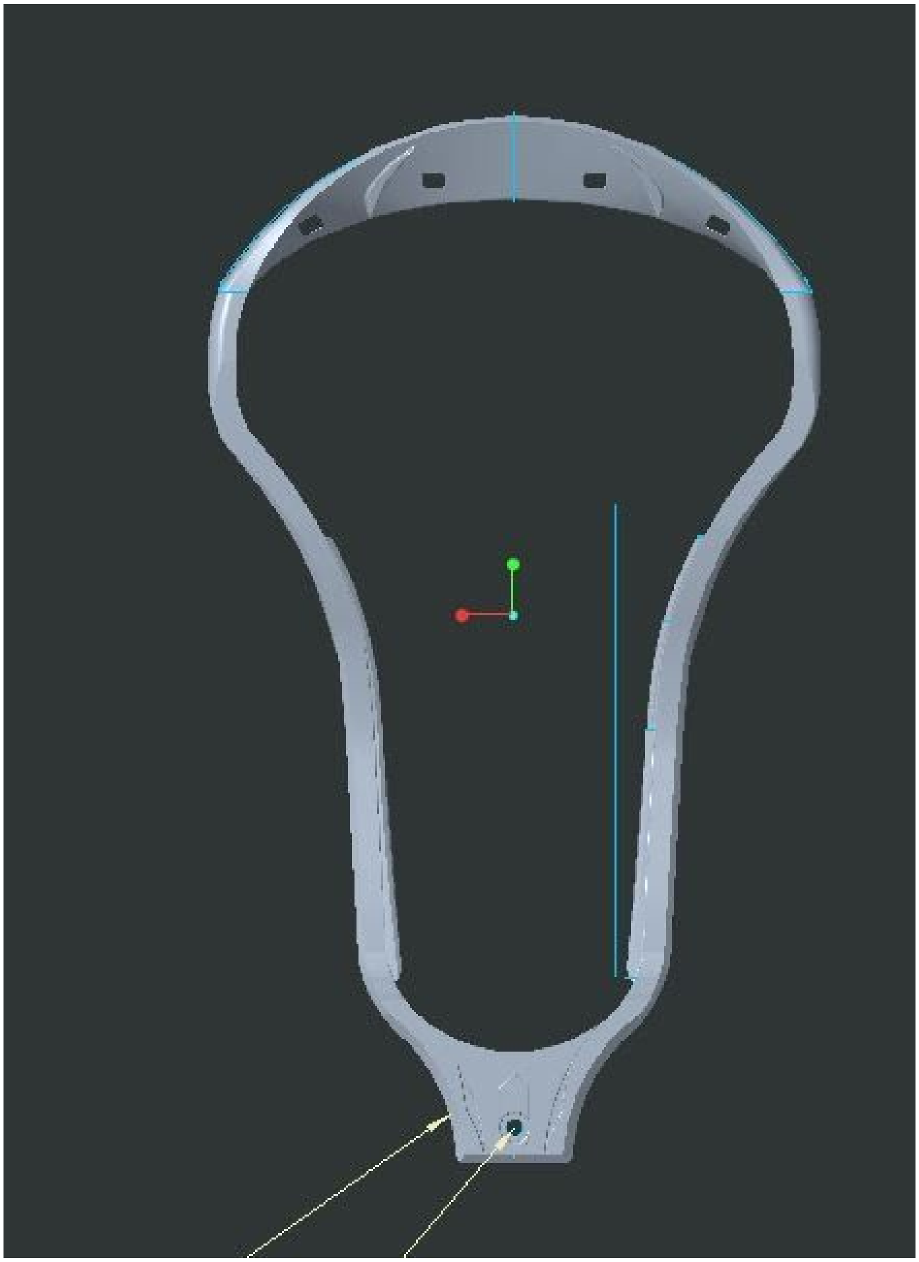
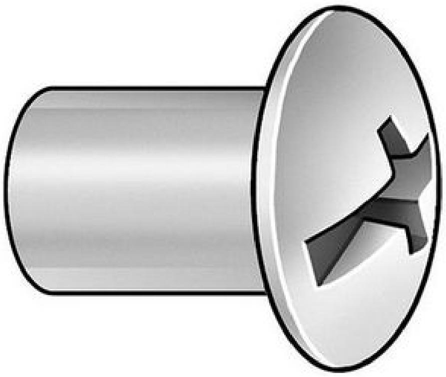


Figure 13: Final Lacrosse Stick Head Creo Drawings

Head and Shaft Connection

As previously mentioned, the head will be connected to the shaft using a binding bolt technique. The female end, or barrel, will be purchased from Zoro.com. It is a barrel bolt with a #6-32 thread made from 316 stainless steel. It has a diameter of 3/16 inches and the threads are 19/64 inches deep. It is able to be tightened with a phillips head screwdriver. The male end of the connection will be a 18-8 stainless steel hex drive flat head screw. Similarly it will have #6-32 threads to match the barrel bolt. It is available on McMaster- Carr. The detailed drawing of this connection can be seen in Figures 14-16. Since the bolts are connected in the X and Y axis, there will be no way for the head to wobble on top of the shaft, thus eliminating the head wobble problem. It also allows for a shorter throat. This allows the player's hands to be closer to the ball when catching, so the player will be able to control the stick more accurately as the ball is coming in. It will also take away plastic so the stick will be lighter.

Figure 14: Screw Drawing



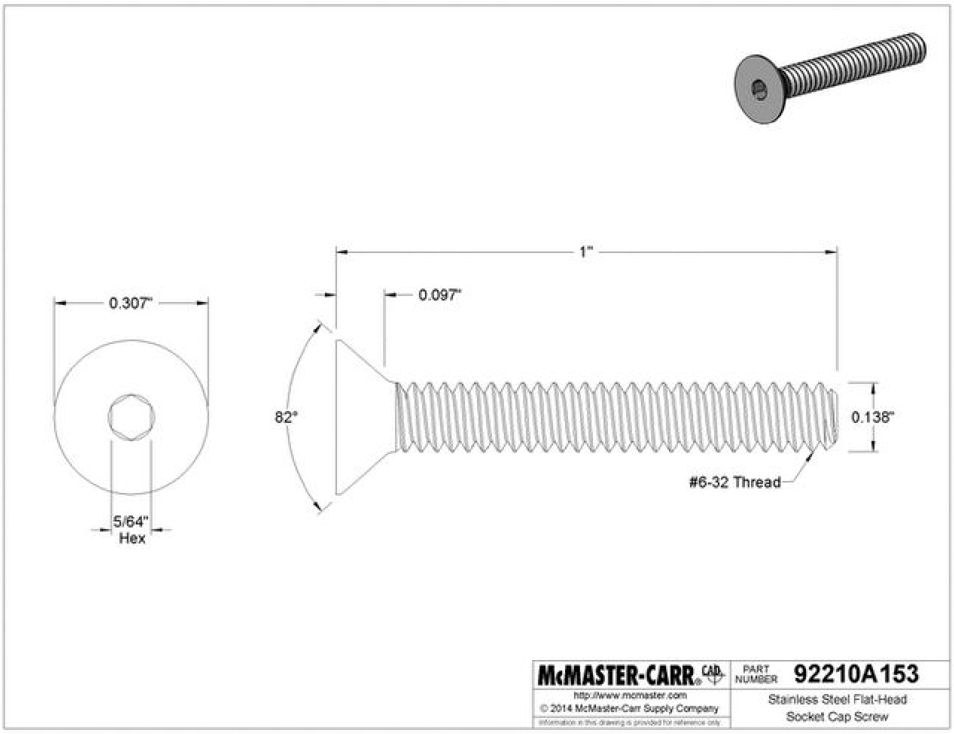
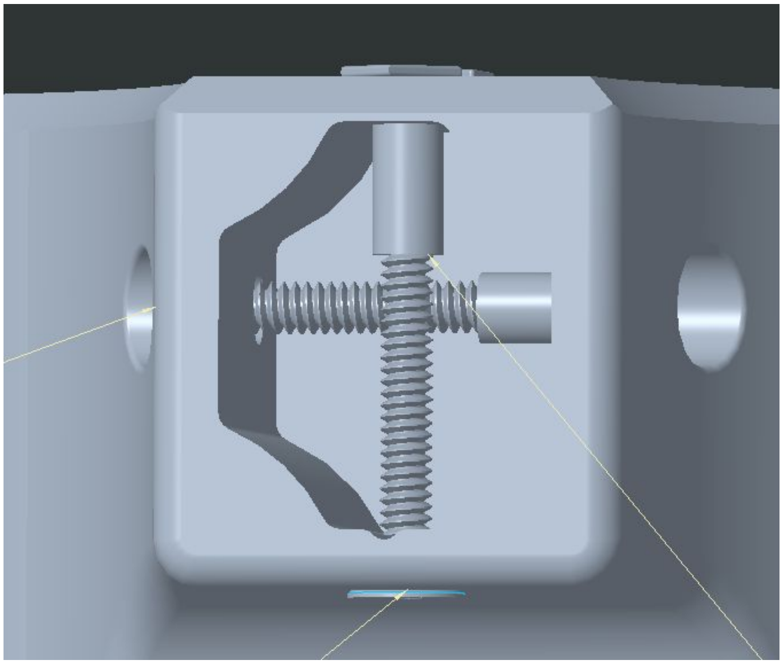
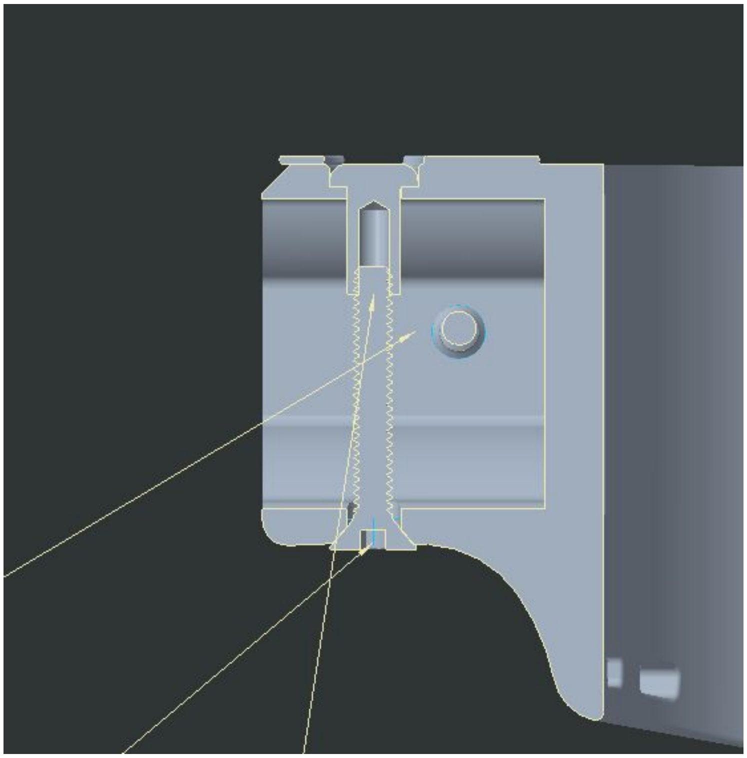


Figure 15 & 16: Creo Shaft and Head Connections





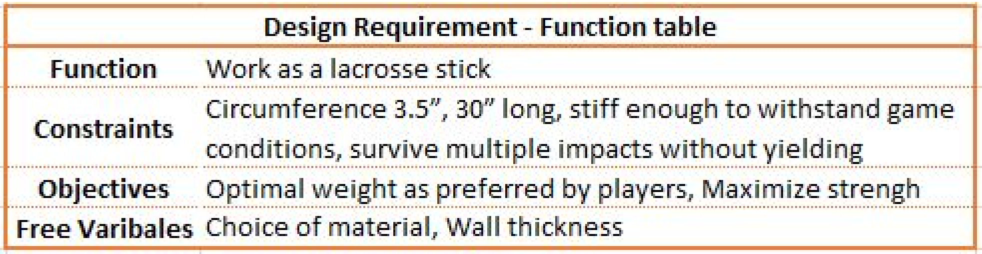
Shaft Material Selection

From the player interviews, we learned several interesting preferences lacrosse players share. The key point for a lacrosse shaft is that it has to be durable and withstand impact at high speeds. Currently, in the lacrosse market, there is a trend to produce the lightest shaft possible with large flex points that will increase shot speed. However, we have found that that is not what players are looking for in their stick. Current players are looking for a stick that is durable and lasts for several seasons. They also seem to prefer a shaft that is a bit heavier within reason. Players said it allows them to feel the ball better to maintain control. So the objective for this shaft is to achieve those goals by choosing a light, strong material and increasing the wall thickness. This will add superior strength as well as keep the weight in a desirable position.

Typically, lacrosse shafts can range anywhere from 135-155 grams being the most lightweight shafts, these are all made of carbon fiber composite materials. Lacrosse shafts are also made of metals such as aluminum and Scandium-Titanium alloys which usually weigh about 170 to 190 grams, and they can be purchased from wood. Wood shafts weigh about 280 grams. For this application, where the objective was to make a strong shaft that was on the heavier side. It is clear players do not opt for wooden sticks because they are not very common. So keeping the weight between the two extremes is the best option for this project. In this case, the group decided on a weight of about 200 grams. Which is heavier than most carbon shafts on the market. This will give players the feeling they desire in a shaft.

To achieve the desired strength and weight requirements, an optimal material must first be selected. To do this we first must analyze the product and the function in the function and constraint table in Figure 17.

Figure 17: Function Table

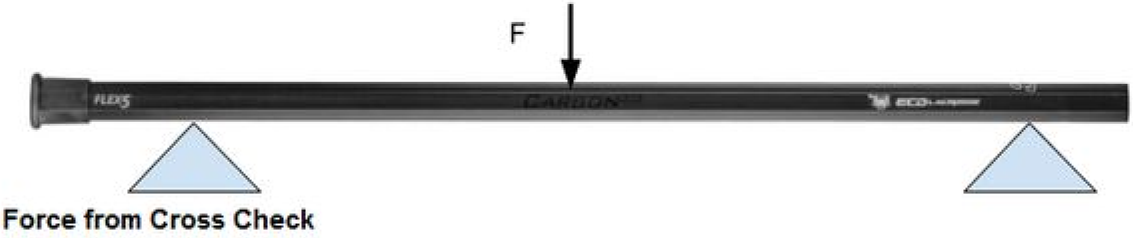


Design Requirement - Function table	
Function	Work as a lacrosse stick
Constraints	Circumference 3.5", 30" long, stiff enough to withstand game conditions, survive multiple impacts without yielding
Objectives	Optimal weight as preferred by players, Maximize strengh
Free Varibales	Choice of material, Wall thickness

From these objectives, it is possible to analyze the free body diagrams that the shaft will be subject to in a game and create a material index to optimize the material selection. The two free body diagrams in Figure 18 show two different scenarios that can occur on the field that impart the highest loading. The force from a slash, which is swinging the stick at another player and hitting their stick and a cross check, where the stick is horizontally lunged into another player.

Figure 18: Slash Forces

Figure 19: Cross Check Forces



These two scenarios bend the shaft. Therefore, using these diagrams and the constraint table, the material index can be derived using bending equations.

Figure 20: Material Index Derivation

Bending Stress: $\sigma = \frac{M\,y}{I}$

Moment of Inertia: $I = \pi r^3 t$

Substituting Moment of Inertia into Stress: $\sigma = \frac{M\,y}{\pi r^3 t}$

Solving for t: $t = \frac{My}{\pi r^3 \sigma}$

Density: $\rho = \frac{m}{V}$

Volume: $V = 2\pi hrt$

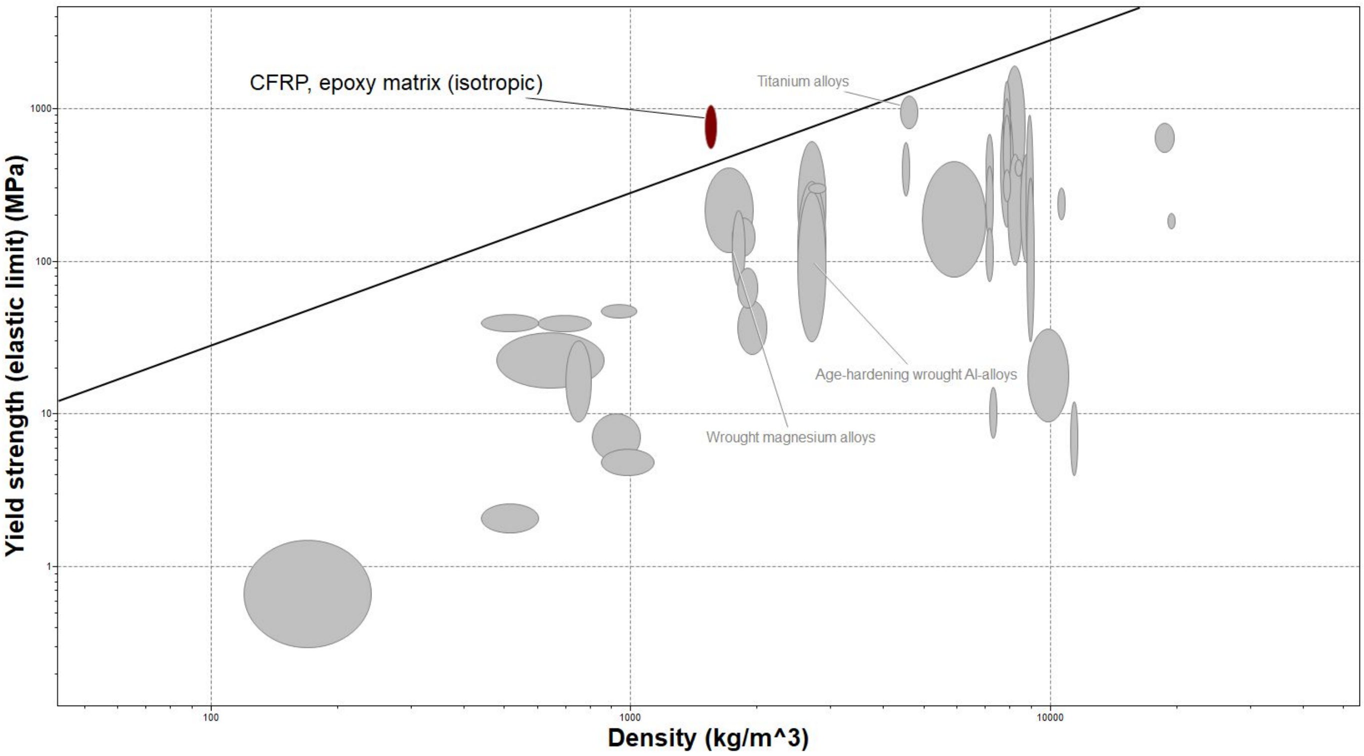
Substituting Volume in Density: $\rho = \frac{m}{2\pi hrt}$

Substituting t into Density: $m = \underbrace{(M)}_{\text{Functional}}\underbrace{\left(\frac{hy}{r^2}\right)}_{\text{Geometry}}\underbrace{\left(\frac{\rho}{\sigma}\right)}_{\text{Material Index}}$

***Material Index*:** $\boldsymbol{\frac{\sigma}{\rho}}$

The resulting equation from the derivation above can be separated into three different components: functional, geometric and material index. For the purposes of selecting material, the material index is the only one necessary. From the derived equation, the material index is $\frac{\rho}{\sigma}$. The inverse of this equation can be taken for ease of graphing. Therefore the final material index is $\frac{\sigma}{\rho}$. Where in this case strength can be observed as the yield strength. From this, a graph can be plotted with yield strength and density. The line on the graph represents the power on the material index. Every material on that line will have the same weight. For this material index, which is raised to the first power, the slope of the line is one. It is clear to see the best possible material is carbon fiber reinforced polymer (CFRP). This will result in the highest strength and lowest density. Therefore the strength can be maximized while the weight is brought to a weight that players desire by varying the wall thickness of the shaft.

Figure 21: CES Material Selection Chart



Final Shaft Design

With the feedback from the players on our first four designs for the shaft, an additional iteration was able to be made. The first design feature that needed to be corrected was the problem of new players not knowing which way their stick was facing. Since the players did not like the shape of Design #2 which solved this problem, a new feature needed to be developed. Rather than having a whole shape to denote the direction of the head, a small notch was put into one side of the shaft. The feature is large enough the player will be able to feel it even when wearing bulky gloves. It can be seen in Figure 21. Additionally, for this design, the concave sections of the head were extended as a place for the fingers to grip the shaft.This made the shaft feel more compact in the hand. The radius on the bends was made very tight to keep that sharp feel players liked from the first designs. It also coincides with hand and gripping research represented and summarized in Figures 23 and 24

Figure 22: Final Lacrosse Stick Shaft Creo Design

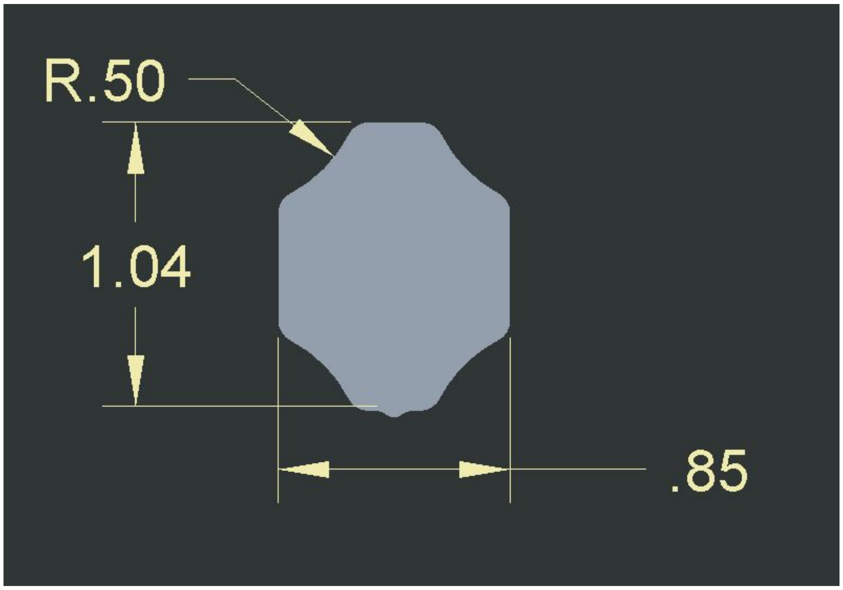


Figure 23: Gripping point research

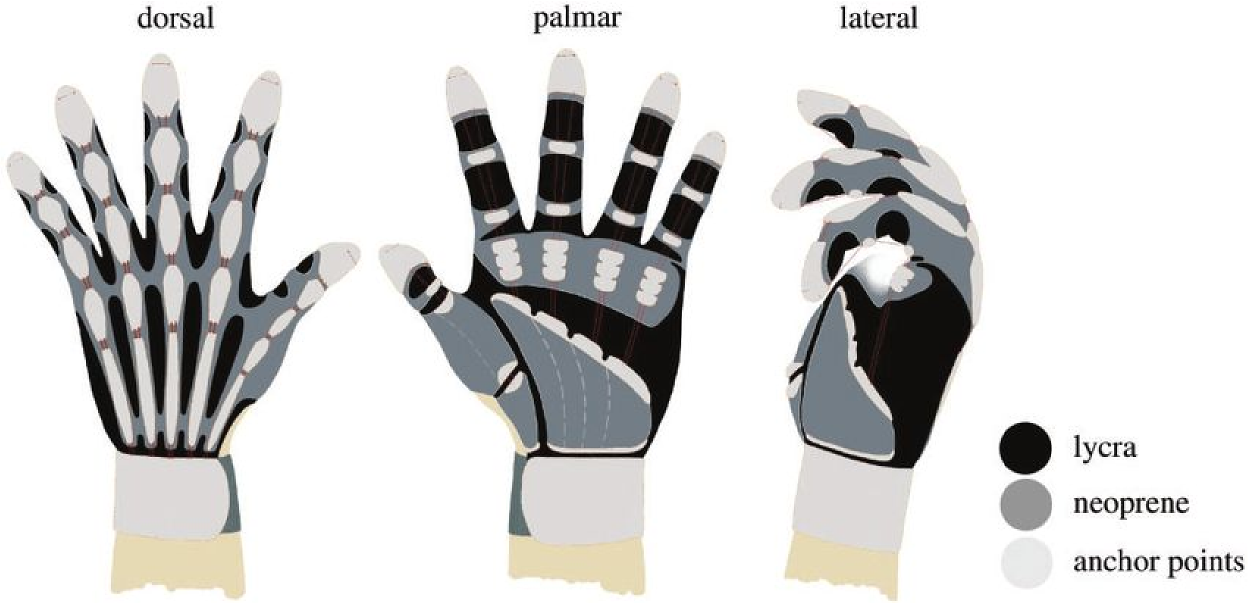


Figure 24: Gripping point research with Lacrosse Shaft

The anchor points shown above are from research shown in Citation C. This is research on gripping of the hand and it can be seen that the anchor points or pressure points of gripping coincide with our final design cross section. Three out of the four extruded points of the shaft match right up with the anchor points of the hand along with the protruding line that will rest in the back of the palm and will indicate whether the holder is holding it correctly during play.

As mentioned in the material selection section of this report, the decided weight for the shaft was approximately 200 grams, to meet player preferences. To achieve this weight, the wall thickness of the shaft was adjusted. With a wall thickness of 0.08 inches, and the density of the carbon fiber material chosen, it is possible to calculate the weight of the designed shaft. This wall thickness of 0.08 gives a weight of 0.44684 pounds or 202 grams. It can be seen in the Figure 25.

Figure 25: Shaft Thickness Creo Drawing

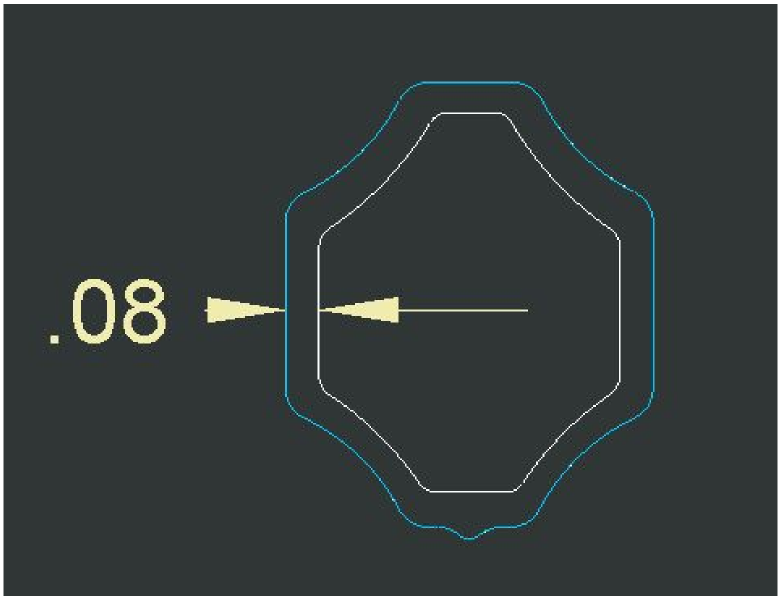
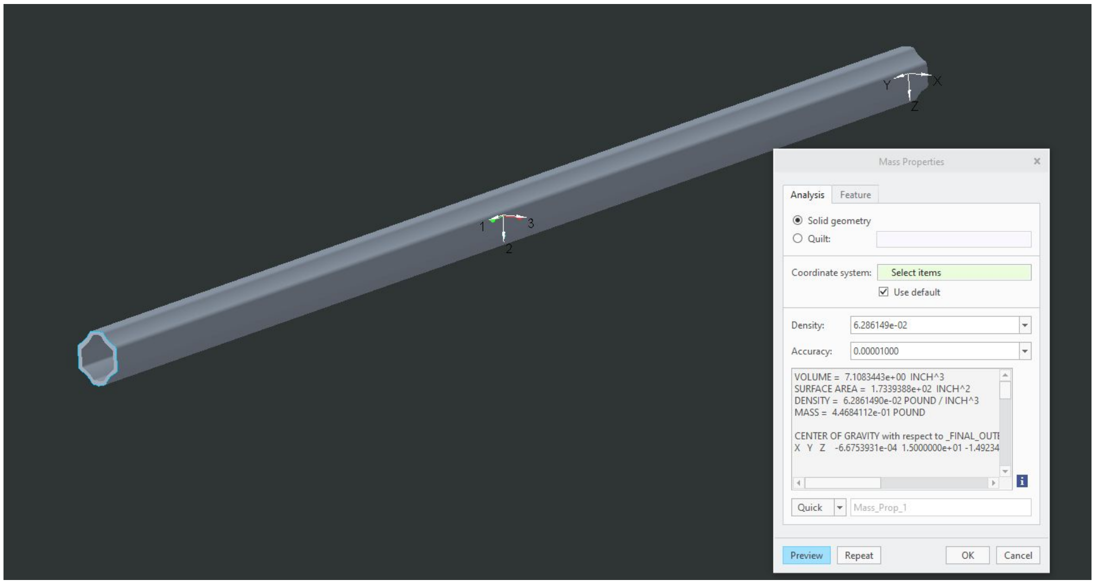


Figure 26: Creo Shaft Design



● Solid geometry
○ Quilt:

Coordinate system: Select items
☑ Use default

Density: 6.286149e-02
Accuracy: 0.00001000

```
VOLUME =  7.1083443e+00  INCH^3
SURFACE AREA =  1.7339388e+02  INCH^2
DENSITY =  6.2861490e-02 POUND / INCH^3
MASS =  4.4684112e-01 POUND

CENTER OF GRAVITY with respect to _FINAL_OUTE
X   Y   Z    -6.6753931e-04  1.5000000e+01 -1.49234
```

Quick Mass_Prop_1

Manufacturing Process

With the shaft design finalized and the material selected it is possible to work out a manufacturing process for the carbon fiber. Carbon fiber is a material that comes in a rolled fabric form and is layered with resin epoxy then cured to maintain its strength. Traditional methods include laying out the carbon fiber on top of a mold and pulling a vacuum on top of the part to straighten out the carbon fibers. Carbon fibers are only strong in tension. Therefore, the more pressure you can apply during curing, the straighter they will become resulting in a stronger part. However, this vacuum method poses a problem for this application because of the hollow shape of the shaft. Other methods of molding a hollow tube include roll wrapping, where the fiber is rolled onto a mold and then the vacuum pulled on the outside of the mold. However, for this application, that would not be ideal because, after several layers, the fine details on the mold would be lost on the outer edges. Instead of pulling a vacuum, you can also apply pressure to the inside of the mold. These methods tend to be very expensive as custom made bladders are needed to fill the inside of the mold. The last option is to mold the part in two halves and bind them together after the molding process. Unfortunately, this option also poses a problem as the final binded part will not be strong enough to withstand the impact of this application.

After exhausting traditional methods of carbon fiber manufacturing, a new method needed to be developed for the purposes of this project. The best way is to have a mold of the exterior of the shaft and have the carbon layed on the inside of the mold. This is the best way to get the outer shape as it is designed. Therefore, the mold would be split in two halves. The carbon fiber will be attached by an overlapping piece of carbon on the bottom half of the mold. This will overlap with the inside of the top piece when the mold halves are brought together. To help create pressure inside the mold, a silicone tube will be inside the mold. The vacuum bag will encase the mold and attach on the inside of the silicone tube. The tube will expand under the heat and pressure of the curing process and push the carbon into the mold. This unique method was verified in its ability to achieve the desired result by carbon fiber experts at the University of Akron. The detailed step by step process is defined below.

Step 1: Create a mold in two halves to the desired outer shape.

Step 2: Cover the mold in a finishing paint.

Step 3: Cover the mold in a release agent.

Step 4: Cut the carbon fiber into the desired length to fill the inside of the mold. Cut as many sections as layers are needed to achieve the desired thickness.

Step 5: Lay the carbon fiber into the mold layer by layer. Every layer adding resin epoxy in between each layer until the desired thickness of 0.08 inches is achieved.

Step 6: Mate the two mold halves together ensuring the carbon layer on the bottom is overlapping the top layer.

Step 7: Insert a sheet of bleeder fabric into the mold. This will allow the resin to travel through the mold during curing.

Step 8: Insert a layer of release film into the mold.

Step 9: Insert the silicone tube into the mold.

Step 10: Encase the whole assembly in a vacuum bag and secure it with tacky tape to the inside of the silicone tube.

Step 11: Verify vacuum seal

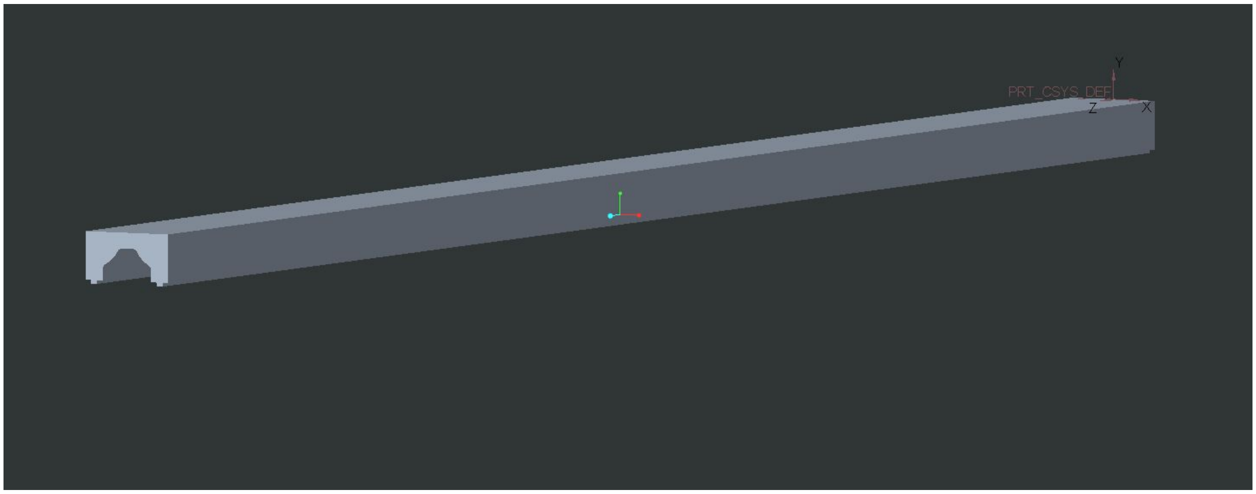
Step 12: Pull vacuum on part and place inside an Autoclave at 140 degrees Fahrenheit for about an hour.

Step 13: Remove from the autoclave and mold and finish the product.

The University of Akron does not have an autoclave. UTC Aerospace agreed to be of assistance in this project and allow the use of their autoclave provided it was not already in use.

Detailed drawings of the mold are found in the following pages. Note the molds are longer than the finished product. When molding carbon fiber it is useful to mold extra material and cut off some of the end as a part of the finishing process. This ensures a uniform finish even on the edges of the part. Additionally, a male notch was cut into the top half of the mold with the female end on the bottom half. This is to ensure the mold goes together properly and does not move during manufacturing.

Figure 27 & 28: 3D Creo Shaft Mold Design



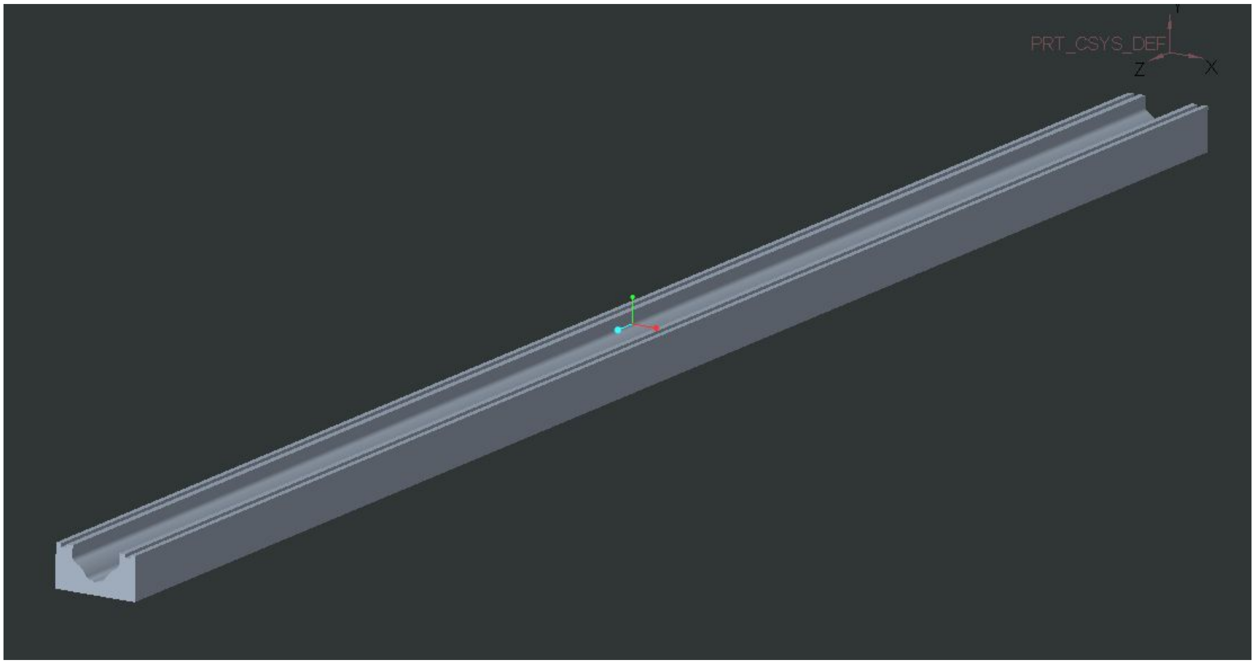
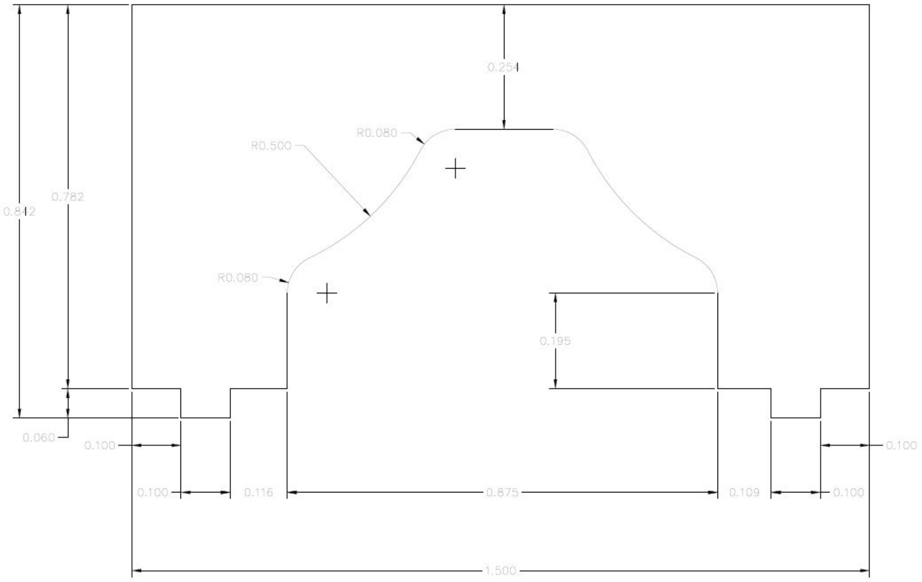
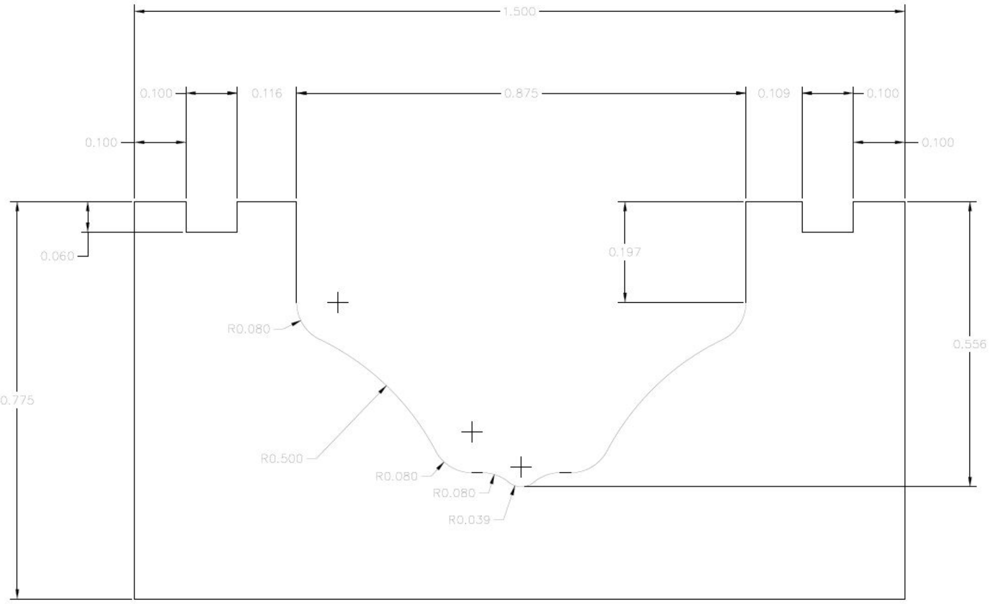


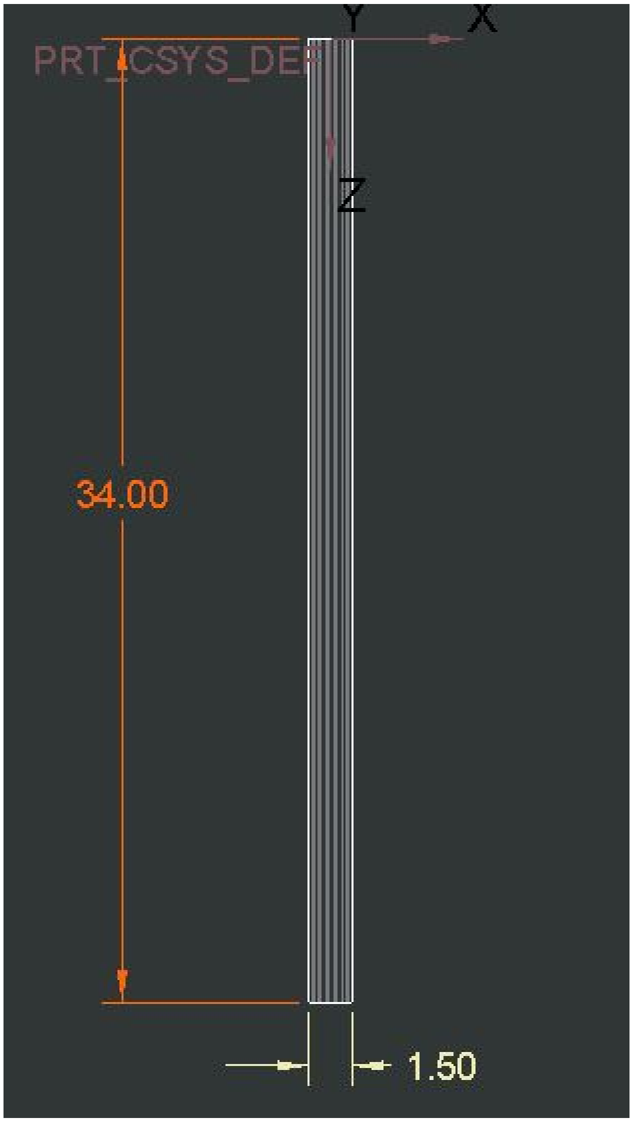
Figure 29, 30, 31: 2D Creo Shaft Mold Dimensions

TOP


0.254
R0.080
R0.500
0.842
0.782
R0.080
0.195
0.060
0.100
0.100
0.116
0.875
0.109
0.100
0.100
1.500


1.500
0.100
0.116
0.875
0.109
0.100
0.100
0.100
0.060
0.197
R0.080
0.556
0.775
R0.500
R0.080
R0.080
R0.039

BOTTOM



*Due to Covid-19, we could not manufacture the carbon fiber shaft as mentioned. However we still were able to manufacture a 3D printed version of the head and 3D printed version of the shaft as well. This prototype can be seen below in Figures 32-35.

Figure 32, 33, 34, 35: 3D Printed Head and Shaft

The 3D printed shaft gives us an accurate representation on how it would fit in a player's hand and how the nub shows orientation of the stick and fits well with the 3D printed head. Since the shaft was 3D printed we could not test the strength but we could analyze the general feel. For the head, we could do more testing by putting it on a real shaft and testing how it held and shot. It threw very well and was very consistent with ball speed and accuracy. It was very smooth and had a ton of hold to it. The sidewall shield covered the strings and shooting strings perfectly and did not inhibit catching or throwing at all. Overall, we believe that this prototype gives a great insight into what a fully manufactured version of our stick could do. Our features were implemented well, and we believe this would be a premium stick on the market. More pictures can be seen in *Appendix H - 3D Printed Shaft and Head Pictures.*

Embodiment Design:

Due to the stick having several features the embodiment design was heavily emphasized in the division of task. These tasks were the main features we created that are not on the market and are seen below:

- Separated sidewall and shooting string holes - Shooting string can be replaced without replacing all of the netting
- Shaft nub - To detect orientation of stick by just feeling in hands
- Tight flare + Aggressive Offset - Better receiving, ball retention, control, faster release
- Thicker Sidewall bridges - To prevent warping of head
- Sidewall string shield - To prevent ball receiving from tearing strings
- Shield hole string shape - To prevent pinching and tearing of strings
- Ball Guide Scoops - New design that we believe will be perfect for scooping the ball off the field

The connections were shown previously in the report but also help with the embodiment principle of force transmission. The two screw setup helps prevent shear of the connections and with force transmission of the stick getting hit from multiple directions.

Design Verification - Validation/Testing

Our ideal lacrosse stick was tested in Ansys Workbench and CREO Simulate. Two simulation softwares were used because of the COVID-19 pandemic. In a perfect world, the entire simulation would've been completed using Ansys Workbench in the computer labs of ASEC, but because of the campus shut down, we have results from both softwares.

The purpose of the FEA was to put our exact stick model in a simulation of realistic cross checking force it would experience throughout a lacrosse match. There was a fixed constraint placed on both ends of the stick, while a force of 5,260 $\frac{in\ lb}{s^2}$. In these softwares, you are capable of inputting material properties such as density, Young's Modulus, and Poisson's ratio so you can get exact results based on your material. Our density used for carbon fiber was 113 $\frac{lb}{ft^3}$, Young's Modulus of 3.31 x 10^7 psi, and a Possion's Ratio of 0.3. Pictured below is a reference on the setup of the simulation.

This force was approximated by referencing a Sports Science Lacrosse on Youtube, based on how fast a lacrosse ball travels and equating that speed to our stick head speed. Then dividing our velocity of the stick by the time it takes for the ball to reach the goalie. Our stick experienced only 0.02 in of displacement using the approximated force, then we even magnified our force by four times, and fracture still did not occur in our stick. Simulation results can be found in Figure 33 and under Appendix F.

Figure 36: Shaft Forces

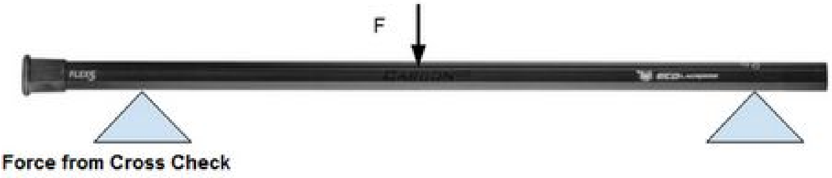
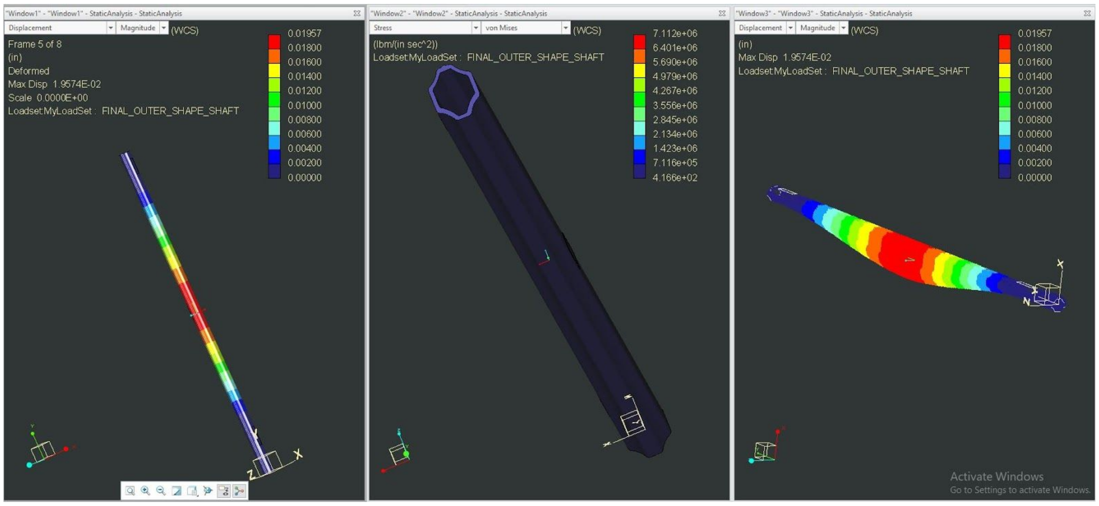


Figure 37: Creo Simulate Results Using Approximated Cross Checking Force



Frame 5 of 8
(in)
Deformed
Max Disp 1.9574E-02
Scale 0.0000E+00
Loadset:MyLoadSet : FINAL_OUTER_SHAPE_SHAFT

(lbm/(in sec^2))
Loadset:MyLoadSet : FINAL_OUTER_SHAPE_SHAFT

(in)
Max Disp 1.9574E-02
Loadset:MyLoadSet : FINAL_OUTER_SHAPE_SHAFT

Design Evaluation - Cost/Economic

The lacrosse stick design is in its prototype phases of the process but is set up to be sold at a reasonable price at market. Even with carbon fiber being relatively new to the lacrosse stick market, using carbon fiber gives us room to price in a reasonable range if a full manufacturing line could be set up for our stick. With even more time we would be able to select certain weaves of the fibers, test certain resins, and carbon fiber suppliers to get the best product at a reasonable price. Overall, the prototyping process is expensive as it is for most industries. With more time and money we would be able to do more tweaking to our design and create a mold for the Lacrosse Stick Head along with the Lacrosse stick itself and create a manufacturing line that would maximize our gross margins on the product and in turn be sold at a reasonable price for a premium stick on the market. We would also keep gaining experience and knowledge of the process.

Discussions

Due to the Covid 19 outbreak and the statewide shutdown, several aspects of our project were hindered. We were not able to manufacture the carbon fiber shaft ourselves. We also had several hardware and software issues with not being able to get into the computer lab. However, we were able to 3D print the head of the lacrosse stick and the shaft as well and instead of continuing with FEA we were able to do some CREO analysis on the shaft of the Lacrosse Stick.

With the functional 3D printed Model of the head we were to emulate the initial customer experience with the head. When a customer buys a head the first thing they must do is string it and break it in. This head provides an exceptional stringing experience. There are plenty of hole options so a player can truly customize their stick. It strings a high pocket and a low pocket with ease. The stick was tested with a mid pocket. That is the pocket (where the ball naturally sits in the mesh) lies approximately in the middle of the head. With some use of the stick throwing a ball is a fantastic experience. The ball comes out of the stick very quickly and smooth. What players most look for however is consistency. The consistency of the passes thrown was spectacular. It exceeded all expectations the group had for it.

Though it performed very well there are some room for additional iterations. Such improvements to the head would be to add one extra long stringing hole to the top of the head for a more custom top string option. The holes on the scoop of the head for the top string and the base of the head for the bottom string could both be larger for easier stringing. However, after these minor tweaks this head would be ready for manufacturing and distribution if desired by a business.

The shaft of this stick has already gone through a full product development cycle and as far as features go it is ready for manufacturing. The shaft is a good shape and design and will perform well for its customers. It would still have to go through physical testing to verify its performance capabilities.

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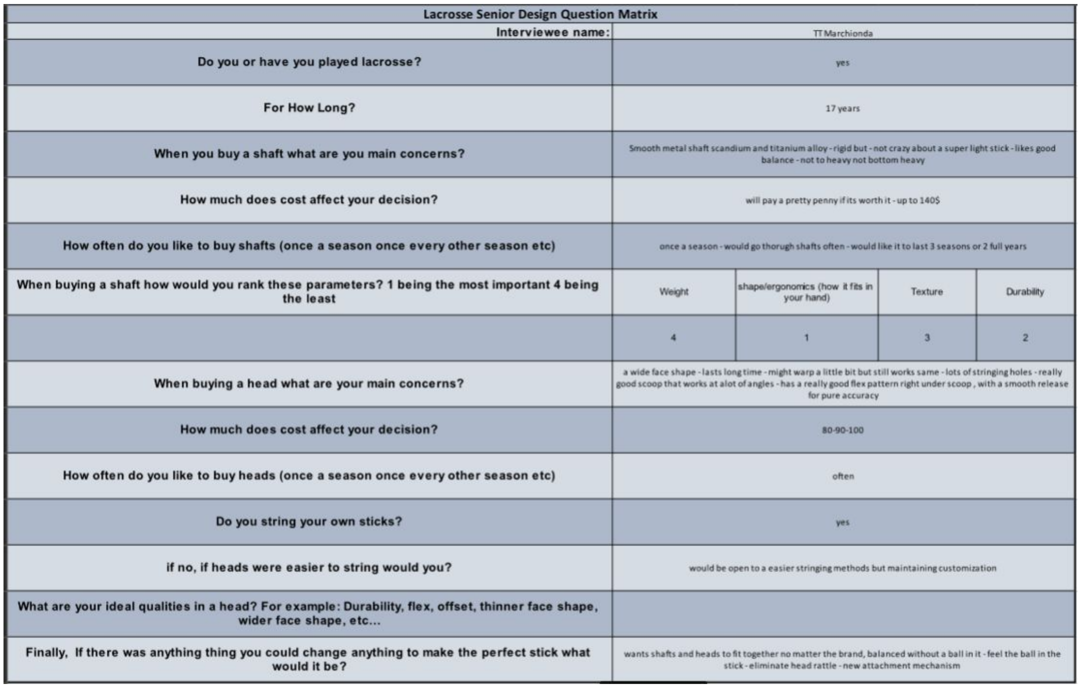
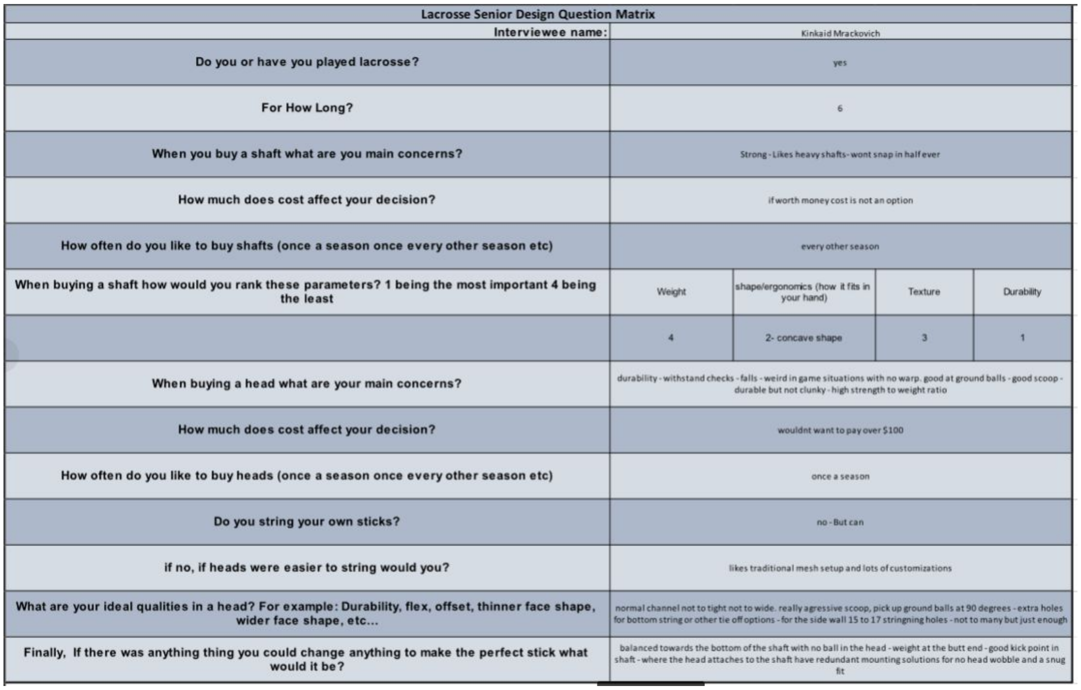
Appendix

A. Interviews with Customers and User Examples



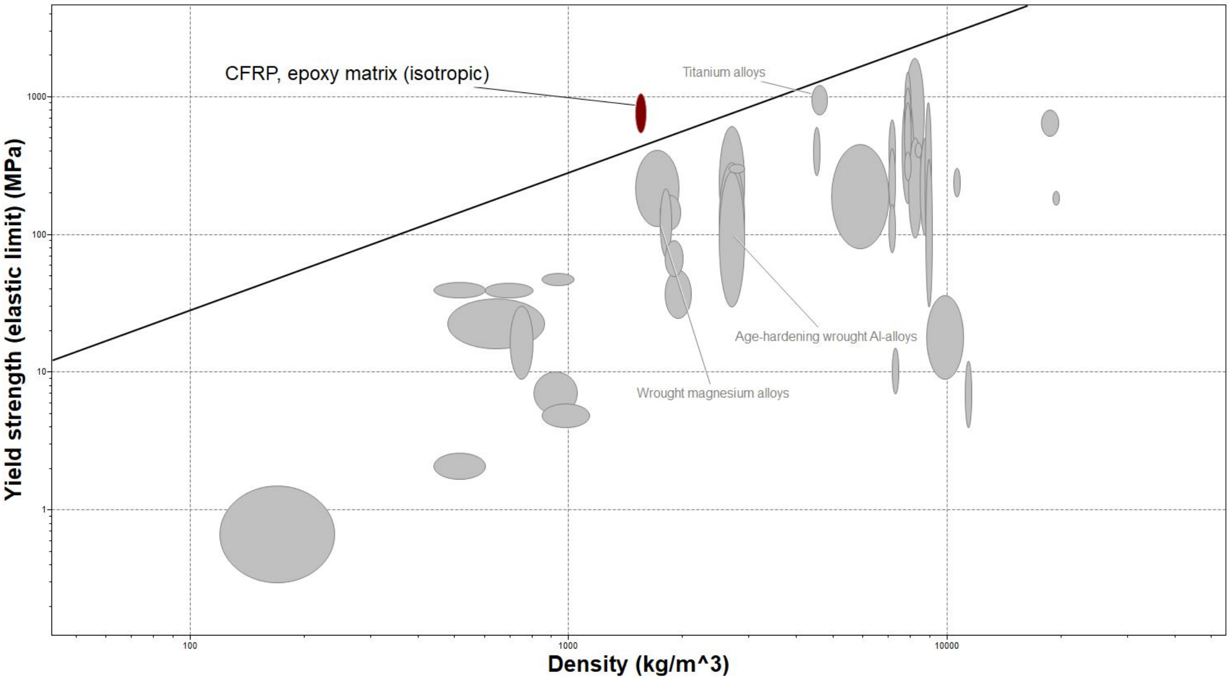
Lacrosse Senior Design Question Matrix

Interviewee name:	TT Marchionda			
Do you or have you played lacrosse?	yes			
For How Long?	17 years			
When you buy a shaft what are you main concerns?	Smooth metal shaft scandium and titanium alloy - rigid but - not crazy about a super light stick - likes good balance - not to heavy not bottom heavy			
How much does cost affect your decision?	will pay a pretty penny if its worth it - up to 140$			
How often do you like to buy shafts (once a season once every other season etc)	once a season - would go thorugh shafts often - would like it to last 3 seasons or 2 full years			
When buying a shaft how would you rank these parameters? 1 being the most important 4 being the least	Weight	shape/ergonomics (how it fits in your hand)	Texture	Durability
	4	1	3	2
When buying a head what are your main concerns?	a wide face shape - lasts long time - might warp a little bit but still works same - lots of stringing holes - really good scoop that works at alot of angles - has a really good flex pattern right under scoop , with a smooth release for pure accuracy			
How much does cost affect your decision?	80-90-100			
How often do you like to buy heads (once a season once every other season etc)	often			
Do you string your own sticks?	yes			
if no, if heads were easier to string would you?	would be open to a easier stringing methods but maintaining customization			
What are your ideal qualities in a head? For example: Durability, flex, offset, thinner face shape, wider face shape, etc...				
Finally, If there was anything thing you could change anything to make the perfect stick what would it be?	wants shafts and heads to fit together no matter the brand, balanced without a ball in it - feel the ball in the stick - eliminate head rattle - new attachment mechanism			

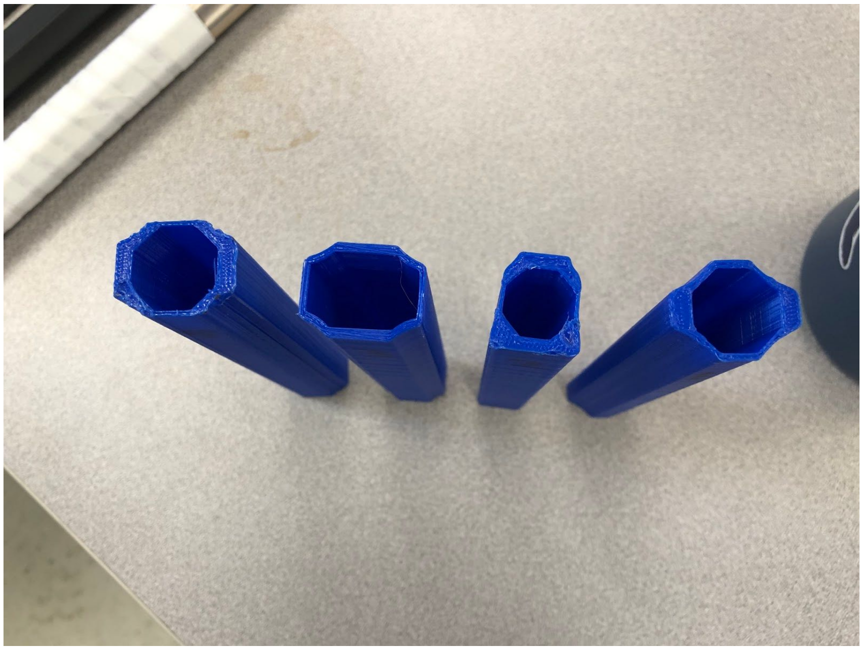


Lacrosse Senior Design Question Matrix				
Interviewee name:	Kinkaid Mrackovich			
Do you or have you played lacrosse?	yes			
For How Long?	6			
When you buy a shaft what are you main concerns?	Strong - Likes heavy shafts- wont snap in half ever			
How much does cost affect your decision?	if worth money cost is not an option			
How often do you like to buy shafts (once a season once every other season etc)	every other season			
When buying a shaft how would you rank these parameters? 1 being the most important 4 being the least	Weight	shape/ergonomics (how it fits in your hand)	Texture	Durability
	4	2- concave shape	3	1
When buying a head what are your main concerns?	durability - withstand checks - falls - weird in game situations with no warp. good at ground balls - good scoop - durable but not clunky - high strength to weight ratio			
How much does cost affect your decision?	wouldnt want to pay over $100			
How often do you like to buy heads (once a season once every other season etc)	once a season			
Do you string your own sticks?	no - But can			
if no, if heads were easier to string would you?	likes traditional mesh setup and lots of customizations			
What are your ideal qualities in a head? For example: Durability, flex, offset, thinner face shape, wider face shape, etc...	normal channel not to tight not to wide. really agressive scoop, pick up ground balls at 90 degrees - extra holes for bottom string or other tie off options - for the side wall 15 to 17 stringning holes - not to many but just enough			
Finally, If there was anything thing you could change anything to make the perfect stick what would it be?	balanced towards the bottom of the shaft with no ball in the head - weight at the butt end - good kick point in shaft - where the head attaches to the shaft have redundant mounting solutions for no head wobble and a snug fit			

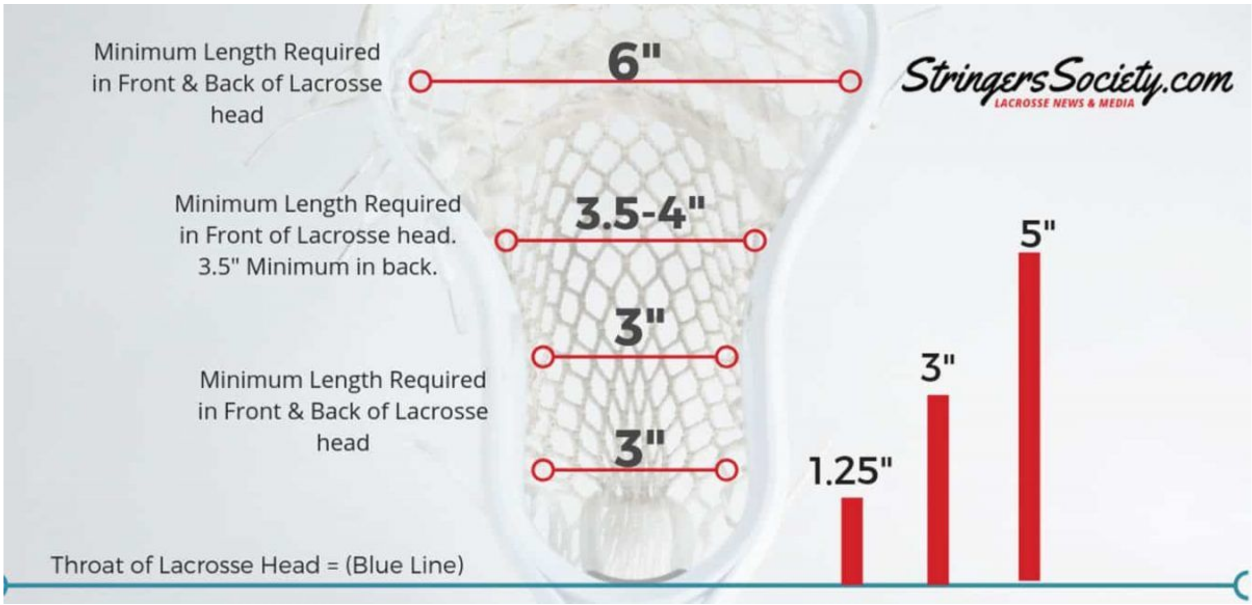
B. CES Software Graph examples



C. 3D Printed Shafts Designs



D. NFHS and NCAA Lacrosse Stick Regulations



E. Possible Carbon Fiber Manufacturers and email draft

Company	**Email**	**Contact Name**	**Can Manufacture?**	**Will Sponsor?**
Hexcel	eddie.rubey@hexcel.com	Emailed		
Solvay	https://www.solvay.com/en/form/communication	Messaged		
Teijin	industry@teijincarbon.us	Emailed		
Zoltek	http://zoltek.com/contact/	Messaged		
Rockwest	custom@rockwestcomposites.com	Emailed	Yes	15% discount (So far)
Soller Composites	info@SollerComposites.com	Emailed		
Dexcraft	info@dexcraft.com	Emailed		

Carbon Fiber Gear	https://carbonfibergear.com/pages/carbon-fiber-manufacturing-fabrication	Messaged	No	
Toray	https://cs2.toray.co.jp/contact/c0100.nsf/inquiry?Openform&https://www.toray.us/contact/index.html?https%3A%2F%2Fwww.toray.us%2Fproducts%2Fprod_004.html&En	Messaged		
Composite Envisions	cthorson@compositeenvisions.com	Emailed		5-10% and free shipping
Fibreglast	sales@fibreglast.com	Emailed		
Composites One	https://www.compositesone.com/contact/general-inquiry/	Messaged	Yes	Free? (have extra)

Email Draft

Carbon Fiber Lacrosse stick senior design project

Hello,

I wanted to reach out to you with hopes you would be interested in supporting academic work at the University of Akron. I know many take pride in supporting students and being involved with UA. I am working with a senior design group that is well on their way in making an Ideal Lacrosse stick. It is a privilege of mine to be able to combine my passion with my engineering education. I am working with a group of 3 other students and our goal is to manufacture a mechanically improved lacrosse stick. We are hoping to make a stick that players at every level can use and benefit from.

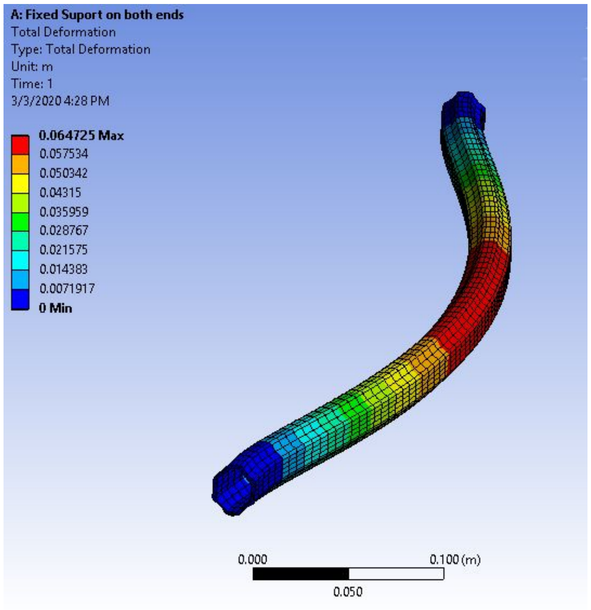
So far we have created 3D printed models of shaft designs and handed them out to current lacrosse players at various different levels of play to get a customer opinion of the best shaft design. The selected design will then go through an iterative process to further improve it. We are also starting modeling of the "Head" of the lacrosse stick based on hand drawings we have created. We are currently 3D modeling and using FEA to show stress concentrations, structural integrity, etc.

The shaft will be made of a carbon fiber or titanium alloy material. To further this project we are going to need a carbon fiber sponsor to be apart of the shaft. We ask for a possible pre preg carbon fiber donation (or a different type that may be better for a lacrosse stick design). We will then put the sponsorship on our final design for the senior design day and possibly have it displayed with the University lacrosse team. Please consider supporting our project with a small donation and let me know if this is something you would be interested in doing and thank you so much for your time!

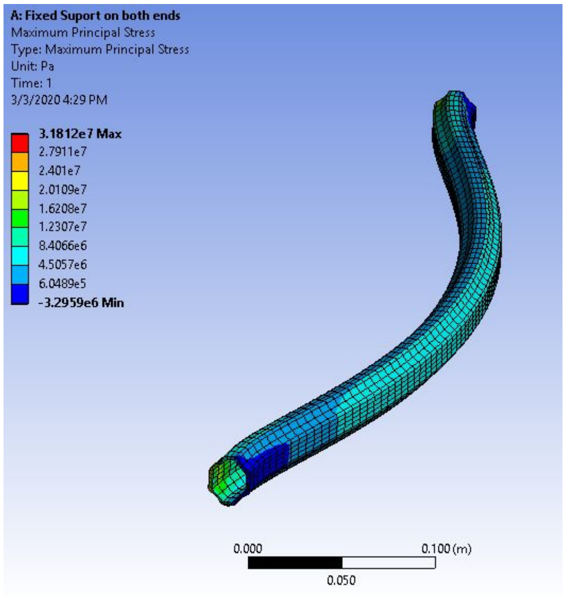
F. Ansys FEA Figures

A: Ansys test completed with a fixed support on both ends of the lacrosse stick and a force of 444 N (100lbf) on one face of the lacrosse stick

Displacement:

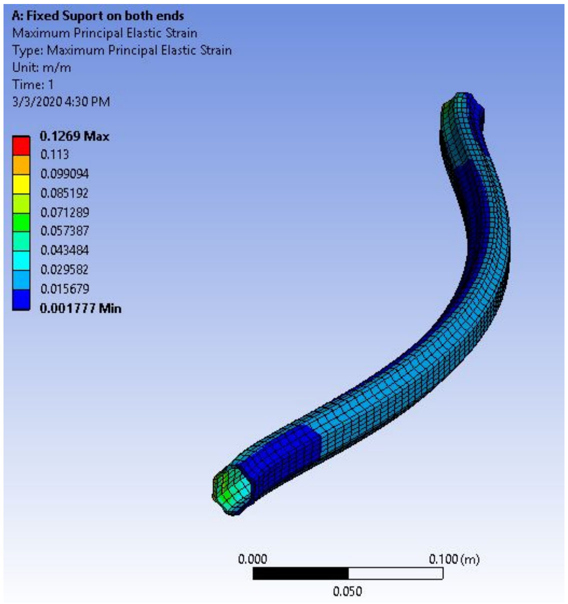


Maximum Principal Stress:



A: Fixed Suport on both ends
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
3/3/2020 4:29 PM

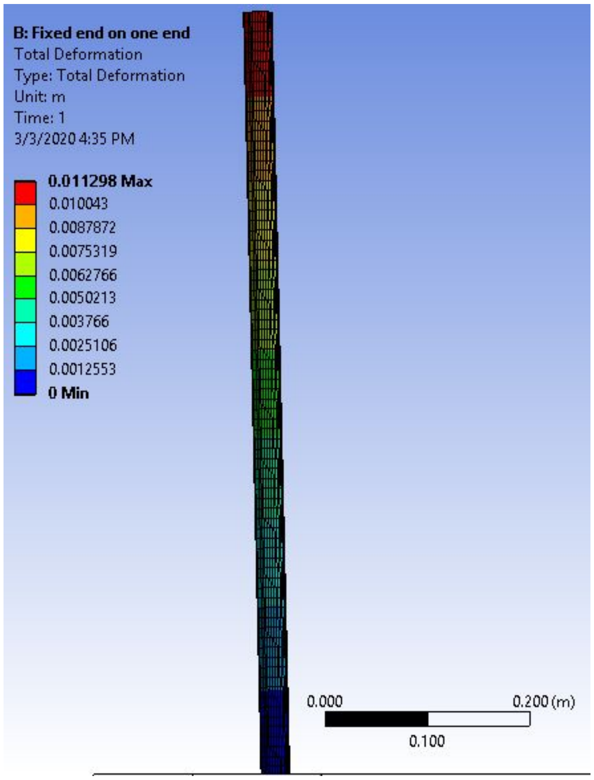
Maximum Principal Strain:



A: Fixed Suport on both ends
Maximum Principal Elastic Strain
Type: Maximum Principal Elastic Strain
Unit: m/m
Time: 1
3/3/2020 4:30 PM

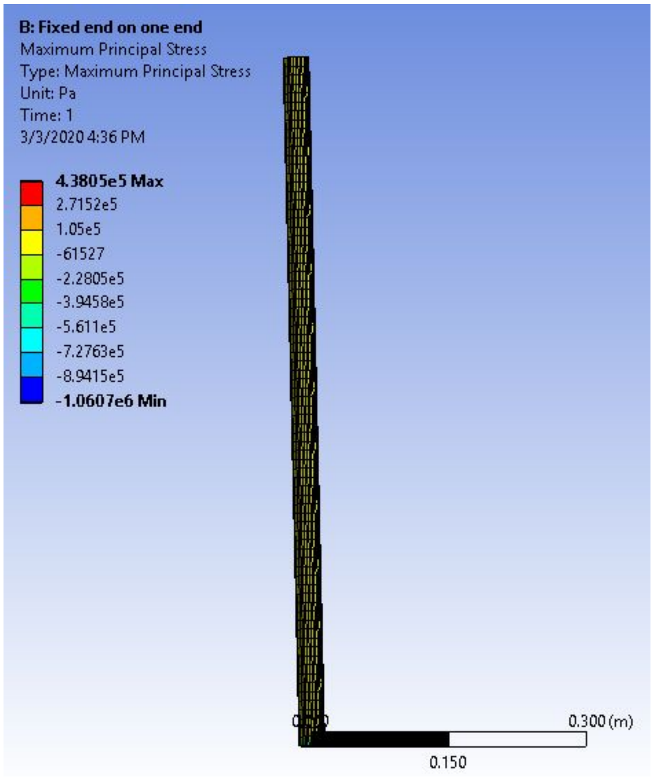
B: Ansys test completed with a fixed support on one ends of the lacrosse stick and a force of 444 N (100lbf) on the opposite end of the stick.

Displacement:



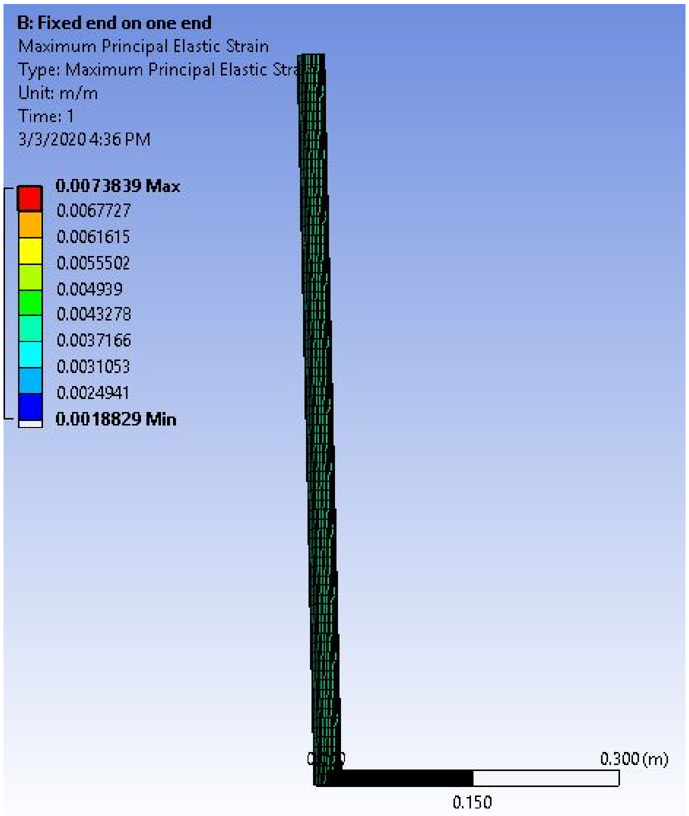
B: Fixed end on one end
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
3/3/2020 4:35 PM

Maximum Principal Stress:



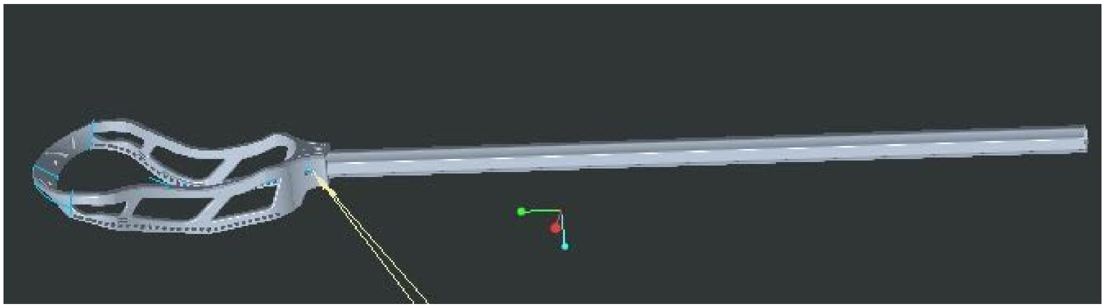
B: Fixed end on one end
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: Pa
Time: 1
3/3/2020 4:36 PM

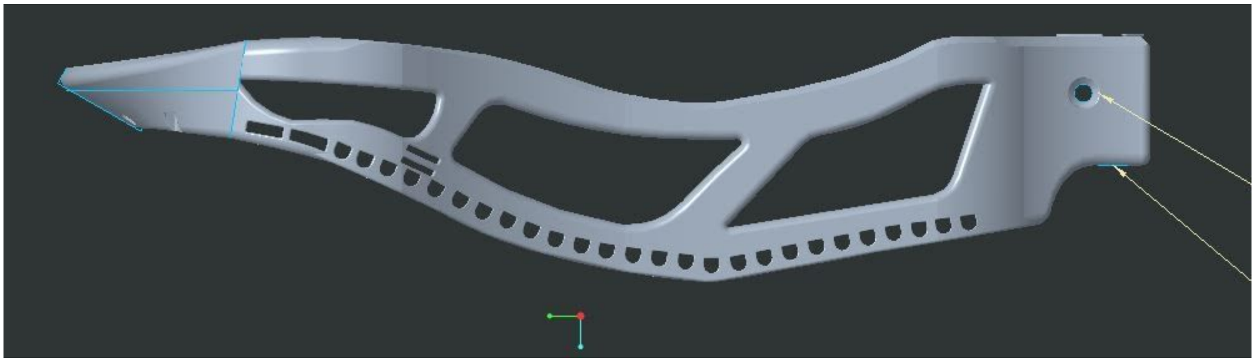
Maximum Principal Strain:

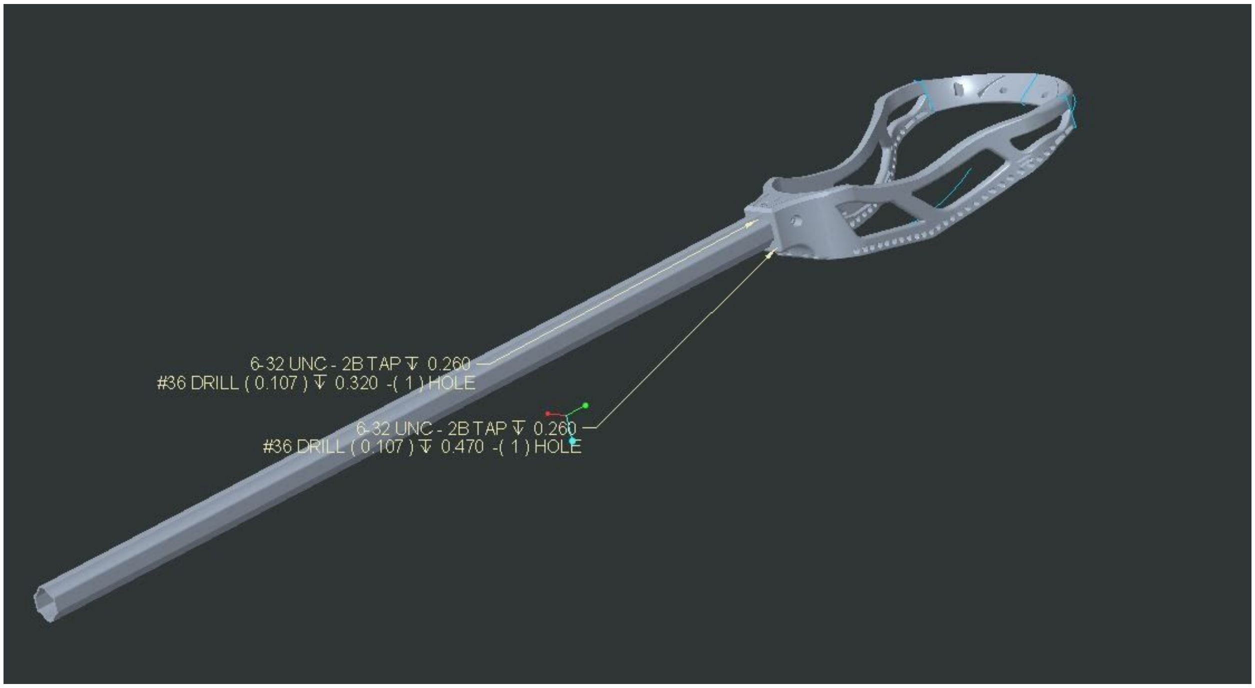


B: Fixed end on one end
Maximum Principal Elastic Strain
Type: Maximum Principal Elastic Stra
Unit: m/m
Time: 1
3/3/2020 4:36 PM

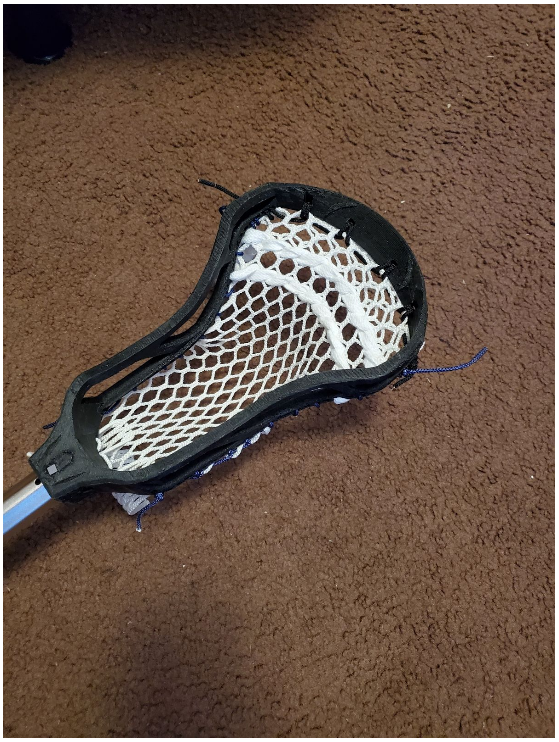
G. Creo 3D Models of Lacrosse Head and Shaft







H. 3D printed Head and Shaft pictures



CARBON PRO