Investigating and Redesigning the Modern Lacrosse Stick Head

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Introduction

History of the Modern lacrosse Stick:

The modern lacrosse stick is an evolutionary process in and of itself. The oldest surviving sticks date back only to the first quarter of the 19th century. However, the game itself is the oldest North American Sport, dating back to the 1400's [1]. In regards to the lacrosse stick itself, there were three main types of sticks used by different regions. Namely these were the Southeastern, the Great Lakes, and the Iroquoian Natives. Among the southeastern tribes, a version of lacrosse was played where two sticks were used with two hands to trap the ball between. Tribes in the Great Lakes region used the one stick style version that utilized a carved wooden scoop on the end of a three foot wooden stick. The scoop was hardly bigger than the deerskin ball used. And finally, the Iroquoian version, which is the grandfather of the modern lacrosse stick, utilized a long stick that curved at the end and was connected by large triangular shaped webbing forming a pocket at the intersection with the shaft [1]. This webbing was highly effective in the sport because it allowed an athlete to cradle the ball in the pocket reducing the risk of losing the ball while running. Additionally, it provided a player with the ability to throw and catch the ball with ease. This wooden stick would have looked very similar to the one shown to the right in **figure 1**. The stick is all one piece besides the leather webbing making up the pocket of the stick.

Figure 1: An all wooden early lacrosse stick used until 1970 [3].

There were several problems with the stick shown in **figure 1**. First, these wooden style sticks were all hand-made. This made every stick different. Thus finding a well-respected manufacturer was a large part of stick selection. The main components for a good stick were weight, balance, and failure resistance. In general, these sticks were heavy, unbalanced from left to right, had poor manufacturability, and often incapable of holding up to the physical demands of the sport [2]. When sticks would break, it was often impossible for an athlete to find a replacement that had the same handling and feel as the previous one. Additionally, sticks were manufactured separately for left handed players. Thus these sticks were even harder to find and replace [3].

New Innovation:

In order to eliminate the problems of manufacturability, weight, balance, and durability, the STX lacrosse company designed a synthetic stick head that was released in 1970 to the world lacrosse market. The design erupted onto the lacrosse world and by 1971 was the stick of choice in the National Lacrosse Championship Game [2]. The STX stick shown below in **figure 2** was a solid double-walled head made of DuPont "Adiprene" urethane rubber, which could be attached to a wooden hickory shaft [2].

Figure 2: The 1970 STX synthetic lacrosse stick head made of DuPont "Adiprene" urethane rubber [3].

This stick is crude by today's standards, but at the time it revolutionized the game by addressing every major problem with the aforementioned wooden sticks. The holes on the top and sides of the stick were placed for easy stinging of the web portion of the stick. The stick is symmetrical and therefore balanced for better handling. It can also be used ambidextrously and therefore eliminates the need to manufacture both right and left handed sticks. Furthermore, this new stick was completely reproducible, helping to cancel any unfair advantages given to bigger teams with superior manufacturers. Additionally, the new stick's robust design made it nearly unbreakable compared to the life of the old wooden brand [3]. It was not surprising that this stick was adopted into collegiate and professional play so quickly.

The Modern Stick Head:

The modern lacrosse stick head has come a long way since this first major breakthrough in 1970. For instance, the sticks have become lighter, more stylish, and more elaborate. There are several companies that produce and manufacture lacrosse stick heads as well as many stick designs within each company. Different sticks have different strengths and weaknesses and others are simply looking to be the most aesthetic. One of the most popular design changes since the 1970 STX stick, has been the introduction of the truss connected double sidewall. Manufacturers realized that the solid sidewall was robust and added a lot of unnecessary weight to the stick. In order to decrease this weight, they designed a double-sidewall system interconnected with a truss network. A similar design was formulated much earlier on the wooden sticks by Robert Pool in 1937 [3]. However, with the new plastic sticks, this design was easily produced.

In particular, the modern stick that is the focus of this investigation is the Warrior Lacrosse Revolution Stick Head shown in **figure 3**. The revolution stick is a popular modern lacrosse stick used throughout all levels of play. The design is complex in that the sidewall is pinched in near the neck of the stick and flared out near the top. This allows for advanced ball control/handling as well as an optimal area for catching. The part of the stick that is worth mentioning for this investigation is the double-walled sidewall with interconnected sidewall network. This network shown in the right image of **figure 3** is the structural support of the stick that helps to reduce the weight while still maintaining durability. It is this portion of the stick that will be the focus of the investigation in this project.

Figure 3: Warrior Revolution Lacrosse Stick Head with double-sidewall [4].

Background, Purpose and Research

The Problem:

The biggest problem with the new era modern lacrosse stick head is the durability of the sidewall structure. In the aforementioned early synthetic models, design throughout the stick was robust and durable. This is because weight was not the issue. Compared to the wooden stick of old, these new synthetic sticks were lightweight. Thus it was not necessary to sacrifice durability in the design in order to reduce weight. However, in the modern lacrosse era, stick weight has become the forefront of innovation in the game. This has led to the use of new shaft materials such as titanium and composite graphite, as well as lightweight plastics for the head. Because of this, the double-walled design has taken on numerous new shapes and configurations in order to eliminate excess weight in the stick. The problem with this is that stick durability has been sacrificed. Unfortunately the result has been numerous broken stick heads for players at all levels in every season. The purpose of this investigation is to determine where the failure in these sticks is occurring and how to design against it.

Research:

Location of the problem was the first task for this project. For this, data was collected from existing broken sticks donated by varsity lacrosse players at Union College. In total 10 stick heads were collected. The breakdown of failure location and probable cause is shown in **table 1**. The cases of failure seen from the data were found somewhere along the sidewall or at the tip or point of the head. The most common cause for this as seen in **table 1** was ball impact.

Broken Stick Data

Stick #	**Failure Location**			**Cause**
	Sidewall	Point	Other	
1	X			ball
2	X			ball
3	X			ball
4	X			ball
5		X		ball
6	X			ball
7	X			ball
8	X			slash
9	X			ball
10	X			ball

Table 1: Data collected from Union College Lacrosse team donated stick heads.

From this data it was concluded that the sidewall region was the most vulnerable failure region in the stick head. In order to clarify the different regions of the lacrosse stick head, **figure 4** shown below is a top view image of the stick with labeled regions. Since it was concluded that the sidewall region of the stick is most vulnerable, it is necessary to investigate what is going on in this region.

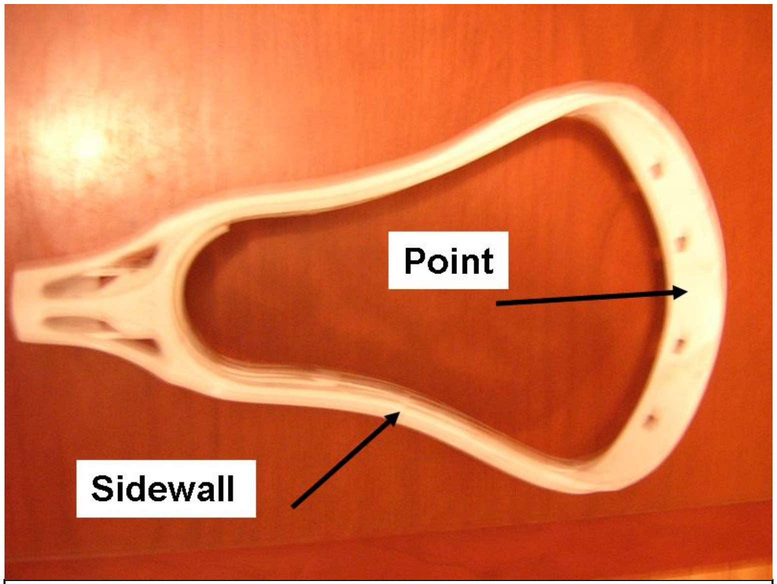


Figure 4: Labeled regions of the lacrosse stick head.

Design

Baseline 3D Model Design:

In order to develop and analyze a 3D model and prototype of the new design, it was necessary to construct a 3D-Baseline Model of the existing stick. For this, the CAD program SolidWorks was utilized. This program allows the user not only to design complex 3D structures, but also to analyze them for certain loading conditions. The first step in constructing this model was to gather data from the existing stick head. This was accomplished by collecting lots of data points throughout the complex structure of the stick relative to certain other reference geometries. This data included radii of curvature, lengths, heights, thicknesses, etc. Ongoing data collection is used to further the accuracy of the 3D model. With this data, the model is constructed to mimic the existing structure. The purpose for this model will be to compare and contrast different optimized sidewall designs that will be discussed later. The initial baseline model was completed to the degree shown in **figure 5** at the end of the first semester of work.

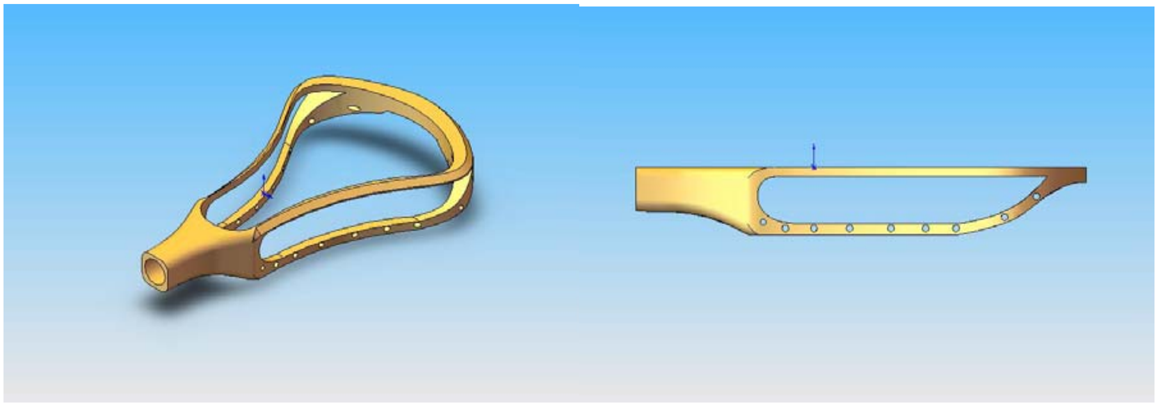


Figure 5: Images from the 3D SolidWorks Baseline model showing the overall design and the side view.

The design shown above in **figure 5** is purposefully missing the sidewall truss network that connects the upper and lower portions of the sidewall. This is because the new design will be placed in this gap and compared to the existing model.

After a second semester of extensive data collection and research, a final baseline 3D model of the Warrior Revolution was completed in SolidWorks. The model is a nylon plastic which is closely correlated to the material properties of the real stick. The elastic modulus of the material is 8300 MPa and the yield strength is 139 MPa. The final design used for comparison can be seen below in **figure 6**.

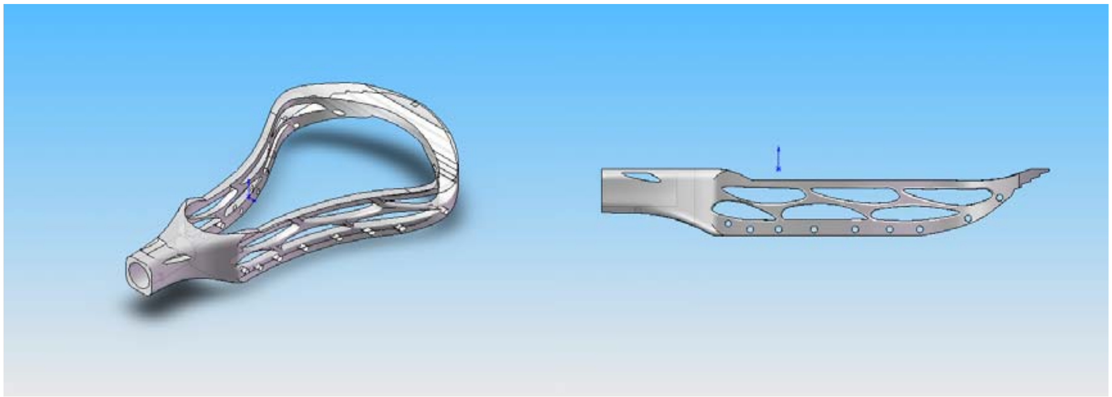


Figure 6: Finalized 3D model of Warrior Revolution

The final model shown in **figure 6** above is 214 grams.

Model Validation:

The 3D model must be validated in order to prove that it is a good mode of comparison to the real stick. Thus, experimentation was needed to verify its validity. A simple test to validate this design is a force vs. deformation test. If the actual stick deforms in the same way or amount under a given loading condition as the model, then the model can be verified. Thus an experiment was set up to measure the deformation of the actual stick. A simple force sensor was used with a computer data acquisition device to measure the loading forces. The force sensor was hung from the very tip of the stick and the handle end of the head was fixed. The force sensor was pulled until the tip of the head deformed a certain predetermined distance. This distance was measured to be 2 cm. To get a better understanding of the experimental set-up, see **figure 7** below showing a picture of the apparatus. The figure shows the force sensor being pulled vertically down from the tip of the stick head. The handle end is fixed with clamps. There is a metric scale on the wall where the deformation distance of the tip of the head is measured. Several trials of deformation were taken in order to minimize the error associated with the sensor and/or the precision of the scale. The deformation target distance of 2 cm was an eyeball approximation on the measuring scale. A plot of the force trials was generated in order to find an average value. The

result was compared to the finite element analysis generated in the model. The comparison can be seen below in **figure 8**.

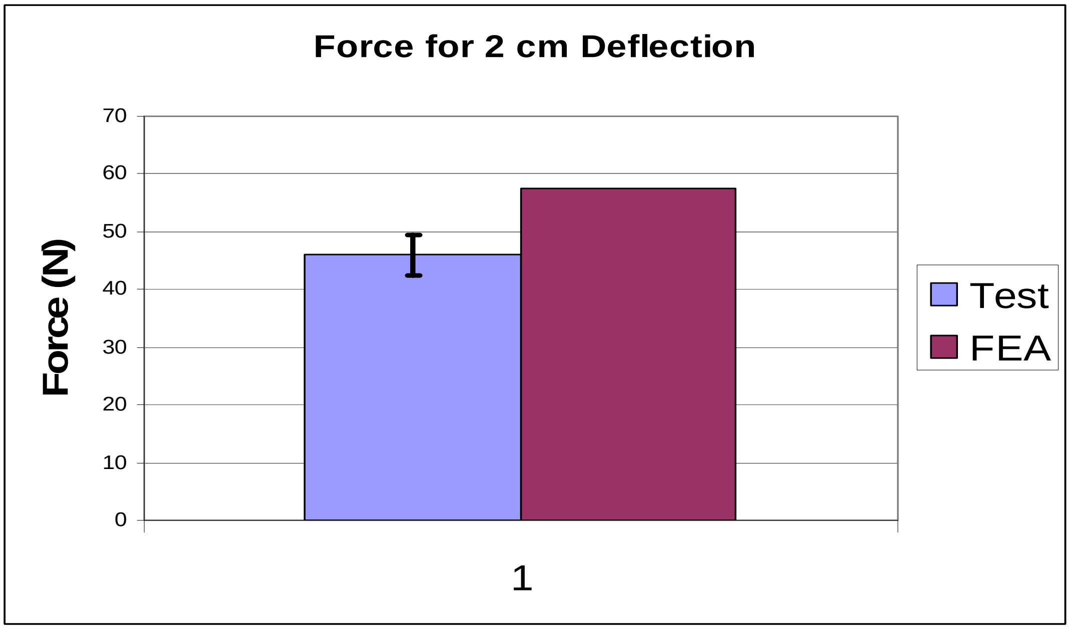


Figure 8: Force required for 2cm deformation in stick.

In order to validate the model, the same deformation must occur for a given applied loading condition. A force of 46 N was thus applied to the tip portion of the 3D model in SolidWorks and the deformation was measured to be 2.5 cm. This is a percent difference from the actual stick of 25%. This is an acceptable error for finite element analysis and can most probably be attributed to the differences in exact material properties. Thus the model was validated and approved for testing against other designs.

Design Requirements:

In order to optimize the new design, some requirements are necessary to ensure a quality product. The first design constraint is weight. As mentioned earlier, the overall weight of the stick is of utmost importance in new stick design. Thus the constraint on the new design will be to keep the weight equal to or below the existing design. Further, the strain within the stick is a constraint. The current design provides a comfortable level of flexibility within the stick. This is to be achieved again in the new design.

The new design will focus on minimizing the stress throughout the sidewall structure due to impact loading. This is what is meant by optimization. The stress throughout the sidewall is what is to be minimized using only the minimum amount of material necessary. Of course a completely solid sidewall like the one seen in **figure 1** and **figure 2** above will be robust and resistant to fracture. However, this design is too heavy for modern standards. Thus, the optimization will be to design for minimal stress and minimal mass.

2D Optimization

Due to the complex structure of the 3D model, it was decided that a simpler design must first be optimized. Thus, the 3D structure was first modeled as a 2D sidewall structure. The design was optimized in 2D in the hopes that the results would carry over into the 3D model. A simplified 2D sidewall design space was thus created in order to find the best design. However, in order to continue to use the SolidWorks finite element program for analysis, the 2D design space was modeled in 3D with a nominally small thickness. The design space was then modeled as a simple rectangle of dimensions 18.5 cm long by 2.79 cm tall. The nominal thickness of the structure was 0.254 cm and was a constant throughout all members. The simplest design of course was a solid sidewall space. The 2D representation of this design can be seen below in **figure 9**.

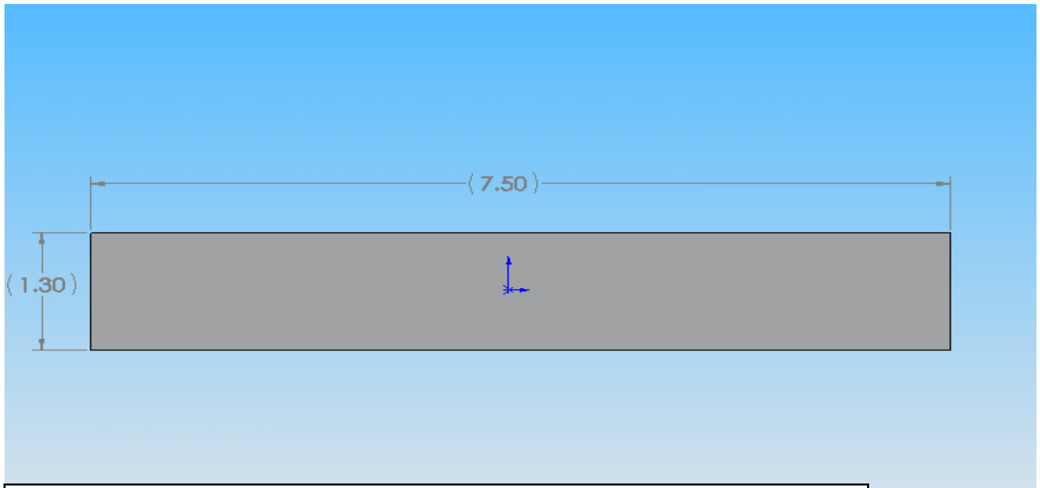


Figure 9: Solid sidewall structure in 2D (dimensions are plus thickness)

The optimization matrix consisted of 11 different models. The variables for the design matrix were number of struts and strut spacing throughout the design space. The idea was to eliminate entire series of designs based on prior results. For instance, the family of 1 strut designs could be eliminated because the stresses were far larger than any other design no matter what the orientation of the one strut. Different designs of 2, 3, and 4 strut structures were analyzed for maximum von mises stresses. Von mises stresses were used in SolidWorks because they are commonly used in the literature for failure analysis on somewhat ductile materials. For each design, the maximum stress and the mass were analyzed. The optimum design was chosen when the stress and mass were minimized. The optimum design was then determined and shown below in **figure 10**.

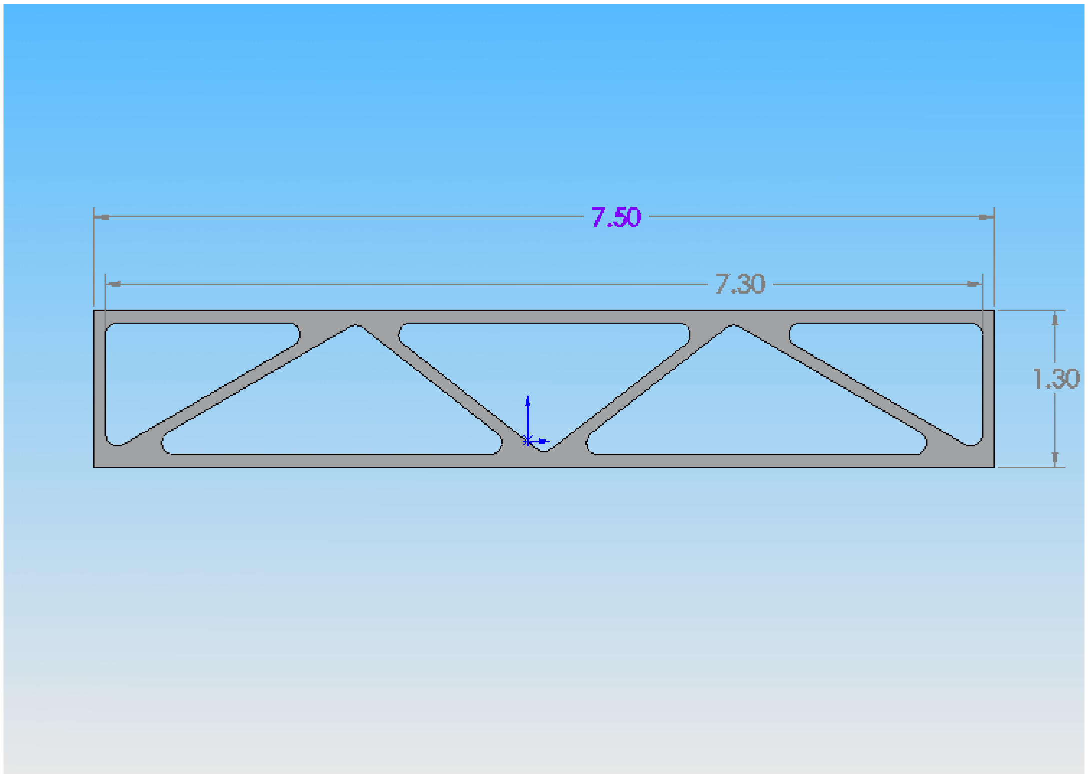


Figure 10: Optimized design with 4 strut truss network

The 4 strut network is evenly distributed throughout the design space, and the top nodes are placed at (2/7)*L and (5/7)*L, where L is the length of the space (18.5 cm). The specifications for this optimized design were a max stress of 357 MPa and a weight of 6.19 g. This is compared to the revolution 2D design which had a weight of 7.23 grams and a max stress of 1390 MPa. The finite element result of the optimized design can be seen below in **figure 11.**

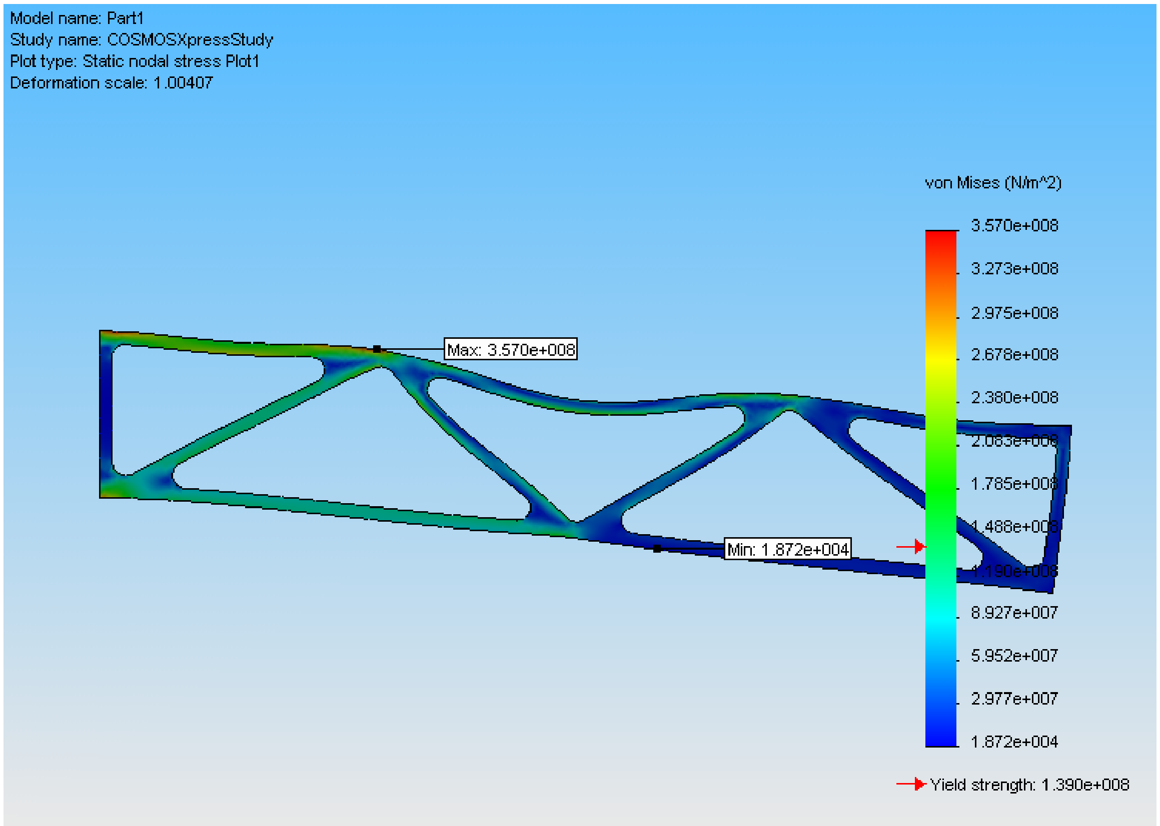


Figure 11: Stress distribution in optimized design for given loading conditions

In **figure 11** above, the stress is shown for a fixed left end and a loading of 100 pounds on the top of the sidewall. It should be noted that the corners of the structure have been filleted to avoid the program from finding the max stress in the corners (nodes) of the truss. With this optimal 2D design, the 3D model had to be created and analyzed.

3D Implementation

The 2D optimal design was then modified into a completely 3D design with the same overall structure as the revolution model. This was accomplished by removing the sidewall region of the revolution model and implementing a 3D fabrication of the 2D truss described above in **figure 10**. Clearly in the 3D model, the sidewall is not a perfectly straight and rectangular design space. Therefore, some creative liberty had to be taken to accurately implement the 2D design into the 3D structure.

Once the new design was modeled in 3D, it was necessary to further optimize the design. Since only 2-dimenions of space were optimized initially, the third dimension, namely thickness, had to be considered now. Variations in strut thicknesses and filleting were examined in order to determine if a further optimal design could be achieved. The proposed optimized design is displayed below in **figure 12**.

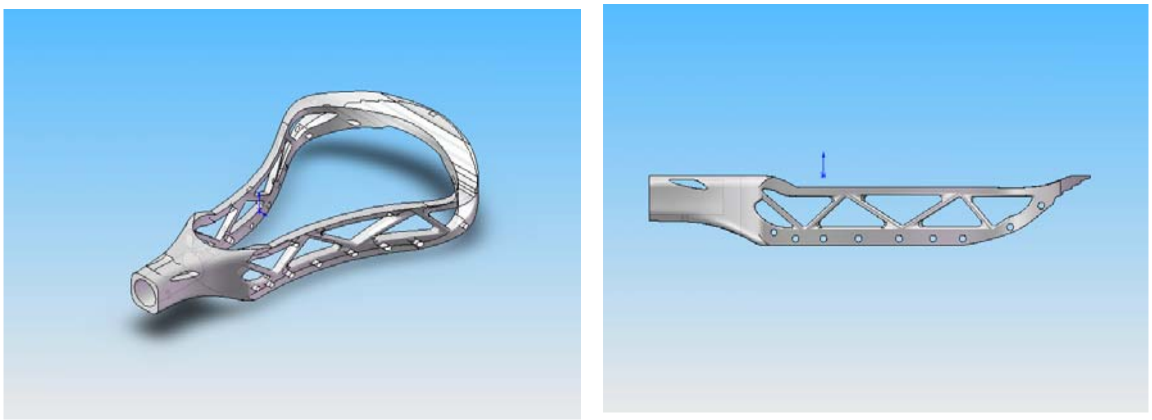


Figure 12: Final Optimized 3D design (isometric and side views)

Once the final design was found, it had to be compared to the revolution model. This was done by recreating the initial failure criteria seen in early data collection on active sticks. Since most sticks failed when impacted on the top of the sidewall, this force was recreated. A force of 100 pounds was applied to a small section of the top of the sidewall region. Since impacts vary along the top of the sidewall, the middle section was chosen as a suitable place to analyze the designs. This force is shown to the left in **figure 13**. Since the major portion of the stick, excluding the sidewall gap, is the same on both

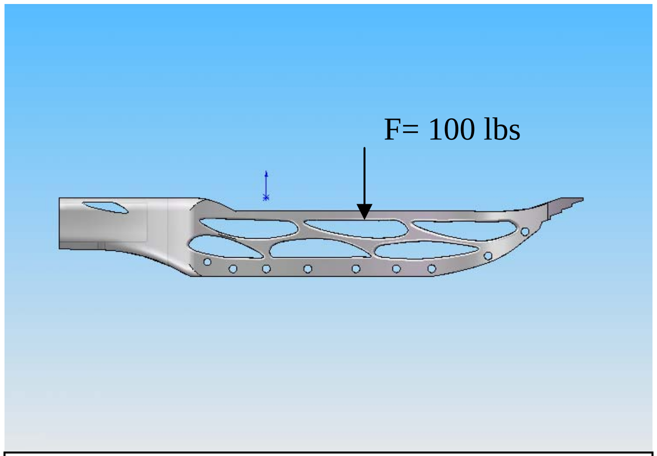


Figure 13: Force load testing of 3D design.

model and new design, the force is applied to the same exact spot in both cases. The handle end of the head is completely fixed as if the shaft were inserted into the whole and held rigid in all directions. This is an idealized case used for comparison purposes only.

Results

The finite element results for both the revolution model and the optimized design are shown below in separate figures labeled **figure 14** and **figure 15** respectively. In both cases the data focused on finding the maximum stress and the overall mass. In order for the new design to be considered an improvement, it must not only succeed in reducing the maximum stress in the sidewall, but also exhibit an equal or lesser mass.

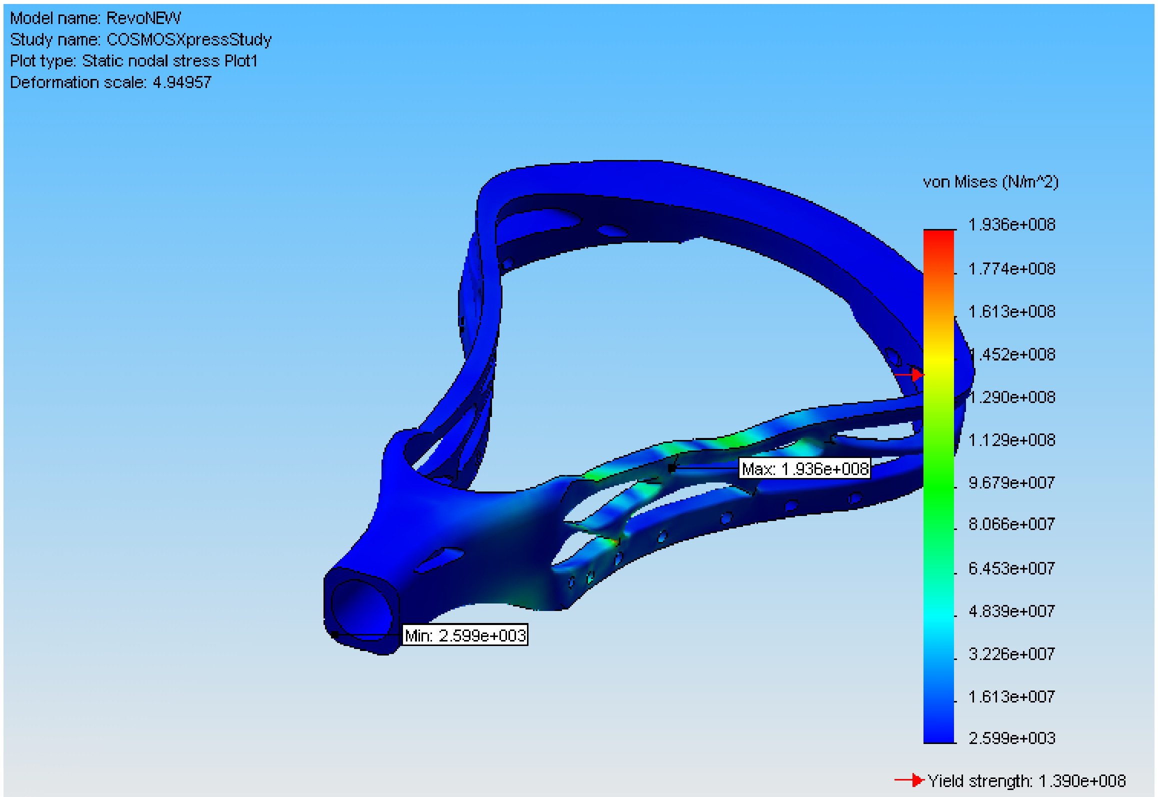
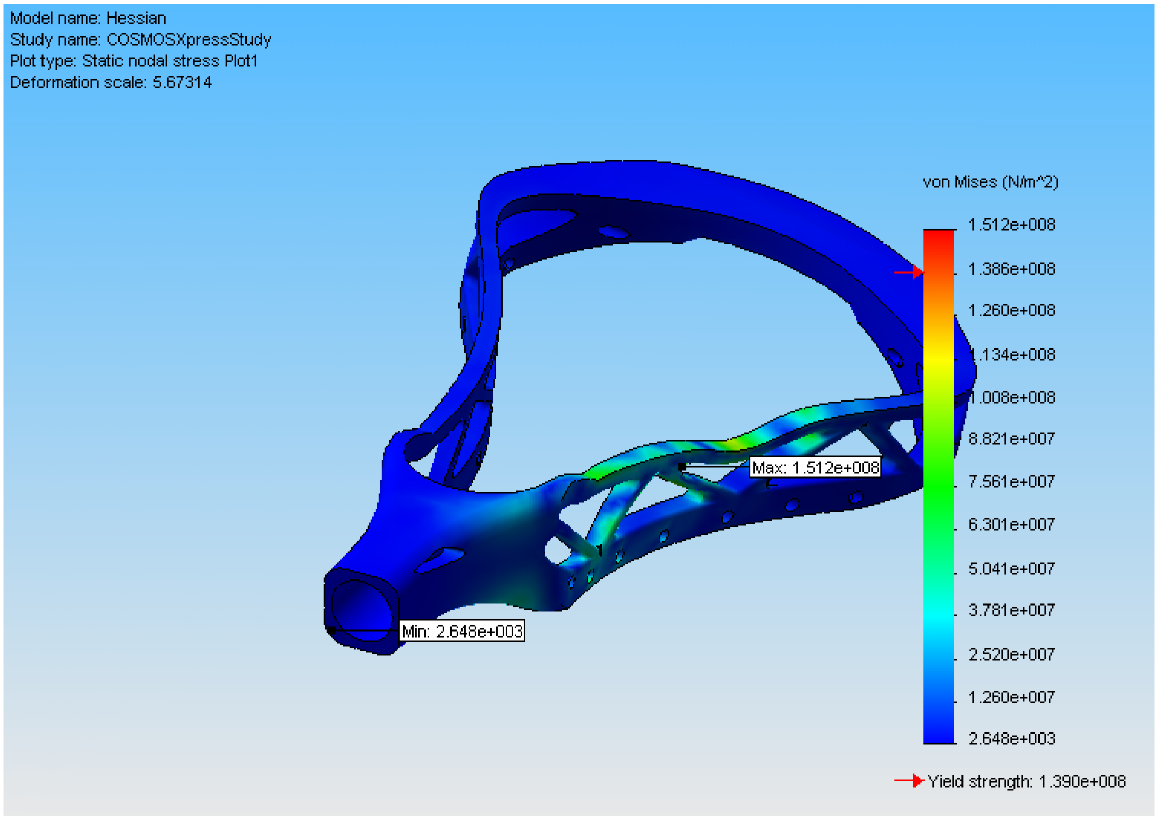

Model name: RevoNEW
Study name: COSMOSXpressStudy
Plot type: Static nodal stress Plot1
Deformation scale: 4.94957

Figure 14: Stress distribution in revolution model with 100 lb sidewall force.

The maximum stress in the revolution model was found to be 194 MPa. The total mass was 0.214 kg. The minimum factor of safety is 0.7183.



Model name: Hessian
Study name: COSMOSXpressStudy
Plot type: Static nodal stress Plot1
Deformation scale: 5.67314

Figure 15: Stress distribution of the optimized new design with 100 lb sidewall force.

The maximum stress in the design was 151 MPa. It has a total mass of 0.211 kg. The minimum factor of safety is 0.9195.

Conclusions/Recommendations

The outcome of this project has been the development of an alternative design to the warrior revolution lacrosse stick head. The design not only reduces the maximum stress due to impact loading in the sidewall but also has a reduced mass of about 3 grams. There is a significant reduction in the maximum stress as well as an increase in the minimum factor of safety from 0.7183 to 0.9195. The new design consists of a 5 strut truss design with filleted corners and edges to minimize wasted material. The maximum stress found in the new design was greater than the yield stress of the material and therefore implies that plastic deformation or failure will occur for this given loading condition. However the force loading was exaggerated in order to determine the peak values and is not representative of normal use. It is simply a comparison for a specific loading condition between designs.

It is difficult to say whether the findings completely correlate to the actual stick. The validation of the computer model was accurate within 25% and so there is some degree of error in the correlation. However, when compared to the computer model, there is no doubt that the new design is a more effective prototype. Additionally, there are many other types of loading that were not explored in this investigation. There are problems of creep in which the plastic deforms over time and extended use. Further, there may be defects and manufacturing errors that could affect the life of this product. All of these factors are considerations in the development of a competitive lacrosse stick head. Another portion of this project that should be investigated is determining what impact this reduced stress will have on the fatigue life of the product. This could correlate to improved warranties and increased reliability. However, this project did not focus on these areas of concern, and it was altogether successful in determining an alternative design to meet the target constraints. As with all lacrosse sticks, the name is potentially the most important part, and therefore I have named this design “The Hessian”.

Future Work

An entirely different area of study that could be investigated in the future is alternative materials. There are many different materials currently being used in the design of lacrosse stick shafts and other equipment. However, until recently, the variation in stick head material has been limited. It would be interesting to see if the kind of success that the hockey-stick industry has seen with carbon fiber, could translate into the lacrosse world.

The Warrior Company recently introduced the first titanium reinforced stick head. This stick is designed to increase the stiffness of the head without adding excess weight. This does not answer the question of durability as addressed in this report, but it is a stepping stone into a new branch of research that could produce the next generation of lacrosse stick heads. With the popularity of lacrosse reaching off the chart numbers, the push for new and innovative designs will be just the beginning.

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